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A New Hybrid Prediction Reduces the Bullwhip Effect of Demand in a Three-level Supply Chain

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Abstract
In this paper, we present a new predictive hybrid model using discrete wavelet transform (DWT), and the artificial neural network (ANN) to reduce the bullwhip effect of demand in supply chain to obtain a real amount of final customer demand. Also, we compare our result with more comprehensive sample of previous research to extend the scope of our study. In this new research our methodology is combine two discrete wavelet transform (DWT), and the artificial neural network (ANN) was used to analyze the data. Results indicated that in comparison with the previous methods of prediction to reduce the bullwhip effect in supply chains, the use of DWT and ANN is more favorable leading to less error against other methods. Moreover, we discrete our data in liner data and nonlinear data because since the combinational method uses nonlinear data and gives importance to these data rather than linear data, it can be concluded that in comparison with linear data, nonlinear data have more importance in predicting the bullwhip effect. According to this new combinational technique, organizations can obtain suitable amounts of demand at all stages of supply chain, which makes a low distance between true and forecasting demands. Therefore, organizations can avoid some costs that playing an inessential role in their products.

Keywords
Supply chain, Bullwhip Effect, Demand, Artificial Neural Network, Discrete Wavelet Transform

1. Introduction
Each supply chain aims to deliver the product in appropriate amount, time, and place with the lowest possible cost in order to meet the final customer satisfaction in the supply chain [1]. Three-level supply chains include suppliers, manufacturers, and distributors that connect suppliers to a manufacturing company and a company to customers. A supply chain involves all factors that engage in customer satisfaction either directly or indirectly. A customer is an important part of the supply chain. It is necessary to ensure about superior customer service, cost, and product cycle times to manage the supply chain properly. Therefore, customer demand prediction is an important principle for managers who care about the performance of supply chain [2]. Supply chain management is essential for companies to improve their business in global markets. One of the problems in supply chain is uncertainties to forecast the demand. Demand prediction is affected by

several factors such as competition, prices, current technological development, and customer commitment levels [3]. The bullwhip effect is one of the challenges of supply chains. The most important reason for this effect is the lack of information on the final customer demand and the decision of each supply chain member based on the information received from the downstream member. Variations created in the demand level of supply chains and lead to deviations in demand prediction is called bullwhip effect [4]. The bullwhip effect leads to unsuited planning, growth in inventory levels, and a reduction in the profitability and service levels. The bullwhip effect is one of the problems observed due to continuous movement of inventory demands and increases the demand flow in the upward movement of a supply chain. The bullwhip effect is the result of variations and changes in information at different levels of the supply chain in relation to the demand. Information sharing among supply chain entities has a significant impact on the efficiency of the supply chain. Information sharing about orders and requests among different entities of supply chain will reduce the bullwhip effect [5]. There are many factors involved in the creation of leather footwear, the most important of which are the demand forecast, the volume of orders, the fluctuating costs, the precautionary reserve, and the lack of supplies. By controlling these factors, it is possible to improve the performance of the supply chain. Among the factors mentioned above, demand prediction is one of the important factors to control supply chain activities and bullwhip effect [6]. A greater influence of bullwhip effect on supply chain leads to a higher cost of supply chain, and the lower influence of bullwhip effect leads to reductions in production costs, inventory costs, delivery times, transportation costs, human force costs, and growth in the levels of product availability [7]. So, in order to prevent problems in the supply chain, there is a need to manage the bullwhip effect. The special situation in our country necessitates resource management and reduction of product costs. In recent years, many studies have been conducted to reduce the effect of bullwhip effect at supply chain level. However, as linear data were more important in such studies, there were significant errors. According to uncertainty in the effect of nonlinear data on bullwhip effect, this study tries to investigate the effects of these data to reduce the bullwhip effect. In this new subject Razavi Haj Agha et al. investigated the impacts of different prediction methods on bullwhip effect at different supply chain levels. In this research, there was a three-level supply chain, each of its components used moving average, exponential smoothing and linear regression [8]. Comparisons showed that under the assumptions of the problem, the best combination of predictive methods from the bottom to the top of the supply chain was the moving average method, linear regression, and exponential normalization. Chetnfield and Richard achieved a prediction demand model to reduce the bullwhip effect using mathematical modeling and moving average model in a multi-level supply chain. In this study, they investigated factors influencing the bullwhip effect and concluded that it is very important to use of a strong prediction model to reduce the impact of bullwhip on the supply chain level. Tanweer et al. (2014) investigated the accuracy of predicting various demand forecast models to reduce the bullwhip effect in a two-stage supply chain [9]. They concluded that although a variety of demand forecasting models had a small impact on the bullwhip effect, hybrid models that measure the impact of linear and nonlinear data had better performance to predict demand and reduce the bullwhip effect. Yousefi and Menhaj investigated the impact of the turbulent demand prediction systems on bullwhip effect in the supply chain [10]. They tried to predict the combination of forecast supply demand in a supply chain using a plan of a framework, and used precise control and prediction to reduce the amount of bullwhip effect. In their studies, they tried to use a variety of predictive combinational models to reduce the bullwhip effect on demand in the supply chain. They concluded that the integration and production of a purely predictable combination of methods would improve predictive performance and reduce the bullwhip effect. Wang et al. (2015) examined the goals, trends, and implications of the causes of the bullwhip effect [11]. They concluded that many causes of the bullwhip effect could be managed and reduced in supply chains. Yenchiang et al. investigated the impact of demand deviations in three-stage supply chain levels on the bullwhip effect and concluded that the accuracy of predicted demand for input at each stage of the supply chain is of great importance [12]. Ozelkan et al. (2018) investigated the bullwhip in pricing and make a new decision on customer's behavior in a three stage supply chain. Dominguez et al. make use of a new method to share information in supply chain and compare its result with unshared method for reducing bullwhip in supply chain [1].

