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Forward–backward analysis of RFID-enabled supply chain using fuzzy cognitive map and genetic algorithm

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Abstract

Supply chain is a non-deterministic system in which uncontrollable external states with probabilistic behaviors (e.g., machine failure rate) influence on internal states (e.g., inventory level) significantly through complex causal relationships. Thanks to Radio frequency identification (RFID) technology, real time monitoring of the states is now possible. The current research on processing RFID data is, however, limited to statistical information. The goal of this research is to mine bidirectional cause-effect knowledge from the state data. In detail, fuzzy cognitive map (FCM) model of supply chain is developed. By using genetic algorithm, the weight matrix of the FCM model is discovered with the past state data, and forward (what-if) analysis is performed. Also, when sudden change in a certain state is detected, its cause is sought from the past state data throughout backward analysis. Simulation based experiments are provided to show the performance of the proposed forward–backward analysis methodology.

Keywords: RFID-enabled non-deterministic supply chain; Forward–backward analysis; Fuzzy cognitive map (FCM); Weight learning; Genetic algorithm

1. Introduction

Recently, radio frequency identification (RFID) technology has emerged as an important tool for securing real time product location data throughout supply chain. When a logistics object (e.g., product, pallet, etc.) with an RFID tag comes within the detection range of RFID reader, an RFID data composed of (EPC, reader ID, and time stamp) is stored in an RFID information system. The current tag information uses Electronic Product Code (EPC) code which contains information consisting of manufacturer, product type, and a unique serial number per product (Kin, Mun, & Daniel, 2005).

The RFID data can be also used for monitoring continuously changing supply chain states such as inventory level, product (or part) supplying lead time and production rate by transforming the raw RFID data into business logic data (Wang & Liu, 2005). Luis, Magdy, and Chalermmon (2004) stated that the most important factors in supply chain management under dynamic environment are the understanding of the state change of supply chain resulted from the inner/outer influences of the supply chain and predicting the short-term and long-term effects on the supply chain.

In this research, the states of supply chain that can be measured from RFID data or are directly obtainable are divided into the next three kinds.

- *External states*: Variables changing probabilistically such as machine failure rate and inventory shrinkage rate and, which have decisive effect on the performance of supply chain. Those states are uncontrollable in supply chain, but the real time monitoring of the states is possible.
- *Policy states*: Decision variables, such as inventory safety stock and the number of transportation vehicles, controlled by supply chain managers periodically in response to the change of external states.

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- *Internal states*: Target performance indexes of supply chain such as inventory level and transportation lead time. These states are determined through complex causal relationships among external and policy states. So, the changes in the internal states are also uncertain.

1.1. Research objective and methodology

The goal of this research is to extract bidirectional cause-effect knowledge from supply chain states. Currently, the research on processing RFID data is limited to statistical information (Zhu & Shasha, 2002). The most known inductive knowledge needed for supply chain management is *forward analysis* (what-if analysis) knowledge which finds out the effect on the internal states of supply chain when a sudden change appears on external and policy states, and *backward analysis* (cause analysis) knowledge which finds out the cause (external or policy state) of the sudden change of internal state. This kind of bidirectional cause-effect knowledge is discovered through data mining of the lower level state data.

This research will first define the causal relationships among the supply chain states mentioned above using Fuzzy Cognitive Map (FCM), second propose a genetic algorithm based FCM weight learning method, third implement forward and backward analyzes in a simulated RFID-enabled supply chain environment where the states change non-deterministically, and finally test the performance of the two methods extensively through simulation-based experiments.

FCM (Kosko, 1992) helps to understand the causal relationships among complex supply chain states visually. An FCM consists of a set of nodes and a set of edges. In supply chain, the nodes form a state vector. A state (or node) has a real value between $[0,1]$. Generally, the state value is interpreted through a fuzzification mapping as shown in Table 1. For example, if inventory state is 1, it means that the real inventory level is much higher than a normal condition. On the contrary, the state with a value near 0 implies that the real inventory is at a very low level. The edge between two nodes has a causal direction and a weight between $[-1,1]$ which indicates the causal strength between the two nodes. The weight has a positive number when the relationship between the two nodes is positive, zero when there is no correlation, and a negative number when the relationship is negative. The set of edges can be expressed by a weight matrix.

Table 1
Fuzzification of state value

Symbolic values	Numeric value $[0,1]$
Strong positive	$(0.8,1.0]$
Positive	$(0.6,0.8]$
Normal	$(0.4,0.6]$
Negative	$(0.2,0.4]$
Strong negative	$[0.0,0.2]$

In the forward analysis of FCM, right selection of the weight matrix influences on the accuracy of the model's prediction on future state greatly. This research develops a genetic algorithm based weight learning method. A learned weight matrix is the one which minimizes the prediction errors made by the forward analysis. On the other hand, for the backward analysis, the state vector when a sudden change appears is defined as a result vector, and genetic algorithm coupled with FCM operation finds the cause vector which brought about the result vector. Another important contribution of this paper is the quantitative analysis of how accurately the learned FCM predicts the future states that show probabilistic behaviors.

1.2. Literature survey

FCM is an extension of cognitive map (Axelrod, 1976), which was originally proposed to analyze complex political situations. FCM is relatively easier to foresee future state transitions through a simple matrix calculation based FCM operation than the system dynamics model (Sterman, 2000) and Bayesian network model (Neapolitan, 2003). Due to the advantage, FCM has been applied to not only management and social science fields such as investment analysis problem (Lee & Kim, 1997), political problems (Athanasios, Ilias, & Konstantinos, 2003), and critical success factor modeling for an IT project process (Luis, Rossitza, & Jose, 2007), but also engineering fields such as behavioral analysis of electronic circuit (Styblinski & Meyer, 1988) and knowledge modeling for urban design (Xirogiannis, Stefanou, & Glykas, 2004). However, applying FCM to the dynamic supply chain domain has not been attempted yet.

Most applications of FCM have been made for forward analysis, and the research on backward analysis has been rarely performed. Khan, Khor, and Chong (2004) showed as an example that backward analysis using genetic algorithms is possible in the decision making of purchasing equipment and the cause analysis of public health problem. However, their research assumed that weight matrix is given. Furthermore, the research did not engage in any broad experiment on the accuracy of the backward analysis in the applied domains they considered.

At present, weight learning methods based on the hebbian algorithm, which is a kind of artificial neural network learning algorithms, have been presented (Aguilar, 2002; Caudill, 1990; Huerga, 2002; Khan, Chong, & Gedeon, 2000; Papageorgiou, Stylios, & Groumpos, 2003, 2004). The hebbian algorithm changes the weights gradually toward reducing the differences between the state vectors predicted by FCM and actual state vectors. Also Papageorgiou and Groumpos (2005) presented a two-step FCM weight learning methodology where differential evolution algorithm decides the ending point of the learning, and a nonlinear hebbian learning algorithm executes the weight learning during the learning interval. Besides this, Parsopoulos, Papageorgiou, Grumpos, and Vrahatis (2003)