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An improved demand forecasting method to reduce bullwhip effect in supply chains

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ABSTRACT

Accurate forecasting of demand under uncertain environment is one of the vital tasks for improving supply chain activities because order amplification or bullwhip effect (BWE) and net stock amplification (NSAmp) are directly related to the way the demand is forecasted. Improper demand forecasting results in increase in total supply chain cost including shortage cost and backorder cost. However, these issues can be resolved to some extent through a proper demand forecasting mechanism. In this study, an integrated approach of Discrete wavelet transforms (DWT) analysis and artificial neural network (ANN) denoted as DWT-ANN is proposed for demand forecasting. Initially, the proposed model is tested and validated by conducting a comparative study between Autoregressive Integrated Moving Average (ARIMA) and proposed DWT-ANN model using a data set from open literature. Further, the model is tested with demand data collected from three different manufacturing firms. The analysis indicates that the mean square error (MSE) of DWT-ANN is comparatively less than that of the ARIMA model. A better forecasting model generally results in reduction of BWE. Therefore, BWE and NSAmp values are estimated using a base-stock inventory control policy for both DWT-ANN and ARIMA models. It is observed that these parameters are comparatively less in case of DWT-ANN model.

1. Introduction

In the past, a large number of studies have analysed the adverse effect of different uncertainties existing with demand, lead time and manufacturing process on supply chain performance and proposed various methodologies to reduce their impact (Hwarng & Xie, 2008; Mahnam, Yadollahpour, Famil-Dardashti, & Hejazi, 2009; Petrovic, 2001; Xie, Petrovic, & Burnham, 2006). One of the major manifestations of uncertainty is the amplification of order termed as bullwhip effect (BWE) (Forrester, 1961; Sodhi & Tang, 2011; Sterman, 1989). Lee, Padmanabhan, and Whang (1997) have identified five major causes for bullwhip effect in the supply chain context. They are listed as demand forecasting, order batching, price fluctuations, supply shortages and non-zero lead-time. However, BWE can possibly be moderated by addressing these issues in a planned manner. Among the five causes, accurate demand forecasting is considered as one of the challenging tasks by researchers as well as practitioners. Generally, demand is assumed to follow a time series pattern. Therefore, various time series models like autoregressive (AR) (Duc, Luong, & Kim, 2010; Luong, 2007; Luong & Phien, 2007), moving average (MA) (Chen, Drezner, Ryan, & Simchi-Levi, 2000a; Hong & Ping, 2007; Ma, Wang, Che, Huang, & Xu, 2013), exponential moving average (EMA) (Chen, Drezner, Ryan, & Simchi-Levi, 2000b), exponentially weighted moving average (EWMA) (Hong & Ping 2007), autoregressive moving average (ARMA) (Bandyopadhyay & Bhattacharya, 2013; Duc, Luong, & Kim, 2008a, 2008b; Zhang, 2004) and autoregressive integrated moving average (ARIMA) (Gilbert, 2005; Gilbert & Chatpattananan, 2006) have been proposed to improve the forecasting accuracy and subsequently reduce BWE by controlling the model parameters. According to Boute and Lambrecht (2009), moderating bullwhip effect does necessarily reflect the inventory fluctuations which influence associated inventory costs. Hence, variation in net stock with respect to demand known as net-stock amplification (NSAmp) is treated as another major supply chain performance measures. Therefore, accuracy of demand forecasting must be enhanced in such a manner that both the important performance measures of supply chain such as BWE and NSAmp must be reduced.

The widely used time series models for forecasting purpose especially ARIMA model is generally applicable to linear modelling and it hardly captures the non-linearity inherent in time series data. Therefore, artificial neural network (ANN) is preferred as a superior forecasting model because it addresses the limitations of time series models by efficient non-linear mapping between input and output data (Hwarng, 2001; Wei, Song, & Khan, 2012). For forecasting purpose, ANN neither requires any statistical information nor stationary nature of data series. It is basically a black-box model, data driven and a function approximator to solve complex

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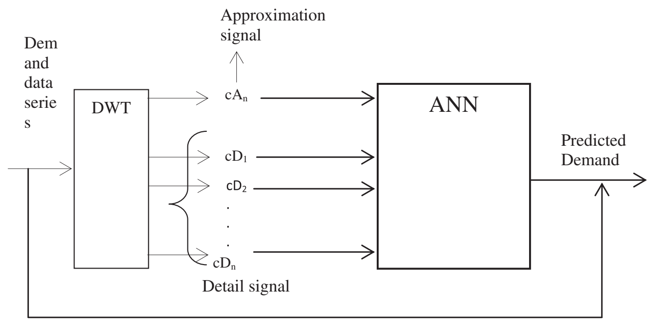

Fig. 1. Architecture of proposed DWT-ANN model.

problem. ANN has the ability of self-learning, self-organising and self-adapting to the data series. Therefore, ANN is applied in various fields of engineering and management including supply chain for prediction purpose when mapping relation between input and output is not known at priori (Doganis, Alexandridis, Patrinos, & Sarimveis, 2006; Patnaik, Satapathy, Mahapatra, & Dash, 2008; Sahu, Khatua, & Mahapatra, 2011; Zhang, Patuwo, & Hu, 2001). However, ANN being a data driven method, it simply maps the input and output without emphasising on the pattern of the data series. In contrast, wavelet theory (WT) is an efficient mathematical tool to gain information on the data series with respect to time. Wavelets are basically small waves which provide information about the data series in time and frequency domain. Recently, the combined approach of WT and ANN is introduced for prediction but hardly used in supply chain management for demand forecasting (Aggarwal, Saini, & Kumar, 2009; Khan & Shahidehpour, 2009; Partal & Cigizoglu, 2009).