2. Material and Methods

2.1 Supply Chain

In the current global competition, the customer's demand for high quality, more product diversity, and fast serviceability has increased the pressure on organizations that had not existed before. As a result, organizations cannot handle all the process [13]. In the current competitive market, in addition to address the organization and internal resources, small and medium enterprises need to manage and supervise the resources and the outside entities of organizations in order to achieve a competitive advantage or advantage with the aim of gaining more share of the market [12]. Therefore, activities such as supply and demand planning, material provision, product manufacturing and planning, product service maintenance, inventory control, distribution, delivery, and customer service, which were carried out at the company level, are transformed to the supply chain level. A supply chain consists of all businesses and entities that provide the final customer demand directly or indirectly [14]. In other words, supply chain consists of two or more separated organizations and is linked by the flow of materials, information, and financial flows. These organizations can be enterprises that produce raw materials, components, end products, or services such as distribution and warehousing, wholesale and retailing. Even a final consumer can be considered as one of the organizations. A key issue in a supply chain is to manage and control the synchronization of these activities [7]. In fact, the supply chain involves activities related to the flow of goods from the supply of raw materials to the delivery of goods or from the service to the final customer. The supply chain includes all the units that are effective in meeting customer requirements. These activities include finding resources for material supply, system management, assembly, and sale the goods. A supply chain typically includes: 1) customer, 2) retailers, 3) wholesalers, 4) distribution companies, 5) manufacturers, 6) investment producers (banks, institutions, etc.), and 7) raw material suppliers (Figure 1).

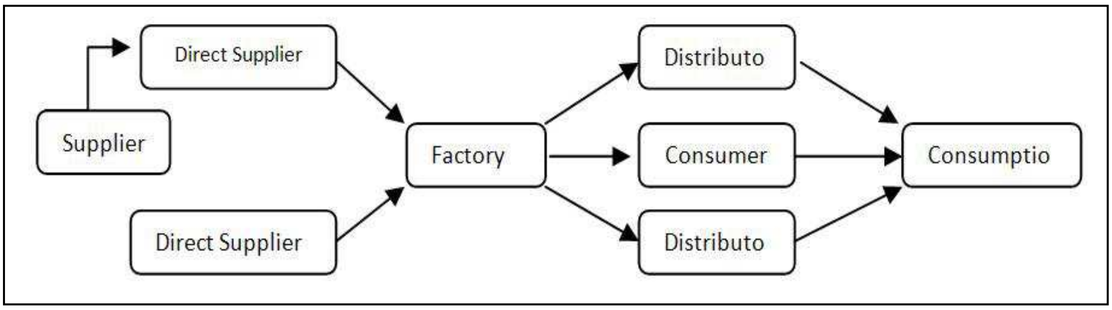

Figure1. A general schema of a supply chain

2.2 Supply Chain Management

Supply chain management is an integrated process to manage the overall distribution flow path from the supplier to the final user. It includes the extent and limits of integrated behaviors for cooperation between the customer and the supplier in the course of the external integration process. Supply chain management is a set of activities that optimize the value of goods and services from the source to consumption by coordinating physical, financial, and informational flows, and, on the other hand, raise the value of the customer by meeting and satisfying his/her demands [1]. Although the flow of materials has a forward movement, the flow of information is moving backward, that is, information about demand, cost and quality are provided from the customer to the system. Supply chain management as a set of management processes includes a process of management relationships, information, and flow of materials within the designated boundaries for the provision of services and economic value to the customer through the management of physical channels of relevant information from resources for consumption [5]. It is better to clarify the operational objectives and the task of supply chain management to realize the definition. The supply chain management mission is customer satisfaction, which leads to survival and continuity of the company. The objectives of supply chain management are to minimize the costs associated with the flow of materials and information so that appropriate goods and services are delivered to the customer sufficiently and in suitable conditions. It is clear that these goals will not be achieved without integrating the supply chain activities, which not only streams the flow of information and materials, but also meets the strategic and operational demands of the supply chain management [13]. Main components of supply chain management are: 1) Logistics management in the supply chain, 2) Information management in the supply chain, and 3) Management of relations between supply chain members, which are strategic features in the supply chain. It is worth to note that the flow of materials is going forward, starts with the suppliers of raw materials, continues to the final customer, and passes through a three-stage chain members including suppliers, manufacturers, and distributers. But another characteristic that leads to the flow of materials is the flow of information, which is moving backwards and starts with the end customer, ends with the suppliers, and interacts with other members of supply chain [7]. This information reflects customer demand for the products or services. There is another factor that leads to integration of the flow of materials and information, which is the appropriate relationship of members of the supply chain (Figure 2).

