Amoozad Mahdiraji, H., Zavadskas, E.K., Hajiagha, S.H.R. (2015), "Game Theoretic Approach for Coordinating Unlimited Multi Echelon Supply Chains", *Transformations in Business & Economics*, Vol. 14, No 2 (35), pp.133-151.

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BUSINESS & ECONOMICS

GAME THEORETIC APPROACH FOR COORDINATING UNLIMITED MULTI ECHELON SUPPLY CHAINS

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Received: January, 2015
1st Revision: March, 2015
2nd Revision: March, 2015
Accepted: April, 2015

ABSTRACT. ***In order to achieve the overall objectives of the supply chain (SC), there have been seen many contradictions between the components and different levels, and these disorders may result in decreased strength and competitiveness.***

The main contradictions that are considered in this paper comprise inventory, pricing and marketing costs in an unlimited three echelon supply chain. The basics of the game theory make it a suitable and reliable tool for solving contradiction situations by considering all the levels and players' goals. Initially, an unlimited three echelon supply chain, including S suppliers, M manufacturers, and K retailers, is considered in order to solve the aforementioned problem. Further on, a nonlinear mathematical cooperative model based on specific assumptions, game theory approach, Nash equilibrium definition, Pareto efficiency, and revenue sharing contract is proposed. Subsequently, the proposed model is employed in a numerical example, and the results are illustrated according to the genetic algorithm. Furthermore, the sensitivity of the proposed model is analysed using the design of experiment. Ultimately, the validation of the proposed cooperative model is assessed by the simulation.

KEYWORDS: supply chain, game theory, coordination contracts, design of experiment, genetic algorithm, simulation.

JEL classification: C15, C44, C68, M11, M21, O14.

Introduction

Forrester and his colleagues at the Massachusetts Institute of Technology developed many ideas and theories during the late 1950s that later became the cornerstones of supply chain management (hereafter SCM) (Mentzer, 2001; Mentzer *et al.*, 2001; Blanchard, 2010). The concept of the supply chain means that many experts believe that competition is transferred from companies to chains (Jespersen, Larsen, 2005). Many scholars and experts gave different definitions of SCM that depend on their viewpoints and attitudes. The role and importance of SCM have faced many challenges and problems. Although a comprehensive model has not been explained, it should be indicated that the issues, such as, reviewing the theoretical foundations of information systems, marketing, financial management, logistical, and organizational relations, has been considered by many researchers (Wang *el al.*, 2007; Amiri *et al.*, 2012). There are many challenges that latent in supply chain concept. The decisions made in SCM are mainly concerning the flows between the chains stages. Therefore, many scholars express the challenges and problems that SCM have and tried to answer them (Chandra, Kamrani, 2004; Simchi Levi *et al*., 2004; Chopra, Meindel, 2007; Wisner *et al*., 2008; Amiri *et al.*, 2012).

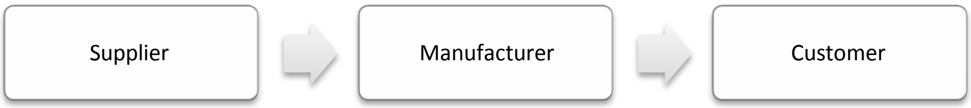
The objective of SCM is to improve various activities and components to increase the overall benefits. Many decisions are made in different levels covering detailed and strategic decisions. The planning of important decisions in a multi echelon chain could affect all the levels and the SC as a whole (Stadtler, Kilger, 2007). If each level makes their inventory, pricing, and advertising decision without considering the other levels, the bullwhip effect will occur, and the competitiveness advantage decreases (Lee *et al*., 1997). In order to avoid such loss in SC, many coordination mechanisms have been introduced in the recent researches. There are many possible interactive coordination mechanisms that can occur between the different levels of a given supply chain (Esmaeili *et al*., 2009). By considering a multi echelon supply chain, many problems will occur in the absence of coordination. Considering the ownership and managerial independency at each level, different aims and plans will threaten the overall profit. In today's changing world, the different levels of the supply chain are very wide and varied; thus, the different models and approaches are rolling in planning and controlling the activities. In such situation, if the variety of products and services provided by SC increases, the information distortion will multiply the increase. The main purpose of SCM in the mentioned situation is to solve the levels contradictions. Some of the main and critical contradictions in different levels of SC are inventory, pricing and marketing cost decisions. As a case in point, the supplier (as the seller) intends to sell raw materials by the highest possible price; on the other hand, the manufacturer (as the buyer) urges to by the raw materials at the lowest plausible point. Similarly, the aforementioned scenario occurs while the manufacturer acts as seller and the retailer as buyer, considering the final product. In addition, these bargaining games are repeated during the negotiations regarding other variables including inventory, order quantity or marketing issues.

