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APPLICATION OF GAME THEORY AND NEURAL NETWORK TO STUDY THE BEHAVIORAL PROBABILITIES IN SUPPLY CHAIN

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ABSTRACT

As a review of game theoretic approach to optimize the logistic costs with the objective of modeling interactions among players in a basic supply chain, this paper focuses on a single channel, two-echelon supply chain with a retailer and his supplier of a one-product where careful attention is given to information sharing in general and demand forecasting in particular. Therefore, in the industrial world, firms cannot risk waiting for the actual demand to occur so they can react and determine the quantities to purchase, produce or deliver. Demand forecasts are important and necessary to any member of the supply chain as they gave them the advantage of planning and anticipating for future needs. However, demand forecasting is one of those crucial decisions where an error can cost too much. This is why we choose to implement the artificial neural network as a forecasting technique. Obviously the closest actor to the market i.e the retailer has the best view of demand levels than the supplier, so sharing demand information with the other actors has an impact on the performance of the whole supply chain but it is not necessarily the case since the retailer can choose to withhold this information. This is why we focus in this investigation on the demand's prediction when information is not shared using the artificial intelligence of neural networks.

Keywords: *Supply chain management, Game theory, demand forecasting, Asymmetric information, Demand uncertainty, Neural network.*

1. INTRODUCTION

When it comes to applying mathematics to analyze or evaluate strategic decisions among at least two rational actors, called players, we are in the realm of game theory; with sometimes cooperative and sometimes conflicting interests. Behaving rationally, for one player, means acting to maximize his own payoff, knowing that the final outcome of each player depends not only on his own action or on chance events, but also on the actions of other players.

Since the ultimate goal of any effective supply chain management system is to reduce its total relevant cost with the assumption that products are available when needed; this paper uses a game theoretic approach to model and analyze the decision making process in a basic supply chain as a game of two players. We start by presenting the basic concepts of game theory through examples, in order to explain how the behavior of the supply chain members can be predicted and optimized under a set of given objectives. Followed by demonstrating the importance of demand forecasting among the supply chain's actors. Therefore, in the industrial world, firms cannot risk waiting for the actual demand to occur so they can react and determine the quantities to purchase, produce or deliver. Demand forecasts are important and necessary to any member of the supply chain as they gave them the advantage of planning and anticipating for future needs. However, demand forecasting is one of those crucial decisions where

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an error can cost too much. This is why we choose to implement the artificial neural network as a forecasting technique. Indeed, with their learning ability, neural networks can predict future demands based on previous ones using a real dataset.

The studied system is modeled as a two-echelon supply chain composed of one supplier and one retailer facing a random demand of a final product.

The experimentation part of this paper deals with finding a solution to demand uncertainty using the artificial intelligence of neural networks when demand information is not shared.

2. GAME THEORY THROUGH EXAMPLES

2.1 Literature background

Game theory [1] [2] is a mathematical tool that deals with interdependence decisions (cooperation/competition) among multiple agents, called players, this theory proved its success in many areas (politics, economy, biology…). It was first introduced by Von Neumann and Morgenstern [3], then by John Nash [4], [5], [6], [7] with the development of the solution concepts for games, more precisely the concept of equilibrium. Kuhn [8] focuses in his work on the concept of imperfect information.

Cachon and Zipkin [9] studied a single channel, two-stage supply chain with stationary stochastic demand considering that inventory holding costs and backorder penalty cost are charged at each echelon of the supply chain. Two games are considered where inventory cost is charged by the two independent stage separately (competition) and then by choosing the same local inventory with shared costs (cooperation). The author demonstrate that the games have a unique equilibrium that differs from the optimal solution.

Hongwei et al. [10] Analyzes a non-cooperative mechanism in a two-echelon decentralized supply chain composed of one supplier and n retailers under two conditions: sufficient and insufficient supply. Several Nash Equilibrium contracts are used both in echelon inventory games and local inventory games with the omission of the concept of asymmetric information.

In Esmaeili et al. [11], several seller-buyer supply chain models are studied using non-cooperative and cooperative games with the Stackelberg strategy as a solution concept for the non-cooperative game and Pareto efficient solutions for the cooperative game.