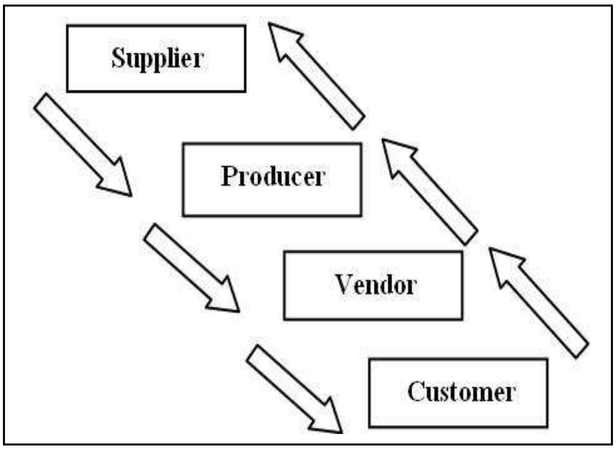

Figure2. Flow of materials and information in a supply chain

2.3 Bullwhip Effect

One of the major effects of uncertainty is the bullwhip effect, which refers to irregular changes in orders over the supply chain. In fact, small changes in customer demand in the supply chain are transformed into huge changes in demand on the manufacturer's side. This work was first observed in one of the products from the Proktel and Gamble Company. Investigations about the bullwhip effect show that its contributing factors are: 1) Demand prediction, 2) Orders classification, 3) Production quotation, 4) Pricing product, and 5) Motivational work [8]. These factors interact in different combinations and supply chains, but their particular impact is to generate fluctuations in supply chain. So the bullwhip effect of demand can be written as:

$$BWE = \frac{\text{Variance of order}}{\text{Variance of demand}} \quad (1)$$

Bullwhip is one of the main reasons for the inefficiency of the supply chain. In fact, the basic definition of the bullwhip effect relates to the meaning of uncertainty. In general, the more the company is away from the end-user's delivery time, the greater the demand variation is. This effect will lead to inefficiencies in the supply chain, which will increase the cost of supplies and reduce competitive power [5]. The bullwhip effect potentially causes supply chain inefficiencies leading to 1) Stocking inventory over demand in the supply chain due to variability and lack of demand, 2) Low level of customer service due to loss of production and sales plan, and poor demand forecast, 3) Long-term delays, 4) Uncertain production plan, 5) Loss of revenue, and 6) Deviation in capacity plans and inefficient transportation. It is important to note that the phenomenon of whipping leather is not only the result of a completely illogical and unreasonable behavior of supply chain members in the supply chain, but also originates from a reasonable behavior of the members. This means that each supply chain element changes its value precisely because of its approach to transfer demand to the next level of the supply chain. One of the important issues to create the bullwhip effect is the prediction algorithm used by various supply chain members. Even if the task of algorithm used in the supply chain is to transfer the same received orders (transferring an order to the next member without modification), and exactly the same amount received from the group is transferred to the top manually, the effect of the bullwhip demand can still be created. In general, the demand variation is greater when the company is farther from another company in terms of delivery time from the end customer. This effect will result in the inefficiency of the whole supply chain because it will increase the cost of supplies and reduce competitiveness [1]. (Figure 3)

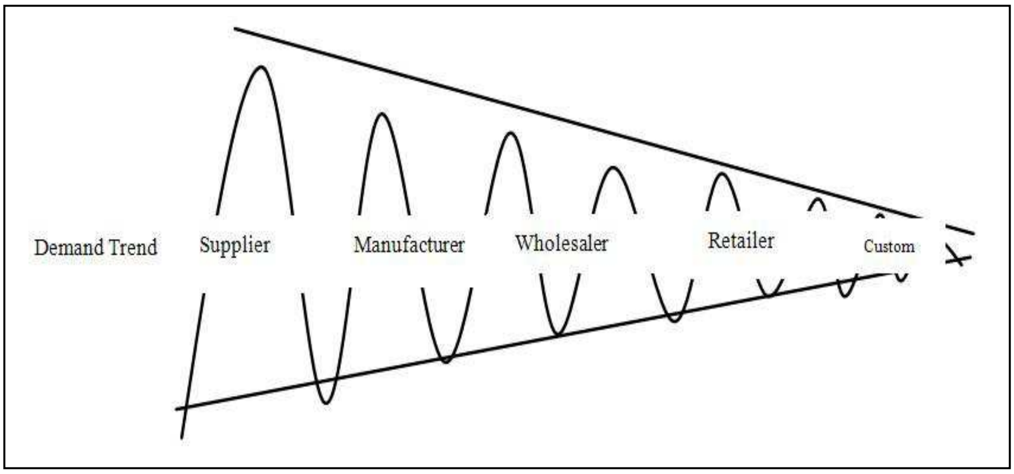

Figure3. Bullwhip effect of demand

Many reasons lead to the creation of bullwhip effect in supply chain, of which the most important are:

- Demand prediction: If the demand prediction of a firm is performed instead of the demand of end customer based on next level orders, this will boost demand changes and the presence of the bullwhip in the supply chain.
- Order category: Companies usually collect their orders because of the set up and order costs. This will prevent the supplier from ignoring the information of the end customer. Indeed, the final customer demand is passed to the points where the demand reaches the level of the category.
- Price fluctuations: Sometimes companies change their product prices for marketing reasons. The consequence is that customers buy more when the price is lower. This changes the pattern of customer demand.
- Overstated order: If the demand for the product increases, suppliers often ration products and only provide a percentage of customer orders. This can lead to customers ordering more than their actual demands, and as soon as the crisis system has gone through, surplus orders become apparent and the result of this phenomenon is a rise in customer demand changes.
- Shortage and bargain: Because manufacturers tend to bargain when there is a lack of supply, customers order more than the actual requirement.
- Delay: The required time for supply chain to respond to the final demand of customer. Delivery is delayed for two reasons. First, because it takes a while for information to reach the supplier. Second, the suppliers need time to adjust their capacities and deliveries.
- The role of human behavior in bullwhip effect: In general, human behavior can be placed in a spectrum that is relaxed on one side and scared at the other end. In case of calm, the

manpower will order more than its requirement and will store additional amounts as a safety deposit. But in case of panic, customers get higher bills before the customer's demand grows. Both strategies have a negative outcome, so it is preferable to use a combination of the two strategies.

2.4 Neural Networks

Since the artificial neural networks (ANN) perform well in predicting nonlinear models, researchers have tried to use these networks to obtain a precise forecast of demand and reduce the bullwhip effect at a three level supply chain. Neural networks include a network of simple processing elements (neurons) that can display a complex and determined relationship between the elements of processing and the parameters of the elements. Because of their considerable ability to deduce the results of complex data, neural networks can be used to extract patterns and identify different trends that are is very difficult for humans and computer systems to identify. ANN has a wide range of applications, which can generally be categorized as follows: (the network recognizes disturbed patterns) clustering, sorting, pattern retrieval identification, generalization, and optimization. Today, the use of intelligent systems, in particular the ANN, has been widespread so that these tools can be categorized in the framework of basic mathematical operations and as a common tool. The learning process in the human brain also shows that we experience the same process in our brain and all skills, knowledge and attitudes are formed by weakening or enhancing the connection between neurons of the brain. This improvement and weakness in the mathematical language is modeled and described as the setting of a parameter (called weight). (Figure 4)

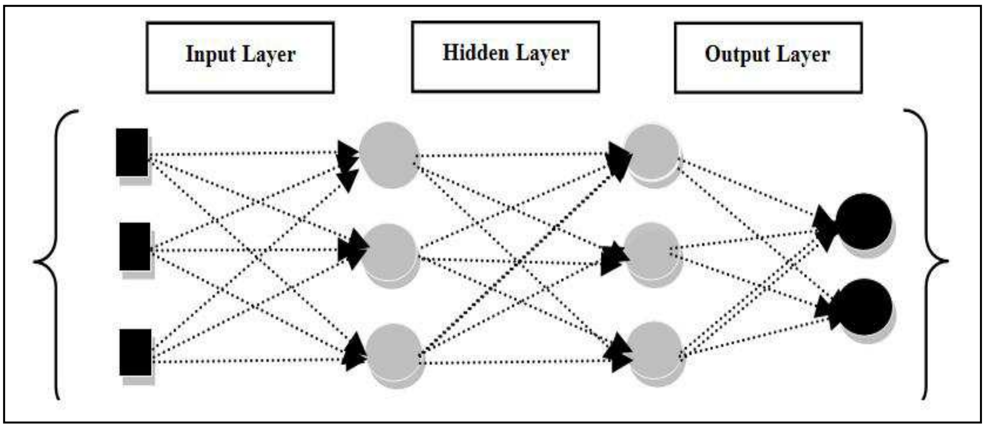

Figure4. Neural network

2.5 Discrete Wavelet Transform

This study used discrete wavelet transform (DWT) as described in the previous section. The function$X_t = f(x_{t-t1}, x_{t-t2}, x_{t-t3}, \dots,\ x_{t-tn})$, t= $(t_1 t_2, \dots, t_n)$ is used in a normal situation. Various methods, such as lineal methods, are used to find the value of function (f) and finally ARIMAX is used as the most complete linear model, or non-linear models such as NARX-FUTTY are used. However, since the decomposed and accurate information of the above function is not obtained, it is written as $x_t = a_t + d_t$ and the $x_t = f(a_{t+t1}, d_{tt1}, a_{t-t2}, d_{t-t3})$. In this function, the constituent fraction of the function a_{t-t1}, d_{t-t1} is known. The low frequency components (far information) and

d_{t-t1} and the high frequency components (close information) are obtained as the decomposition of this function, a_{t-t1}. These functions can be broken up to several levels to achieve the desired information, and ultimately the following function is obtained:

$$X_t = a_{n1\,t} + d_{n\,t} + d_{n-1} + \ldots\ldots\ldots\ldots\ldots\ldots + a_{n2\,t} + d_{n\,t} + d_{n-2}. \quad (2)$$

Low frequency ⟶ high frequency

In this case, the system decides how much time it takes to predict the system more accurately, and the neural network decides about the amount of required low-frequency data based on the type of prediction. In prediction, the higher the amount of delay, the lower the numbers of low frequencies are important, and a lower amount of delay indicates that high frequency system information is required. According to the complexity of this system information, it can find the part of the information being used and provides complete information and serves as a reliable input to obtain a prediction with low error rates. As we know, these data are transformed into three parts of training, testing, and checking in the artificial intelligence network. The percentage of data assignment for each of these steps rests with the user and varies depending on the type of using neural networks.