In this research, these decision variables are considered in an unlimited three echelon SC, including S supplier, M manufacturer, and K retailer, while each manufacturer produces one specific good. The word unlimited specifies that the assumed supply chain is not restricted by one or more than one player at each stage, indicating that the proposed model is applicable for chains with numerous players performing as supplier, manufacturer or retailer. As previously mentioned, solving the contradictions among different levels of a chain engenders higher class of coordination and cooperation; thus, the total profit of a supply chain significantly increases. In virtue of tweaking the overall profit, game theory (henceforth GT) is applied as the main tool for coordinating the SC, based on revenue sharing contracts. Many researchers have considered this dilemma; nonetheless, our proposed model encompassing unlimited players at each stage, nonlinear demand function, gradual production rate and possible shortage at manufacturer level, endeavours to bring a novel approach among the literature. The rest of the paper is organized as follows. First, the literature review related to SCM and GT are provided. The assumptions and notation come afterwards, and the profit function for each level is formulated, subsequently considering Pareto efficiency, the supply chain's overall profit function is modelled. Further on, the best response of each player related to the three main decision variables are calculated and the concavity of the proposed model is analysed by using the Nash equilibrium definition. Finally, a numerical example is proposed, and sensitivity analyses of the proposed model alongside with its validation are indicated by the simulation.

1. Literature Review

1.1 Supply Chain Coordination

Nowadays, many companies have adopted a supply chain approach as their business strategy is to face the increasing pressure of customer-orientation and the growing trend of industrial globalization. However, SCM has been selected as a method for the improvement of competitive performance by merging internal operations and processes, as well as linking them with the external suppliers and customers (Tutuncu, Kucukusta, 2008; Amoozad Mahdiraji *et al.,* 2012). A management construct cannot be used effectively by the practitioners and researchers if there is no common agreement on its definition. Now, SC has become dominant Paradigms in the field of business (Mentzer, 2001; Mentzer *et al.,* 2001). Many researchers believe that the competition between the companies in the last decades changes to the competition between their supply chains (Jespersen, Larsen, 2005). According to the definition, the supply chain encompasses all the parties that are involved directly or indirectly in fulfilling a customer request (Chopra, Meindel, 2007), including all activities which are performed until a raw material delivers as a final good for the customer (Gumus, Guneri, 2007). These sections may consist of producer, supplier, carriers, warehouses, retailers, and customers engaged in a new product development, marketing, executive operations, distribution, financial services, customer services, etc. The supply chain is a dynamic set of information flow, product, and capital in different levels, in which the customer is only engaged as an internal part. According to these definitions, the main objective of SC is to meet the needs of customers to their full satisfaction and create profit. *Figure 1* shows a given supply chain (Amoozad Mahdiraji *et al.*, 2012).



Source: Jia *et al.*, 2013.

Figure 1. **A Given Supply Chain**

Many contradictions between the components and different levels, in order to achieve the overall objectives of SC, have been seen, and these disorders may result in decreased strength and competitiveness. Coordination mechanism and contracts are one of the main drastic tools for decreasing the negative effects of the contradictions. Numerous kinds of coordination contracts exist, which are classified and revealed in *Table 1*. (Maomao, 2006; Nalla, 2008; Hezarkhani, Kubiak, 2010; Govindan, Nicoleta, 2011; Govindan *et al.*, 2013; Amoozad Mahdiraji *et al*., 2014)

Table 1. Coordination Contracts

Demand Type	Contract	Description
Stochastic	Wholesale	the buyer pays a fixed and quantity-independent price to the seller for the each purchased unit
	Buyback	the seller promises to compensate the unsold quantities for the buyer
	Revenue Sharing	the downstream agent commits to return a pre-negotiated portion of its realized profits to the upstream agent
	Rebate	the upstream agent rewards the downstream agent for every sold unit
	Flexible	in contrast to Rebate contract
	Push and Pull	by increasing the amount of the sale or buy, the upstream agent proposes a lower price
Deterministic/ Discrete and Continuous	Side Payment	lump-sum monetary transfers among the contracting agents which are independent from the amount of trade and used as the compensation and incentive alignment mechanisms
Stochastic/ Deterministic	Discount	quantity-dependent unit prices

Source: Amoozad Mahdiraji et al., 2014.

1.2 Game Theory Approach

The main concept of game theory is originated by the mathematical researchers in Argentina and Japan in the 1940s. This group insisted in proofing their theories of mathematics and calculus. Following that, this mixed field of science found its applications in economy and industry and other practical sciences (Rasmusen, Blackwell, 2005). John Nash presented the equilibrium for cooperative situations in 1950 (Nash, 1950). He as well developed a model for bargaining problems (Nash, 1950), and presented equilibrium point for the non-cooperative situations a year later (Nash, 1951). The essential elements of a game are players, actions, payoffs, and information. These are collectively known as the rules of the game, and the modeller's objective is to describe a situation in terms of the rules of a game to explain what will happen in that situation. Trying to maximize their payoffs, the players will devise plans known as the strategies that pick actions depending on the information that arrives at each moment. The combination of strategies chosen by each player is known as the equilibrium. When given the equilibrium, the modeller can see what actions come out of the conjunction of all the players' plans, and this tells him the outcome of the game (Rasmusen, Blackwell, 2005; Raut *et al.*, 2014).