Tetsuo and Zipkin [12] studied the benefits of sharing demand forecasts information of a stochastic demand in both cooperative and competition settings on a simple supply chain of a single supplier and a single retailer. Different modes of decision making are studied: centralized mode, cooperative case, competitive case with centralized demand forecasts and competitive case with decentralized demand forecasts.

In its general form, a game is defined by three parameters [13] $< N, X_i, \pi_i >$:

- N: set of i players where N ={1,2…,n};
- X_i: set of possible strategies of player i; called pure strategies of players
- Payoff function of player i denoted $\pi_i(x_i, x_{-i})$ choosing to play the strategy x_i given the strategies adopted by the other players denoted x_{-i}.

The main objective of each player i is to maximize his individual profit by finding the optimal strategy $x_i^* \in X_i$; where:

$$x_i^*\ (x_{-i}) = \arg\max \pi_i(x_i, x_{-i}) \qquad (1)$$

A mixed strategy for player is a distribution on his pure strategies with given probabilities that determines the player's decision. Note that not every game has a pure strategy equilibrium. However, every game has a mixed strategy Nash equilibrium. The idea is that each action is assigned a probability of play and given these probabilities, a player who is adopting a mixed strategy is indifferent between his actions. The example bellow (see example 2) explain how optimizing payoff might require a randomized strategy.

2.2 Examples of game theory

In order for game theory to apply, two assumptions must be made:

- The players are rational which means that each player is acting in his self-interest
- Each player (choice made) has only partial control of the game's outcome

We can describe a game by listing the players participating in the game as well as listing the alternative actions for each player. The simple form game is a two-player game, in this case the game is modeled in a matrix where the rows are the actions of the first player, and the columns represent those of the second. In this matrix, the utilities of players are represented by two numbers: (First player's

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payoff, Second player's payoff). Note that higher numbers are better (i.e with more utility).

Example 1. Prisoner's dilemma game (Pure strategy)

The prisoner's dilemma game is one of the famous games, where two players are partners in a crime. Each prisoner is placed in a separate cell, and offered the opportunity to confess or not. The game can be represented by the following matrix of payoffs:

		Prisoner 2	
		Not confess	Confess
Prisoner 1	Not confess	(3,3)	(0,5)
	Confess	(5,0)	(1,1)

In this example, (Not confess-Not confess) is a dominant strategy equilibrium. However, it is not Pareto optimal. Both players could be made better off if neither defected against the other.

Example 2. Mixed strategy

		Wife	
		Football	Shopping
Husband	Football	(2,1)	(0,0)
	Shopping	(0,0)	(1,2)

In pure strategies, the probability of each action is $1/2$:

Husband's payoff:

π_H(Football) $=1/2* 2 + 1/2* 0 = 1$

π_H(Shopping) $= 1/2* 0 + 1/2* 1 = 1/2$

Wife's payoff:

π_W(Football) $= 1/2$

π_W (Shopping) $= 1$

We conclude that if we limit to pure strategy players will not coordinate therefore the best solution for players is being indifferent to their choices by associating a probability to each action:

- α: probability of choosing football for husband
- β: probability of choosing shopping for wife

Since payoffs must be equal for both players:

Husband:

$\alpha * 2 = (1-\alpha) * 1$ Meaning that $\alpha = 1/3$

Wife:

$(1-\beta) * 1 = \beta * 2$ Meaning that $\beta = 1/3$

In both cases the expected payoff of each player is $2/3$

3. DEMAND FORECASTING TECHNIQUES

3.1 Traditional techniques

In the industrial world, firms cannot risk waiting for the actual demand to occur so they can react and determine the quantities to purchase, produce and deliver; knowing that each one of these operations takes time and for a supply chain manager time is money. Demand forecasts are important and necessary to any member of the supply chain as they gave them the advantage of planning and anticipating for future needs (Just in Time delivery policy to costumer orders).