3. Results and Discussion

This research is carried out in the context of previous studies to complete this research and to examine the supplementary dimensions and issues. This is a developmental research in terms of purpose that uses the pragmatism paradigm to utilize the most appropriate methods and techniques for research purposes. Pragmatism is a revolution against idealism and purely rational explorations that have no utility for humans. The purpose of using this term is a method to solve and evaluate rational issues. In this research, mathematical modeling is used using MATLAB software to minimize the bullwhip effect of supply chain demand. The bullwhip effect that this research intends to reduce is measured as a dependent variable. Demand is discussed as an independent variable that affects the dependent variable. Therefore, this research considers demand fluctuations as an independent variable and examines its effect on the dependent variable, that is, bullwhip effect and its fluctuations at the first level of supply chain. In addition, the type of data (linear or non-linear) is considered as a moderator variable in this research. It is examined how the type of inferred data from demand fluctuations is effective in obtainin1g a precise amount of bullwhip effect at a three-level supply chain.

Perception and realization of the patterns including information in the past is very necessary to predict future demand values. In situations where demand models are nonlinear, it is very difficult to find patterns for these data. If these nonlinear information and data are entered into an artificial neural network (ANN), they create either inefficiency in the neural network or a false prediction. The ANN provides relatively good results of prediction, but there is still a room for improvements in predictive models. Therefore, wavelet theory plays a crucial role for data patterns decomposition and for data decomposition in appropriate models with high and low frequencies making these patterns useful for analyzing data in an ANN (Figure 5).

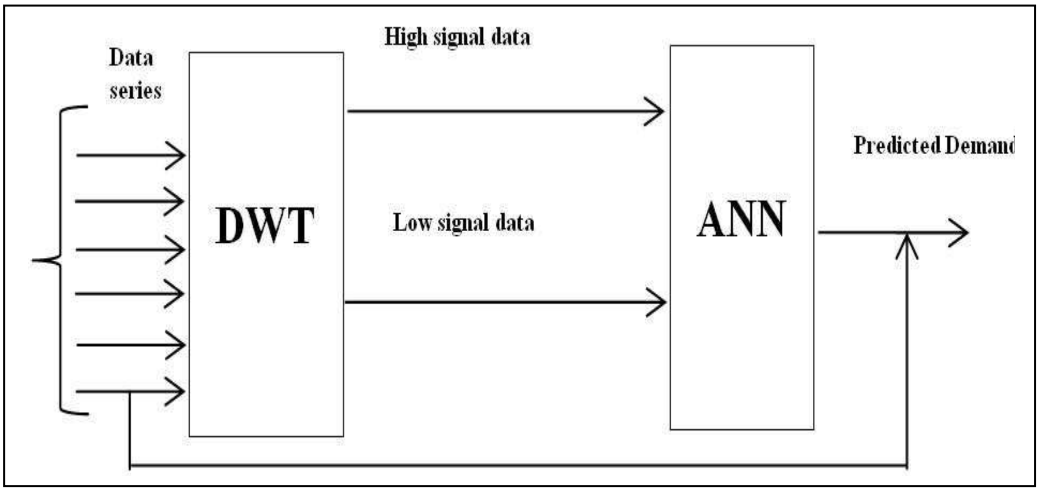

Figure5. Conceptual model of research

Using the new combination of DWT and ANN, this study tried to reduce the error rates of MSE and MAD and compare the results with the ARIMA and ANN hybrid model. As mentioned, the bullwhip effect to be reduced is measured as a dependent variable in this research. Demand is discussed as an independent variable that affects the dependent variable. Therefore, in this research considers demand fluctuations as an independent variable and examines its effect on the dependent variable, which is the bullwhip effect and its fluctuations at the first level of a supply chain. Moreover, the type of data (linear and nonlinear) is presented and investigated is a moderator variable. It is so necessary to identify a model that contains past information to predict future demand values. It is very difficult to obtain these patterns in nonlinear conditions, and if these patterns enter into one of the predictive tools, such as the ANN, they create inefficiency in this network and produce a prediction with a high error rate. Therefore, data fragmentation plays a crucial role in obtaining an accurate prediction. The results are compared to achieve a reasonable comparison between previous research and the results of this research. Since the researchers use the Lynx data to predict using the ARIMA and ANN hybrid model to obtain optimal results, they will try to use them as comparative and base data. The company possesses 114 data for the years 1821-1934. The diagrams for these data are as follows (Figure 6).