When information transaction is not possible between the different players (different layers of the SC), by considering Nash definition, each player will stimulate competitors believes or best responses and while these believes are correct, Nash equilibrium will occur (Osborne, 2004). In a given two player game, the best responses are defined as (1).

$$B_i(S_{-i}) = \left\{ S_i \ : U_i(S_i, S_{-i}) > U_i(S_i^{'}, S_{-i}) \ ; \ \forall s_i \in S_i \right\} \qquad (1)$$

B_i	player *i* best response
(S_i, S_{-i})	strategy chosen by the players
$(i,-i)$	two players of a game
$U_i(S_i, S_{-i})$	utility or payoff when a player opts strategy

By considering the best response definition in continuous payoff functions, Nash equilibrium will be calculated as (2). Nash definition and equilibrium is applicable in famous situations, such as, Bertrand model of duopoly (Bertrand, 1883), a Cornet model of duopoly (Cournot, 1838), the final offer arbitration, and the problem of the commons (Gibbons, 2002). By the way, games which result in more than one answer and a unique point is not clearly identified, focal point will occur. Focal equilibrium takes place when players of a presumed supply chain tend to use it in the absence of communication, information and knowledge sharing, because it seems more natural or relevant.

$$\left. \begin{array}{l} U_1(S_1, S_2) = f(S_1, S_2) \\ U_2(S_1, S_2) = f(S_1, S_2) \end{array} \right\} \rightarrow \left\{ \begin{array}{l} \dfrac{dU_1(S_1, S_2^*)}{dS_1} = 0 \rightarrow B_1(S_2^*) = f_1(S_2^*) \\ \dfrac{dU_2(S_1^*, S_2)}{dS_2} = 0 \rightarrow B_2(S_1^*) = f_2(S_1^*) \end{array} \right\} \qquad (2)$$

1.3 Related Researches

In brief, the scholars have focused on the use of Nash equilibrium by applying profit sharing contract in many researches (Jaber *et al.*, 2006; Zhang, 2006; Ying *et al.*, 2007; Feng *et al.*, 2007; Bai, Wang, 2008; Feng, 2008; Jiazhen, Qin 2008; Liu, Zhang, 2006; Wang *et al.*, 2009; Xu, Zhong, 2011).Other coordination contracts compounding with Nash and Stackelberg games are as well performed as suitable tools for SC coordination problems (Arda, Hennet, 2005; Leng, Parlar, 2010; Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

Many researches focused on the use of other kinds of coordinating contracts, such as, buyback, rebate, cost sharing, discount models, option contracts, and benefit sharing, in the multi echelon SC problems (Cachon, Lariviere, 1999, 2001, 2005; Xiao *et al.*, 2007; Xiao, Qi, 2008; Zhang, 2008; Chen, Xiao, 2009; Leng, Zhu, 2009; Yali, Zhanguo 2010; Zhang, Huang, 2010; Nosoohi, Nookabadi, 2014; Heydari, 2014; Haidar *et al.*, 2014; Xiao *et al.*, 2014; Ming *et al.*, 2014).

Moreover, some used Shapley value and Eliasberg model when confronting similar circumstances (Bahinipati *et al*., 2009; Leng, Parlar, 2009; Zhao *et al*., 2010). Finally, it should be demonstrated that the optimization tools, such as, queuing theory, Markov chain, backward induction, stochastic programming, and genetic algorithm, are as well employed in coordination and cooperation problems, especially in the incomplete information situations (Gupta, Weerawat, 2006; Zhen *et al*., 2006; Hennet, Arda 2008; Cachon, Kok, 2010; Kaviani *et al*., 2011; Ahmadi Rad *et al.*, 2014; Zhang *et al.*, 2014).

2. Basics of Model

2.1 Assumptions

1. The unlimited supply chain consists of K retailer, M manufacturer, and S supplier.

2. The products demand function depends on the price and the marketing cost advertisement which is continuous and nonlinear as presented in (3), where *Alpha* considers the negative price behaviour (Lee, 1993; Abad, 1994; Lee *et al*., 1996; Kim, Lee, 1998; Jung, Cerry, 2001, 2005; Esmaeili *et al*., 2009; Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

$$D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\ \beta} \qquad (3)$$

D_n	demand for product n
P_{r_n}	final selling price of product n by retailer r
C_{M_n}	marketing cost for product n
k,α,β	demand constant for price and marketing cost

3. The shortages are allowed for the manufacturer; hence, the related cost will be considered during the shortage period. The total relative costs for the manufacturer, when produces are incrementally, are calculated as (4). (Oganezov, 2006; Chang, 2008; Pentico *et al*., 2009; Wang, Tang, 2009; Chakrabortty *et al*., 2010; Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

$$TRC = [C_{h_n} \times \frac{(\lambda_n.Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}}] + [\frac{C_{B_n}.B_n^2}{2.\lambda_n.Q_{r_n}}] \qquad (4)$$

C_{h_n}	manufacturer's holding cost
$\lambda_n = 1 - \frac{D_n}{PC_n}$	production rate
Q_{r_n}	production quantity
B_n	manufacturer's shortage
C_{B_n}	manufacturer's shortage cost
PC_n	manufacturer's production capacity

4. Pricing, Inventory, and Marketing cost are the decision variables at each level of SC. Furthermore, the production unit cost, raw material price, and the wholesale price are determined by the negotiation between players of the supply chain.

5. Each manufacturer sells a specific product to a specific retailer. However, the suppliers sell their raw material to any manufacturer when needed, depending on the bill of the material (BOM) and consuming rate (Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

6. Each player at any level of the supply chain has a reasonable behaviour (fully rational) and moves for higher profit and lower cost.

7. Players of SC make a decision cooperatively based on the game theory approach, Nash equilibrium, Pareto efficiency, and revenue sharing contracts.

