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Genetic algorithm dynamic performance evaluation for RFID reverse logistic management

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ABSTRACT

Environmental awareness, green directives, liberal return policies, and recycling of materials are globally accepted by industry and the general public as an integral part of the product life cycle. Reverse logistics reflects the acceptance of new policies by analyzing the processes associated with the flow of products, components and materials from end users to re-users consisting of second markets and remanufacturing. The components may be widely dispersed during reverse logistics. Radio frequency identification (RFID) complying with the EPCglobal (2004) Network architecture, i.e., a hardware- and software-integrated cross-platform IT framework, is adopted to better enable data collection and transmission in reverse logistic management. This research develops a hybrid qualitative and quantitative approach, using fuzzy cognitive maps and genetic algorithms, to model and evaluate the performance of RFID-enabled reverse logistic operations (The framework revisited here was published as "Using fuzzy cognitive map for evaluation of RFID-based reverse logistics services", *Proceedings of the 2009 international conference on systems, man, and cybernetics* (Paper No. 741), October 11–14, 2009, San Antonio, Texas, USA). Fuzzy cognitive maps provide an advantage to linguistically express the causal relationships between reverse logistic parameters. Inference analysis using genetic algorithms contributes to the performance forecasting and decision support for improving reverse logistic efficiency.

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1. Introduction

Enterprises are applying reverse logistics as a means for fulfilling different market regions' recycling requirements. The European Union has a waste electrical and electronics equipment (WEEE) directive and the United States uses state and federal laws for enforcing recycling programs. Reverse logistic processes help enterprises fulfill their social responsibility and build their reputation by providing systems and processes for customers to return products and components either for repair, reuse, or disposal. Traditionally, supply chains without return and recycling processes are modeled as linear structures with a one way flow of goods from suppliers, manufacturers, wholesalers, retailers, and finally to consumers. Modern distribution channels that include repair, recycling, and responsible waste disposal must accommodate bi-directional flows or reverse logistics flows.

Reverse distribution channels include direct returns to manufacturers, indirect returns to repair facilities, individualized returns with small quantities, extended order cycles associated with product exchanges, and a variety of disposition options (e.g., repair versus exchange). The complexity of processes makes the modeling and implementation of reverse logistics a challenging task. In addition, it is difficult to measure the impact of product return and recycling on profitability and customer loyalty. An underlying cause for the measurement difficulties is that most enterprises are unable to trace the reverse logistics processes in real-time.

Radio frequency identification (RFID) technology enables enterprises to gather and track reverse logistics process data in real-time. RFID uses tags that can be automatically detected by readers without manual scanning, a major advantage over bar code readers. RFID uses radio frequency as a means to transmit data from tags affixed to physical objects such as products, boxes, or shipping containers. Data related to physical objects can be identified, stored, traced and monitored during transportation through the entire product life cycle. RFID also makes it possible to simultaneously detect and identify multiple items. For example, a list of goods packed in a sealed box can be automatically identified using a RFID reader without opening the box. Tags with memory can also be dynamically modified, inventory modifications can be batch processed, and stock keeping unit (SKU) data are readily transferred across enterprise systems. As a result, RFID technology enables precise tracking and real-time monitoring of each tagged item with minimal effort.

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In this research, fuzzy cognitive maps (FCM) are used to construct a reverse logistics network decision model. RFID technology provides the mechanism for real-time monitoring of the reverse logistics processes. The FCM decision model, using data collected by RFID technology, provides two critical functions, i.e., inference analysis and decision analysis. Inference analysis is applied to forecast future states of the reverse logistic operations. If sudden changes occur, the information system sends a warning message to alert the manager. The manager also receives decision support to improve logistic performance. In this research, a case is used to demonstrate and evaluate the implementation of fuzzy cognitive maps and genetic algorithms for managing the RFID-enabled reverse logistics of a cold storage chain.

2. Related research

In this section, fuzzy cognitive map, reverse logistics, and RFID technology are reviewed. A fuzzy cognitive map is used to represent causal relationships between the logistic process parameters. RFID technology provides the basis for collecting and transmitting the process data for real-time performance analysis and evaluation.

2.1. Fuzzy cognitive map

Fuzzy cognitive maps (FCMs) are an extension of cognitive maps (Axelrod, 1976). The elements used for building the graphs include the concepts and the relationships between concepts. Cognitive maps (CMs) represent concepts as nodes which contain the key knowledge fact of a specific domain (Dickerson & Kosko, 1993). As shown in Fig. 1, the use of positive (+) and negative (−) signs on arcs between nodes represents the positive or negative effect of one node on another. Thus, a positive sign between nodes represents a stimulating relationship and a negative sign represents an inhibiting relationship. CMs can be represented as a symmetric weight adjacency matrix (consisting of only +1 or −1 elements) to mathematically describe the relationships between nodes. The direction of the arrow reveals the cause-effect relationship between nodes (Kardaras & Karakostas, 1999). For instance, if the condition of node C1 is satisfied, then C2 and C4 will be positively stimulated as depicted in Fig. 1. CMs define links as causal relationships without specifying the strength of the relationship between nodes. FCMs, on the other hand, use fuzzy logic to quantify the strength of the relationships between nodes (Fig. 1). The values range from −1 to 1 where the value 0 stands for no effect and 1 represents the strongest relationship between nodes.