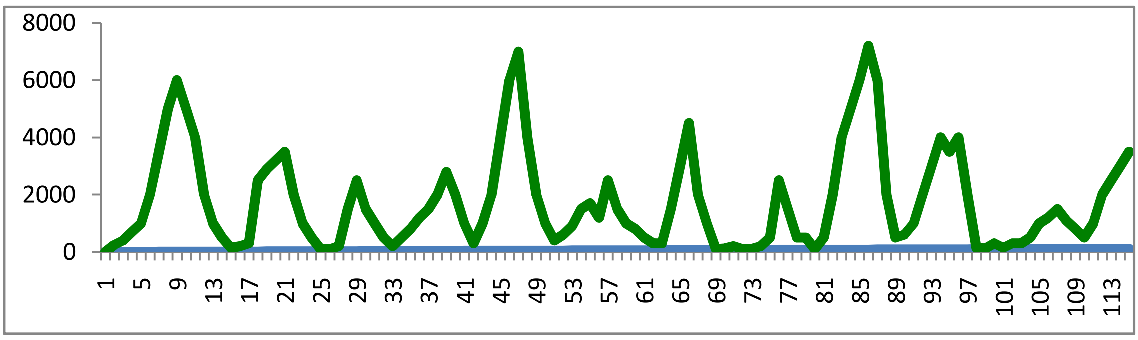

Figure6. Lynx data for the years 1821-1934

Table 1 represents the results obtained in the combination of ARIMA and ANN used to predict the demand and reduce the bullwhip effect of demand data.

Table1: The results with the ARIMA and ANN Lynx data for the years 1821-1934

Series	Sample Test	Training Test	Test Set	MSE	MAD
lynx	114	1921-1934(10)	1921-1934(114)	0.017323	0.103972

The bullwhip effect of demand result the ARIMA and ANN Lynx data is as follow:

$$BWE = \frac{\text{Variance of order}}{\text{Variance of Target demand}} = {}^{0.963}/_{0.993} = 0.971$$

In this section, the extracted data of Lynx Company were used as the input data into DWT in the MATLAB software environment. Coding and a variance error rate (&) of 10 unit in this research were used to determine the target data. The results of the frequency and converting these data are in the level six of decomposition (Figure 7).

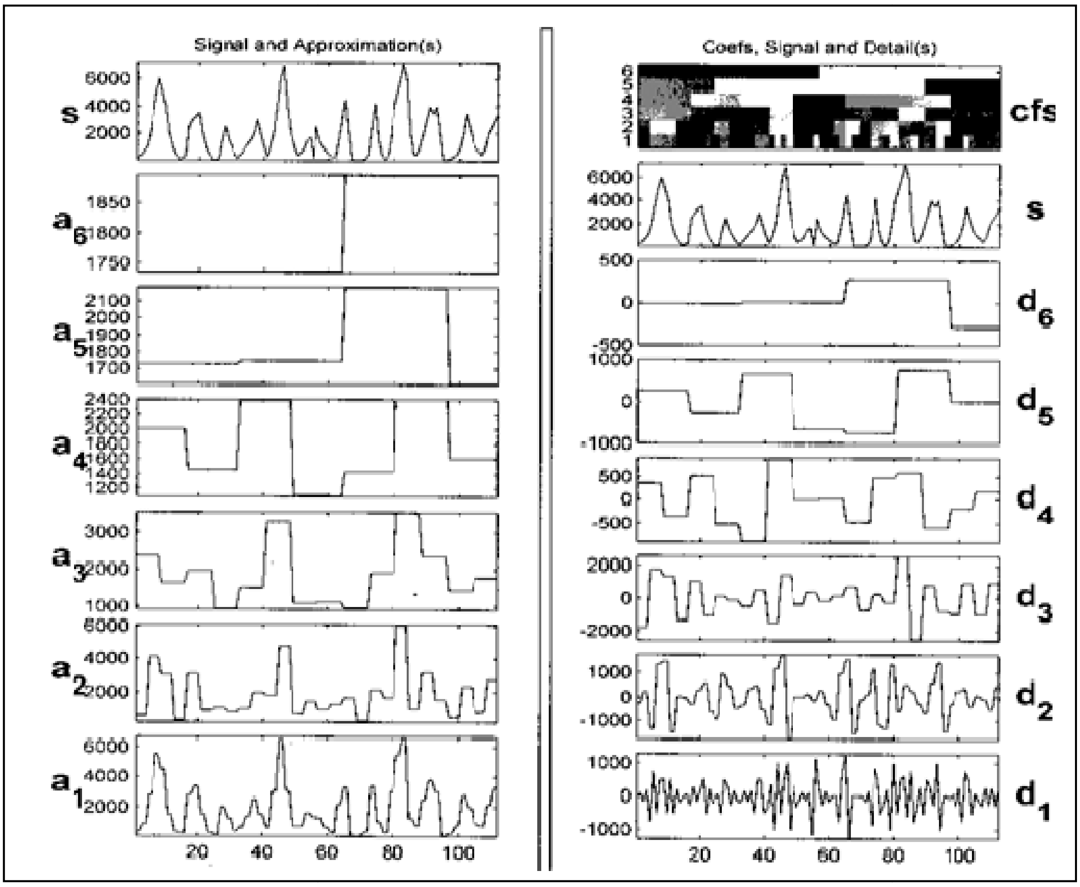

Figure7. Data decomposition using wavelet transform

The result of data with high and low frequencies are follows. (Figures 8 and 9).