2.2 Notations

Note	Description	Note	Description
G	Profit margin for each player	λ_R	**Retailers' Share**
P_n	Wholesale price from manufacturer	λ_N	**Manufacturers' Share**
λ_S	Suppliers' Share	$\lambda_n^{'}$	**Each manufacturer's Share**
$\lambda_r^{'}$	Each retailer's Share	$\lambda_s^{'}$	**Each supplier's Share**
$C_{S_{rn}}$	Retailer's setup cost	$k^{'}$	**Holding Cost coefficient**
TR	Total revenue of each player	PC_n	**Manufacturer's production capacity**
TC	Total cost of each layer	C_{S_s}	**Supplier's unit cost**
Z	Profit function of each player	C_{S_o}	**Supplier's ordering cost**
k	Raw material usage constant	C_{S_n}	**Manufacturer's variable cost**
C_{P_s}	Raw material price from s to n	$C_{O_{sn}}$	**Ordering cost from s to n**

2.3 Retailer Payoff Function

A retailer confronts the holding and setup costs as well as the purchasing cost from the manufacturer. When coupled with any, the retailer should have a positive marginal sale to participate in the game. Finally, a retailer's income involves the revenue achieved by selling final goods to the final customer. By considering the aforementioned issues, the retailers' payoff function and its constraints are shown as (5). The first constraint implies that the final selling price from the retailer to the customer should be greater than the mass price paid to the manufacturer; the second and third constraint insist that demand should not be negative, or greater than the production capacity. Remark that $P_{r_n}, C_{M_n}, P_n, Q_{r_n}$ note decision variables in this situation (Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

$$
\begin{aligned}
&Max\ Z_r = (k.P_{r_n}^{\ -\alpha}.C_{M_n}^{\ \beta}[P_{r_n} - P_n - C_{M_n} - C_{S_{rn}}.Q_{r_n}^{-1}]) - (\frac{1}{2} \times Q_{r_n} \times k_n^{'} \times P_n) \\
&s.t \\
&P_{r_n} - P_n \geq 0\ ;\ D_n = k.P_{r_n}^{\ -\alpha}.C_{M_n}^{\ \beta} \geq 0\ ;\ D_n \leq PC_n \\
&k > 0,\ \alpha > 1,\ 0 < \beta < 1,\ \alpha - \beta > 1
\end{aligned}
\tag{5}
$$

2.4 Manufacturer's Payoff Function

A manufacturer confronts holding, setup, ordering, and shortage costs, plus purchasing costs and the production cost. However, the revenue of selling the final product to the retailer in large scales is acquired by the manufacturer. By considering the aforementioned information, the manufacturer's payoff function and its constraints are shown as (6). The first constraint implies that the mass price from the manufacturer to the retailer should be greater than the price paid for the raw materials; the second and third constraint insist that the demand should not be negative or greater than the production capacity. Remark that $P_n, Q_{r_n}, B_n, C_{P_S}$ note decision variables under these conditions (Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

$$
\begin{aligned}
&Max\ Z_n = [(P_n - \sum_{s=1}^{M}(k_{s_n}.C_{p_s}) - C_{P_n}) \times D_n] - [(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \times \frac{D_n}{Q_{r_n}}] - [C_{h_n} \times \frac{(\lambda_n.Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}}] - [\frac{C_{B_n}.B_n^2}{2.\lambda_n.Q_{r_n}}] \\
&s.t: \\
&P_n - [\sum_{s=1}^{m}(C_{P_s}.k_{s_n}) + C_{P_n}] \geq 0\ ;\ CP_n \geq D_n\ ;\ D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta} \\
&k > 0, \alpha > 1,\ 0 < \beta < 1,\ \alpha - \beta > 1
\end{aligned} \tag{6}
$$

2.5 Supplier's Payoff Function

A supplier confronts holding, setup, ordering as well as the purchasing or acquiring raw material. In contrast, every supplier will gain revenue by selling raw materials to the manufacturers depending on their usage of production. By considering what was mentioned above, the suppliers' payoff function and its constraints are shown as (7). The first constraint implies that the raw material selling price to the manufacturer should be greater than the procurement of raw material by the supplier; the second constraint insists that the demand should not be negative. Remark that P_n, Q_{r_n}, C_{P_S} note decision variables under these circumstances (Jia *et al.*, 2013; Amoozad Mahdiraji *et al.*, 2014).

$$
\begin{aligned}
&Max\ Z_S = [(C_{P_S} - C_{S_o}) \times \sum_{n=1}^{N} k_{s_n}.D_n] - [\sum_{n=1}^{N} \frac{D_n}{Q_{r_n}} \times C_{S_s}] - [\sum_{n=1}^{N} k_{S_s}.C_{S_o}.k_{S_n}.\frac{Q_{r_n}}{2}] \\
&s.t: \\
&C_{P_S} - C_{S_o} \geq 0\ \ ;\ D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta} \\
&k > 0, \alpha > 1,\ 0 < \beta < 1\ \alpha - \beta > 1
\end{aligned} \tag{7}
$$

3. Cooperative Game Modelling

By considering the revenue sharing coordination contract, Nash equilibrium definition as well as the given supply chain assumptions, the total profit ($T_{Z_{SC}}$) will be calculated as (8), which sums the profit of each involved level containing retailers (T_{Z_r}), manufacturers (T_{Z_n}), and suppliers (T_{Z_s}).