The result of better demand forecasts leads to reducing stock, giving the opportunity of planning production, reducing logistic costs, and improving customer service. There are three commonly used techniques of modeling demand forecasts:

- Qualitative techniques: based on opinion and intuition, used with limited or unavailable costumer demand data.
- Quantitative techniques: based on mathematical models and historical data to make forecasts.
- Time series techniques: this technique is the most frequently used method in the literature, we
  - *Simple Moving Average Forecasting Model* that uses historical data to generate a forecast:

$$F_{t+1} = \frac{\sum_{t-n+1}^{t} A_i}{n} \quad (2)$$

Where

F_{t+1}: Forecasts for period t+1

n: Number of period used to calculate moving average

A_i: Actual demand in period i

- *Weighted Moving Average Forecasting Model that is* based on an n-period weighted moving average:

$$F_{t+1} = \sum_{t-n+1}^{t} w_i A_i \quad (3)$$

Where

F_{t+1}: Forecasts for period t+1

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n: Number of period used to calculate moving average

A_i: Actual demand in period i

w_i: Weight assigned to period i with $\sum_{t-n+1}^{t} w_i = 1$

3.2 The adopted technique: Neural network

The human neural network contains many neurons connected between them. Inspired by this functioning of biological human neurons, artificial neural network (ANN) [14] also contains layers of interconnected neurons and has the ability of learning, classifying, calculating and forecasting… With supervised learning, ANNs are capable to respond to problems based on what it is already learned before in the learning phase. In the Multi Layer Perceptron (MLP) structure of ANN, there are three types of layers, the input layer that receives an external input data, the output layer used to return the result or results and the hidden layer containing neurons helping to obtain a better result.

In our case study, we aim to apply ANN for forecasting purposes, this is why we focus in the literature review on the application of ANN in management and more specifically in demand predicting. For more details on neural networks and their applications in management, the reader could refer to [15] [16] [17].

To quote some other works using neural networks for forecasting purposes, Doganis et al. [18] present a complete framework that can be used for developing nonlinear time series sales forecasting models and apply a combinatory technique of two artificial intelligence methods, namely the RBF (Radial Basis Function) neural nets architecture and a specially designed genetic algorithm (GA) for forecasting sales data of fresh milk. Other researchers applied ANNs with fuzzy systems like Chang and Wang [19], Gumus et al. [20] or Wang et al. [21].

Since ANN algorithms have the ability to accommodate non-linear data, to capture subtle functional relationships among empirical data, Kumar et al. [22] use ANN for demand forecasting so that demand and supply are in balance by fulfilling costumer's demand and reducing excess inventories. They also present a comparative analysis of different training methods of neural network using the results obtained from the demand forecasting model.

4. NUMERICAL EXPERIMENTATION: DEMAND FORECASTING

4.1 Model description

This study examines a single product in a two-echelon supply chain composed of a single retailer (buyer) and a single supplier (vendor).

The decision making process of this model is presented in figure 1.