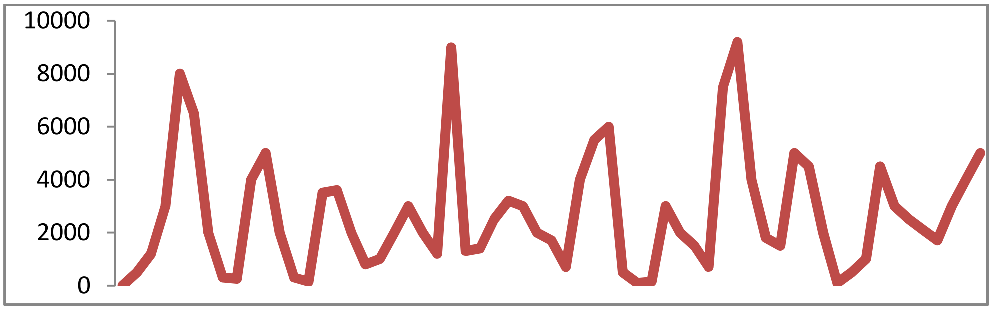

Figure8. High frequency data

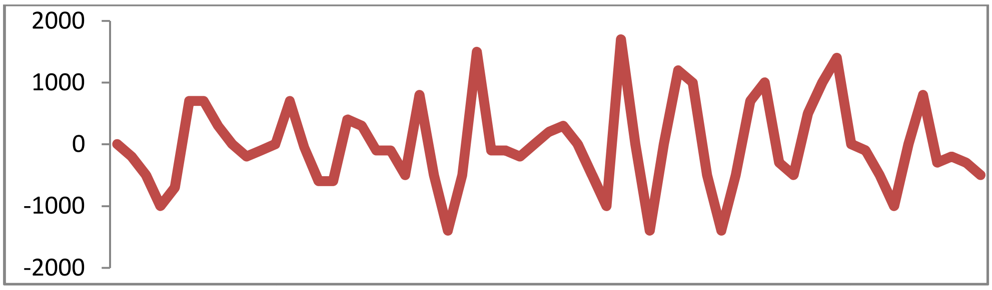

Figure9. Low frequency data

Frequency and data transmitted to high and low frequencies were used as inputs to the ANN to obtain the magnitude of error and to obtain the predictive data. The neural network used in this study is the Haar network, of which 70% of the data is used as Training, %15 as Validation and %15 as Testing. The results of the analysis of these data by ANN are bellow. (Figure 10)

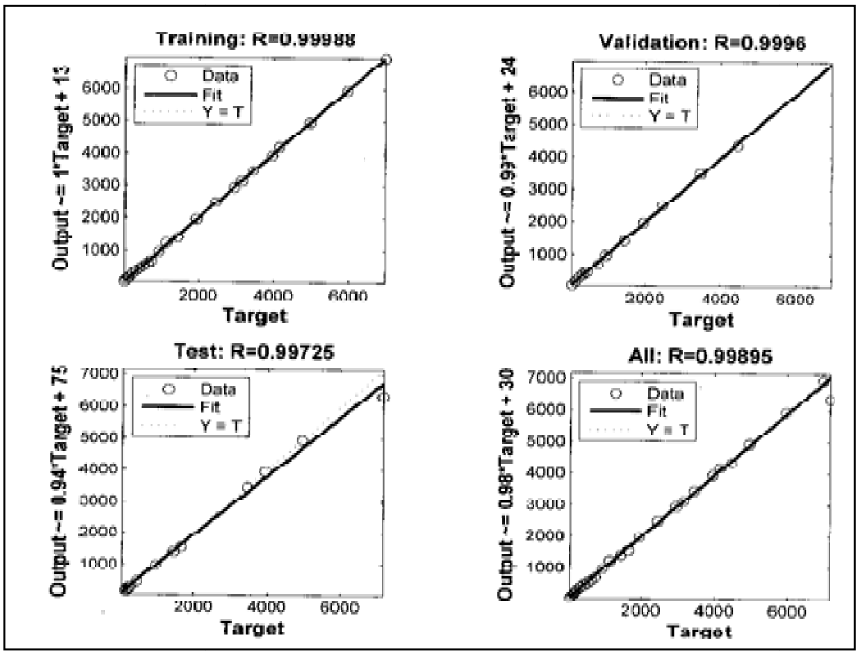

Figure10. Regression plots

Also, the result of the plot prediction trend line can be shown as follow.