$$
\begin{aligned}
&TZ_{SC} = \lambda_R.TZ_r + \lambda_N.TZ_n + \lambda_S.TZ_s \\
&\lambda_S = 1 - \lambda_R - \lambda_N \\
&TZ_r = \sum_{r=1}^{K}((k.P_{r_n}{}^{-\alpha}.C_{M_n}{}^{\beta}[P_{r_n} - P_n - C_{M_n} - C_{S_m}.Q_{r_n}^{-1}]) - \frac{1}{2} \times Q_{r_n} \times k_n^{'} \times P_n) \\
&TZ_n = \sum_{n=1}^{N}([(P_n - \sum_{s=1}^{M}(k_{s_n}.C_{p_s}) - (C_{p_n})) \times D_n] - [(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \times \frac{D_n}{Q_{r_n}}] - [C_{h_n} \times \frac{(\lambda_n.Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}}] - [\frac{C_{B_n}.B_n^2}{2.\lambda_n.Q_{r_n}}]) \\
&TZ_s = \sum_{s=1}^{M}[(C_{P_S} - C_{S_o}) \times \sum_{n=1}^{N} k_{s_n}.D_n] - [\sum_{n=1}^{N} \frac{D_n}{Q_{r_n}} \times C_{S_s}] - [\sum_{n=1}^{N} k_{S_s}.C_{S_o}.k_{S_n}.\frac{Q_{r_n}}{2}]
\end{aligned} \tag{8}
$$

The best share of each level and each player (best response) should be determined by the first order condition of the function regarding the raw material price and the wholesale price for the proposed profit function illustrated as (9).

$$
\begin{aligned}
&\frac{\partial Z_{SC}}{\partial CP_s} = 0 \rightarrow \lambda_N = \frac{(1 - \lambda_R)}{2} \\
&\frac{\partial Z_{SC}}{\partial P_n} = 0 \rightarrow \lambda_R = \lambda_N.\frac{\sum_n D_n}{\sum_n D_n + \sum_n \frac{Q_{r_n}.k_n^{'}}{2}}
\end{aligned} \tag{9}
$$

If the equations mentioned in (9) are solved simultaneously, the optimal share of each level as well as each player is demonstrated as (10).

$$\lambda_R^* = \frac{\sum_n D_n}{3.\sum_n D_n + \sum_r Q_{r_n}.k_n^{'}} \; ; \; \lambda_N^* = \frac{2.\sum_n D_n + \sum_r Q_{r_n}.k_n^{'}}{2\times[3.\sum_n D_n + \sum_r Q_{r_n}.k_n^{'}]} \; ; \; \lambda_S^* = 1-\lambda_N^* - \lambda_R^* \quad \text{For each level}$$

$$\lambda_n^{'} = \frac{\lambda_N^*}{N} \; ; \; \lambda_r^{'} = \frac{\lambda_R^*}{K} \; ; \; \lambda_s^{'} = \frac{\lambda_S^*}{M} \quad \text{For each player} \tag{10}$$

By calculating the determinant of the Hessian matrix of each player, regarding its decision variables, the authors of this article conclude that the model is concave to its decision variables; accordingly, the optimal solution for the proposed model is accessible. Each player in the given SC will take the best decision during a game. As the reasonable behaviour of each player and Nash best response principle, the best decisions for each player in the three echelons SC will be to conclude by the derivation of the payoff function to the decision variables. The first order condition of each payoff function is used for the best response and by simultaneously solving the equations using MATLAB software, the results are garnered. The best responses for the retailers are uncovered as (11).

$$C_{M_n}^{\ *} = \frac{\beta\times[((\lambda_R.Cs_{r_n}) + (\lambda_N.(C_{s_n} + \sum_{s=1}^{M} Co_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})) + (((\lambda_N.C_{p_n}) + (\lambda_S.(\sum_{s=1}^{M} k_{s_n}.C_{s_o})).Q_{r_n})]}{Q_{r_n}.(\alpha-\beta-1)}$$

$$P_{r_n}^{\ *} = \frac{\alpha\times[((\lambda_R.Cs_{r_n}) + (\lambda_N.(C_{s_n} + \sum_{s=1}^{M} Co_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})) + (((\lambda_N.C_{p_n}) + (\lambda_S.(\sum_{s=1}^{M} k_{s_n}.C_{s_o})).Q_{r_n})]}{Q_{r_n}.(\alpha-\beta-1)} \tag{11}$$

Incidentally, the best responses for the manufacturers are witnessed as (12).

$$Q_{r_n}^{\ *} = \sqrt{\frac{2.D_n.[(\lambda_R.C_{s_m}) + (\lambda_N.((\sum_{s=1}^{M} Co_{sn}) + C_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})]}{[(\lambda_N.E_n.C_{B_n}.\lambda_n) + (\lambda_R.k_n^{'}.P_n) + (\lambda_S.\sum_{s=1}^{M} k_{s_s}.C_{s_o}.k_{s_n})]}}$$

$$B_n^{\ *} = E_n.\lambda_n.Q_{r_n} \tag{12}$$

By considering the SC total profit function as the objective function and supposing each best response as a constraint, the final nonlinear coordinated model of the proposed supply chain is figured in (13). The objective function is based on maximizing the SC total profit by considering each level's optimal share of it. The total profit function is based on the sum of all the players' objective function in all the levels. The first three constraints present the optimal share of each level on the basis of equation noticed in (10). The last three constraints indicate that each player acts rationally and the demand always exists, coupled with the final price is greater than mass price; moreover, the mass price is greater than the raw material purchasing cost paid for the each product by the manufacturer. Other constraints are based on the Nash definition and present the best response for each player regarding their decision variables.