The present research work proposes a robust and efficient time series model which can be applied to linear, non-linear, stationary or non-stationary data series. By improving the forecasting accuracy, performance of the supply chain can be enhanced through reduction in BWE and NSAmp. In order to improve the forecasting accuracy, a forecasting model based on discrete wavelet transforms (DWT) embedded with artificial neural network (ANN) is proposed. The self-learning and self-adapting capability of ANN can be explored to predict non-linear time series data if the network is well trained. However, training of the network becomes much easier if the pattern of the data is captured properly. Therefore, the past demand series is pre-processed through DWT to obtain different demand sub-series for capturing the pattern inherent with data. The resulting sub-series are given as input to an ANN model for training and testing. The proposed integrated approach of DWT and ANN denoted as DWT-ANN model is validated with an example data set from open literature and a comparative study between the DWT-ANN and ARIMA has been made. Then, the performance of the model is evaluated using demand data from three manufacturing firms dealing with different products and operating in different environment. The forecasting accuracy of the DWT-ANN model is compared with ARIMA model by estimating the mean square error (MSE). It is observed that MSE is comparatively less in case of DWT-ANN. It is also demonstrated that a better forecasting model leads to reduction in BWE and NSAmp. BWE and NSAmp are estimated by determining the order quantities based on a base-stock policy.

2. Literature review

The process of amplification of order in upward direction of a supply chain is termed as BWE. The effect of BWE on performance of supply chain is first analysed by Forrester (1961) and then demonstrated through famous Beer Distribution Game by Sterman (1989). BWE leads to not only increase in total cost of supply chain but also decrease in fill rate and profitability of the organisation (Chopra, Meindle, & Kalra, 2006). The studies have been devoted in the past to quantify BWE and propose time series forecasting models capable of moderating it. Luong (2007) have examined the effect of autoregressive coefficients and lead time on BWE for a two stage supply chain in which the retailer employs a base-stock policy for inventory management using first order autoregressive model AR (1). Further, the study is improved for higher order autoregressive model (Luong & Phien, 2007). Chen et al. (2000a) have analysed BWE for a simple two stage supply chain by predicting retailer demand through MA time series model. It is found that BWE increases with increase in lead time at lower level of information sharing. Chen et al. (2000b) have improved the study employing exponential smoothing forecasting technique for retailer's demand forecasting. Duc et al. (2008a) have considered a two stage supply chain in which demand is predicted through ARMA (1, 1) process. The effect of autoregressive and moving average parameter on BWE is analysed. It has been observed that BWE does not always exist within the supply chain. It occurs only when the autoregressive coefficients is higher than the moving average coefficients. The study is further modified to analyse the effect of stochastic lead time and demand process parameters on BWE considering a comparative study of demand forecasting process such as AR (1) and ARMA (1, 1) (Duc et al., 2008b). They have concluded that BWE increases with either increase in mean demand or standard deviation of lead time. Duc et al. (2010) have examined the effect of existence of a third-party warehouse on BWE in a supply chain assuming the demand process as AR (1)

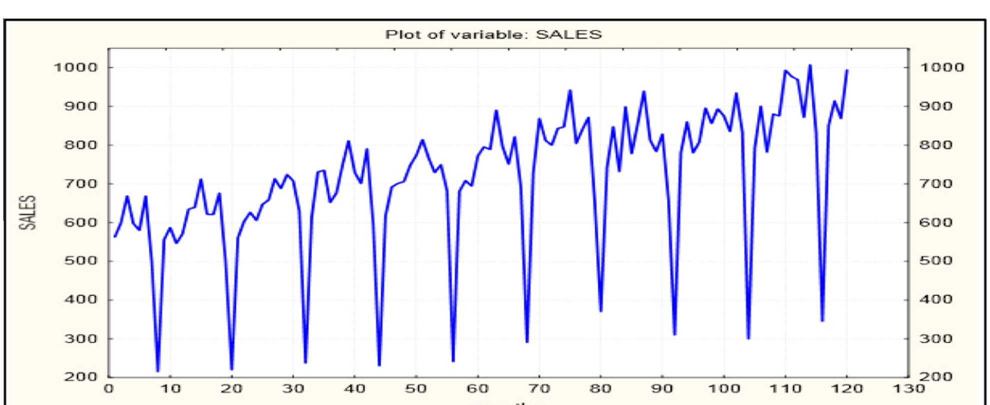

Fig. 2. Sales data for example dataset.