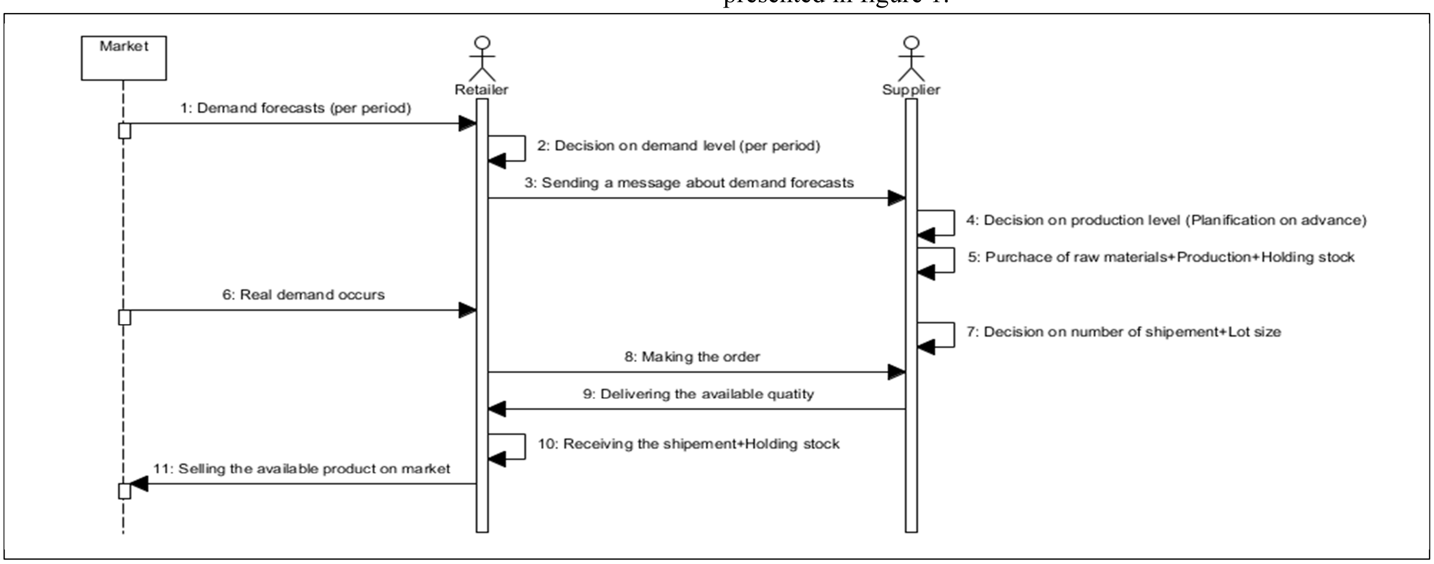

Figure 1: Sequence Diagram Of The Two-Echelon Supply Chain With Demand Forecasting

We suppose that each player has two choices: "Cooperate" or "Not cooperate", as explained in the table 2.

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Table 1: Players Strategies In The Proposed Model

	Retailer	Supplier
Cooperate	Send exact (trust worthy) demand forecasts to supplier	Trust demand forecasts sent by retailer and plan production level based on it
Not cooperate	Send wrong demand forecasts to supplier	Not Trust demand forecasts sent by retailer and use mixed strategy

4.2 Numerical example

The numerical experimentation of this paper only covers the application of neural networks as a method for demand forecasting.

There is no rule for determining the number of neurons contained in the hidden layers in neural networks. Consequently, we have tested several network topologies and the results depend primarily on the absolute difference between the desired output and the obtained one and the mean square error obtained during learning and testing phases.

We use in this experimentation the Multi Layer Perceptron (MLP) structure of neural network, containing 3 inputs and 1 output in order to forecast daily demand based on the history of orders provided by the retailer. The network is trained and tested using real data of a buyer-vendor supply chain in Morocco. The adopted methodology is as follows: for a particular month, the neural network is alimented by demand values of the first three Mondays and returns the forecast value of the forth Monday of the same month then compared with the target value. This method is also implemented for the other days of the week.

Table 3 below is a preview of the obtained demand forecasts results with a comparison of target and output values.

Table 2: Preview Of Obtained Results: Target VS Output

Target	Output	AE	PE
2208	2279,74872	71,748719	3,249489
2232	2245,22605	13,226049	0,592565
4152	3866,88587	285,114126	6,866911
3096	2779,93453	316,065468	10,208833
3768	3886,47352	118,473523	3,144202
2064	2259,9505	195,950503	9,493726
2376	2250,30209	125,697915	5,290316
2472	2254,06541	217,934589	8,816124
2184	2247,09553	63,09553	2,888989
2688	2251,11475	436,885247	16,253171
3624	3807,31366	183,313663	5,058324

AE: Absolute Error that is the difference between output and target

PE: Percent Error

The percent error is between 0,592565 and 16,253171. We can say that the forecast results obtained from the adopted MLP network are satisfactory. Yet, in order return better results we propose in our next work to introduce another phase that is a classification technique before the forecasting phase using fuzzy logic.

5. CONCLUSION

Several works studying two-echelon supply chains using a game-theoretic mechanism were presented in this paper. We focus in this work on demand forecasting through the use of the artificial intelligence of neural network.

As a perspective, we aim to implement the forecasting results in the game's matrix to find the optimal situation for a decentralized retailer-supplier system by finding the equilibrium that guaranties maximum profit for both players and demonstrating how payoffs depend on the two actions. Another perspective of this work is the introduction of a classification phase before the demand forecasting phase in order to obtain better results.

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