$$Max \;\; TZ = (\lambda_R.TZ_r) + (\lambda_N.TZ_n) + (\lambda_S.TZ_s)$$

$$s.t:$$

$$\lambda_R = \frac{\sum_n D_n}{3.\sum_n D_n + \sum_r Q_{r_n}.k_n^{'}} \; ; \; \lambda_N = \frac{1}{2} - \frac{\sum_n D_n}{2\times[3.\sum_n D_n + \sum_r Q_{r_n}.k_n^{'}]} \; ; \; \lambda_S = 1-\lambda_N - \lambda_R$$

$$Q_{r_n} = \sqrt{\frac{2.D_n.[(\lambda_R.C_{s_m}) + (\lambda_N.((\sum_{s=1}^{M} Co_{sn}) + C_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})]}{[(\lambda_N.E_n.C_{B_n}.\lambda_n) + (\lambda_R.k_n^{'}.P_n) + (\lambda_S.\sum_{s=1}^{M} k_{s_s}.C_{s_o}.k_{s_n})]}} \tag{13}$$

$$C_{M_n} = \frac{\beta\times[((\lambda_R.Cs_{r_n}) + (\lambda_N.(C_{s_n} + \sum_{s=1}^{M} Co_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})) + (((\lambda_N.C_{p_n}) + (\lambda_S.(\sum_{s=1}^{M} k_{s_n}.C_{s_o})).Q_{r_n})]}{Q_{r_n}.(\alpha-\beta-1)}$$

$$P_{r_n} = \frac{\alpha\times[((\lambda_R.Cs_{r_n}) + (\lambda_N.(C_{s_n} + \sum_{s=1}^{M} Co_{s_n})) + (\lambda_S.\sum_{s=1}^{M} C_{s_s})) + (((\lambda_N.C_{p_n}) + (\lambda_S.(\sum_{s=1}^{M} k_{s_n}.C_{s_o})).Q_{r_n})]}{Q_{r_n}.(\alpha-\beta-1)}$$

$$P_{r_n} - P_n \geq 0 \; ; \; D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta} \geq 0 \; ; \; P_n - [\sum_{s=1}^{m}(C_{P_s}.k_{s_n}) + C_{p_n}] \geq 0$$

$$B_n = E_n.\lambda_n.Q_{r_n}$$

$$\forall_{n\in N} \; ; \; \forall_{r\in K} \; ; \; \forall_{s\in M}$$

4. Numerical Example

Considering the proposed model mentioned above, regarding the validation and sensitivity analysis, a three echelon supply chain, including: 2 suppliers, 2 manufacturers, and 2 retailers, is assumed. *Table 2* indicates the numerical amounts of parameters in the proposed supply chain. First of all, the different experiments are identified, then the coordinated model is solved by Meta heuristic methods, subsequently the sensitivity analysis of the proposed model based on nonlinear parameters is determined; finally, the validation of the model is examined by simulation.

Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014) used the same numerical example based on Stackelberg and Coalition game. The first research considered and compared three types of leadership and concluded that retailer leadership will beget the highest profit for the supply chain. Regarding the second research consisting of channel integration and proposed coalition best responses, the profit achieved from the coalition was higher than the decentralization and leadership methods. In this new research, a coordinated SC, via which all levels are cooperating upon revenue sharing contract, is considered. Eventually, the authors conclude that the profit achieved by the coordination contract does not outweigh the other methods based upon the given numerical example.

Table 2. Input Parameters

Amount	Par	Amount	Par	Amount	Par	Amount	Par
1.1	φ_1'	3	$C_p(1)$	5	$C_{S_r}(2)$	0.15	k_1'
1.15	φ_2'	4	$C_p(2)$	4	$C_{S_r}(1)$	0.2	k_2'
63	P_1	25	$C_{S_S}(1)$	0.15	$k_{s_S}(1)$	6	$C_{P_S}(1)$
75	P_2	24	$C_{S_S}(2)$	0.2	$k_{s_S}(2)$	4.5	$C_{P_S}(2)$
7	$C_{S_n}(1)$	2	$C_{S_o}(1)$	3	$k_{sn}(11)$	4	$k_{sn}(12)$
8	$C_{S_n}(2)$	1.5	$C_{S_o}(2)$	3	$k_{sn}(21)$	3	$k_{sn}(22)$
0.5	$C_{h_n}(1)$	1.15	φ_1	6	$Co_{sn}(11)$	5	$Co_{sn}(12)$
0.5	$C_{h_n}(2)$	1.1	φ_2	4	$Co_{sn}(21)$	6	$Co_{sn}(22)$
15	$PC(1)$	15	$PC(2)$	1	$C_B(2)$	1	$C_B(1)$

Source: Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014).

Between several types of parameters performed in the coordination model and for the sensitivity analysis the three constants, including α,β,k, which are the basis of nonlinear functions in the proposed model, are opted. The lower and upper bound of these three elements is reflected in *Table 3*.

Table 3. Parameters class limit

Max	Min	Parameter
1.25	1.2	α
0.15	0.05	β
4000	3000	k

Source: Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014).