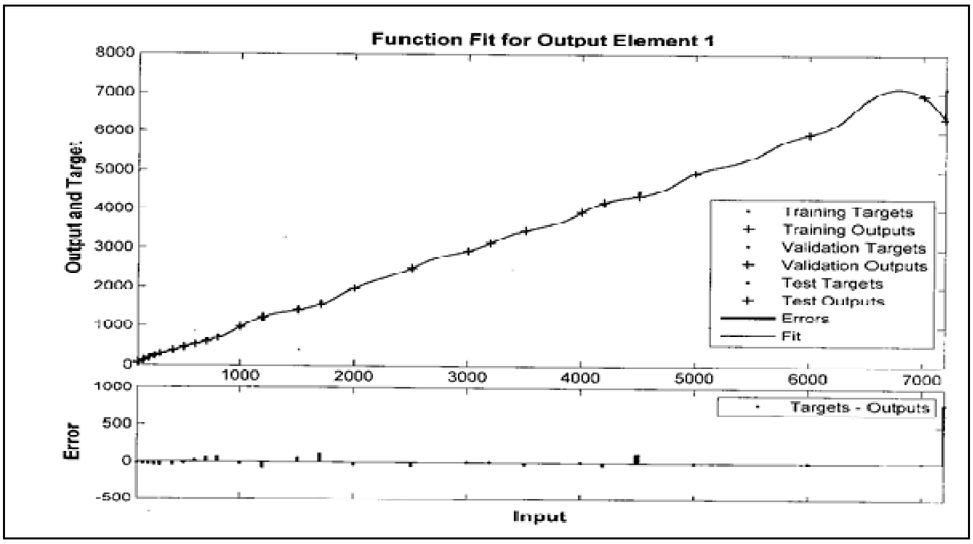

Figure11. The plot of prediction trend line

A comparison was made between the results of the mean absolute error Mean Absolute Deviation (MAD) and Mean Squared Error (MSE) using the above combination method. As shown in the comparison plot, there is a high correlation between Train and Target data with the initial plots in regression plots (Figure 12).

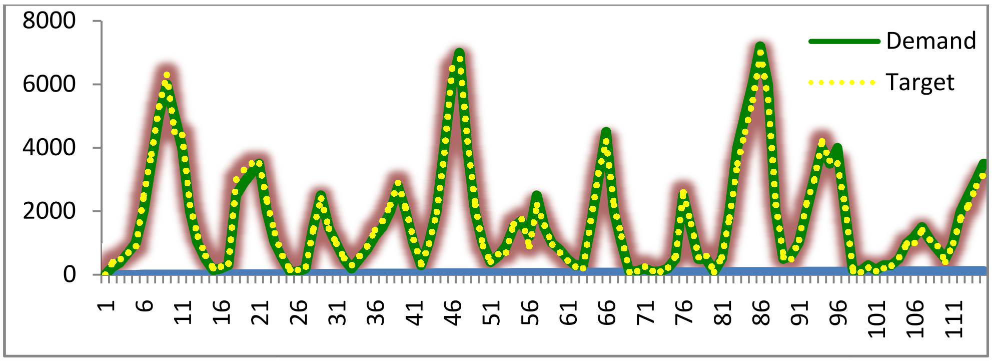

Figure12. Comparative plot with initial data

Table 2 shows the results obtained in the combination of DWT and ANN, which are used to predict the demand and reduce the bullwhip effect of demand data.

Table2. The results with the DWT and ANN Lynx data for the years 1821-1934

Series	Sample Test	Training Test	Test Set	MSE	MAD
Lynx	114	1921-1934(10)	1921-1934(114)	0.015280	0.100050

The bullwhip effect of demand result the DWT and ANN Lynx data is as follow:

$$BWE = \frac{\text{Variance of order}}{\text{Variance of Target demand}} = {}^{0.975}/_{0.991} = 0.984$$

4. Conclusions

In the current competitive world, many companies need to interact between their organization and other organizations to deliver their products to customers with a high quality. These chain activities, called the supply chain, include all activities related to the flow of goods and the conversion of materials from the stage of procurement of materials to the stage of delivery to the final consumer. In this paper, the bullwhip effect was discussed in a three-stage supply chain in order to reduce the bullwhip effect in a three-stage supply chain using discrete wavelet theory and artificial neural network. Data were analyzed by discrete wavelet technique, used as input data to the neural network, and compared with previous methods to reduce the bullwhip effect, yielding a lower error. The best record for bullwhip effect of demand is equal (1) and when the bullwhip effect move to arrives to this optimal number, certainly has a good performance. According this research bullwhip effect of demand on Lynx data in hybrid model (ARIMA) and (ANN) is (0.971). But this amount on Lynx data had been grown with hybrid model (DWT) and (ANN), it arrives about 0.984. This comparison has shown that the amount of bullwhip effect in hybrid model (DWT) and (ANN) is more than of other hybrid models, and absolutely this research model has a good performance against other hybrid models to reduce the bullwhip effect of customer demand. According to the greater use of the above hybrid method of nonlinear data and the importance of these data in comparison with linear data, it can be concluded that nonlinear data are more important than linear data to predict the bullwhip effect in supply chains. In this research, a good result was achieved by considering the combination of two methods to reduce the bullwhip effect. Therefore, it is recommended to use two distinct ANN and ARIMA methods for linear and nonlinear data to reach the same importance, after they were analyzed by the wavelet method.

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