Fuzzy cognitive maps model causal relationships between concepts using directed arcs and logical inference networks (Kosko, 1987). An FCM links the events, values, objects, and tendencies with a feedback dynamic system (Dickerson & Kosko, 1993). The map is a graph with nodes, weights, and directed arcs that represent specific behaviors belonging to a real world system. The FCM defines the relations between causes and their effects using a link and a weight. FCMs are often compared to neural networks or expert systems to emphasize the following benefits (Miao, Liu, Siew, & Miao, 1999). First, the modeling of causal relationships with FCM is less difficult than modeling neural networks since the concepts of a system can be represented as different nodes. Then, the weight associated with the link represents the strength and cause-effect relationships and how a concept will react to causal inputs. Second, in comparison to expert systems, FCM uses matrix operations instead of if–then rules to infer possible outcomes. As a result, FCM offers greater flexibility in computing inference outcomes.

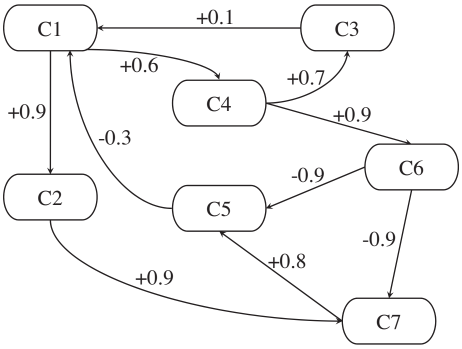

Fig. 1. A fuzzy cognitive map with directed and quantified relationships.

FCM facilitates collaboration between model builders. Different maps from different experts can be integrated into a larger map. An individual FCM represents the domain knowledge or opinion of an expert (i.e., different weighted coefficients represent different beliefs) and maps of several experts can be combined by merging their adjacency matrices (Hagiwara, 1992). Compared to Bayesian networks, FCMs are also relatively easy to use for inferring future state transitions through simple matrix operations (Kim, Kim, Hong, & Kwon, 2008). Thus, the FCM approach has been applied to simulation (Fu, 1991), modeling of organizational strategies (Paradice, 1992), investment analysis (Lee & Kim, 1997), political decision making (Tsadiras, Kouskouvelis, & Margaritis, 2003), and modeling critical success factors (Luis, Rossitza, & Jose, 2007).

2.2. Reverse logistics

The scope of reverse logistics throughout the 1980s was limited to the movement of materials from customers back to producers (Rogers & Tibben-Lembke, 2001). Other definitions for reverse logistics cover activities such as product returns, recycling, materials substitution, reuse of materials, waste disposal, repair, and remanufacturing (Stock, 1998). The goal of reverse logistics is to extract tangible and intangible values from the processes of disposal, recycling, and reuse. For example, if an enterprise has a sound reverse logistics system, then an intangible benefit is a more positive corporate image (Carter & Ellram, 1998). Moreover, reverse logistics includes processes for the return of damaged goods, the disposal of out of date inventory, and the restocking or salvaging of these goods. Also, a better reverse logistics process improves hazardous material control, obsolete equipment disposition, and asset recovery (Rogers & Tibben-Lembke, 2001).

Reverse logistics covers a broad range of activities. When a product return process is triggered, enterprises use different reverse logistics processes depending on the situation and the roles played by the supply chain intermediaries and owners. Rogers and Tibben-Lembke (2001) categorized reverse logistics activities according to products and their packages. The activities for products include reselling, selling through outlets, salvaging, reconditioning, returning to suppliers, refurbishing, remanufacturing, recycling, and disposal. Packaging includes fewer activities such as reusing, salvaging, refurbishing, recycling, and disposal.

A number of authors discuss the reasons for product returns. For example, De Brito, Flapper, and Dekker (2002) categorized three types of supply chain returns, i.e., manufacturing returns, wholesaler/retailer returns, and customer returns. Rogers and Tibben-Lembke (2001) extend the list of returns categories to include customer returns, market returns, asset returns, product recalls, and environmental returns. Product returns are the result of product damage and defects, return policies and warranties, customer dissatisfaction, and incorrect product placement. Market returns are the results of business failures, out of season goods, and excessive inventories. Asset returns include packaging reuse and return

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