By using 2^k design of experiment (hereafter DOE) technique, based on three nonlinear parameters noticed above and including one central point in each block (2^3+1), 9 different experiments are designed by using MINITAB 16.5 software as shown in *Table 4*. These experiments are the basis of sensitivity analysis and the model validation tests.

Table 4. Design of Experiment

Experiments	Alpha	Beta	K
1(Central)	1.225	0.1	3500
2	1.2	0.15	3000
3	1.25	0.05	3000
4	1.25	0.05	4000
5	1.25	0.15	4000
6	1.25	0.15	3000
7	1.2	0.05	4000
8	1.2	0.15	4000
9	1.2	0.05	3000

Source: Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014).

The cooperative proposed model in this research is NP hard type and is not solvable by the deterministic methods. Even Lingo global solver, AIMS nonlinear, and FMINCON and FSOLVE in MATLAB software were not able to perform the model; accordingly, the Meta heuristic methods are used. The Genetic algorithm (henceforward GA) optimization tool in MATLAB software was applied in this part of the research for this matter. After defining and coding decision variables, parameters, and nonlinear objective function and constraints in GA OPTIMSET, lower bound, upper bound, initial solution, and other essentials are coded below.

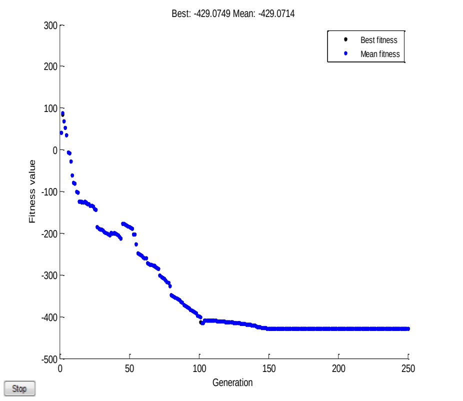
```
A= [-1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0; 0 -1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0];
b= [0 0];
Aeq=[0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0; 0 0 0 0 0 0 0.06 0 0 0 1 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0.06 0 0 0 1 0 0 0 0 0 0 0];
Beq= [1 6 4.5 63 75 1 1];
LB= [63 75 0 0 0 0 0 0 0 0 0.01 0.01 0.01 0.01 0.01 63 75 6 4.5];
UB= [INFINFINFINFINFINFINF 15 15 INFINF 0.99 0.99 0.99 0.99 0.99 63 75 6 4.5];
X0= [70 80 5 5 2 2 12 12 50 50 0.5 0.6 0.3 0.4 0.3 63 75 6 4.5];
Options = gaoptimset (‘plotfcns’, {@gaplotbestf},’display’,’iter’);
[X fval]=ga(@tzsc,19,A,b,Aeq,beq,LB,UB,@contzsc,options);
```

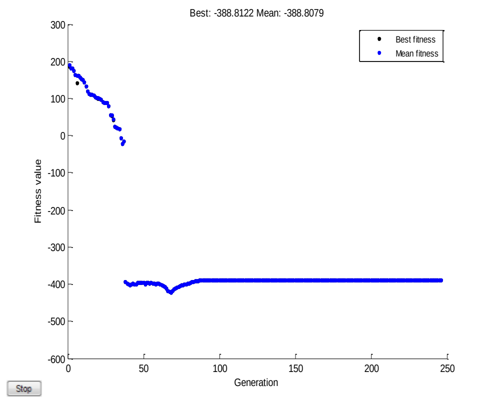
Each experiment mentioned in Table 4 was performed 250 runs in GA, and the results are presented in *Table 5*; moreover, each level’s share besides the player’s profit is represented as well. In order to clarify, the two sample experiment figures in GA method are denoted in *Table 5*.

Table 5. Coordinated model results by GA

Experiment	TZSC	Manufacturer's Profit	Supplier's Profit	Retailer's Profit
1	389.0	100.36	285.14	3.89
2	429.0	160.45	261.69	4.29
3	420.0	126.00	285.60	4.20
4	52.0	24.44	5.36	21.84
5	402.0	8.04	385.92	4.02
6	404.0	14.14	383.80	4.04
7	527.0	221.34	300.92	5.27
8	414.0	44.30	339.48	24.84
9	387.0	207.43	176.09	3.87

Experiment 2 | **Experiment 1**



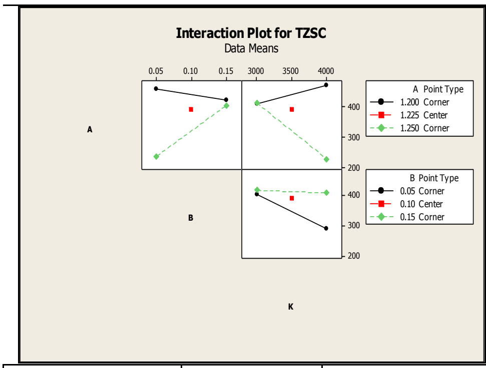


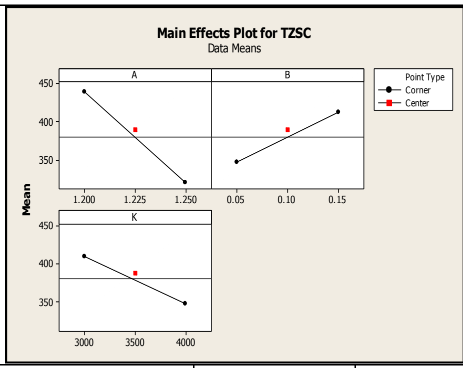
Source: created by authors.

The main and interactive effects of the cooperation model for the three critical elements are calculated by MINITAB 16.5 software and are illustrated in figures of *Table 6*. Alpha and K directly affect the chain profit and Beta effects unfavourably. Coupled with all the three parameters comprise the interactive effects with each other.

Table 6. Parameters Effects

Interaction Effect | **Main Effect**

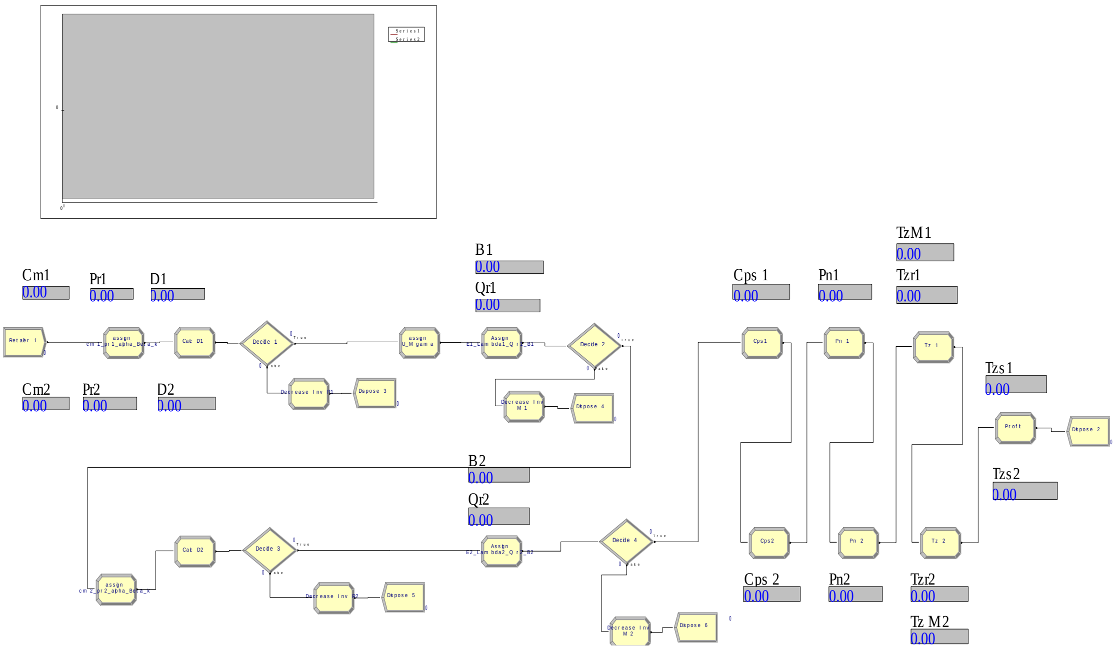




Coefficient	Effect	Interaction	Coefficient	Effect	Main
50.62	101.25	Alpha*Beta	-59.8	-119.75	Alpha
-61.87	-123.75	Alpha*K	32.88	65.75	Beta
26.37	52.75	Beta*K	-30.6	-61.25	K

Source: created by authors.

Verification of the proposed model is basically accessible by considering the assumptions of the models. Thus, the authors of this article have designed a simulated supply chain by the use of ARENA software based on data from the numerical example mentioned above. The simulated model based on ARENA software is shown in *Figure 2*, which is based on random marketing cost and random retailer price for the each retailer. By this randomization, the demand of each product is computable; therefore, the other decision variables will be reached by the best response of cooperative game, depending on the Nash equilibrium definition.



Source: Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014).

Figure 2. **ARENA Cooperative Simulated Model**

The simulated model was performed 100 runs for each type of experiment, and the results are given in *Table 7*. As the result demonstrates, the overall profit of the supply chain by using the proposed cooperative model is similar to the total profit of SC based on the ARENA simulation in each experiment. The SC total profit is always between the upper and lower bound of the confidence limit.

Table 7. Proposed Model Validation Results

Experiment	SC Total Profit by GA	SC Total Profit by ARENA	Min CL	Max CL
1	389.0	358.63	308.81	408.45
2	429.0	419.38	383.44	455.32
3	420.0	408.52	362.68	454.36
4	52.0	500.50	433.24	567.76
5	402.0	385.38	332.62	438.14
6	404.0	416.95	376.01	457.89
7	527.0	582.44	514.90	649.98
8	414.0	373.78	316.67	430.89
9	387.0	453.05	390.23	515.87

Source: created by authors.

Finally, the authors examined the validation of the simulation model by using extreme points for each decision variable. The verification of simulated model was tested. In order to endorse this contention and as an illustration, the authors examined the model at the lowest and highest possible price $(0,+\infty)$ for the retailer to check the behaviour of the model. The results of this situation are presented in *Table 8*, which indicates that while the final product price increases, subsequently the profit of each level and plus the overall profit increases.

Table 8. Results for Extreme Final Price of the Products by Retailers

Players	Maximum Average
Manufacturers' Profit	2098
Retailers' Profit	9616
Suppliers' Profit	5007
Supply Chain's overall profit	16721

Source: created by authors.

In order to clarify, the behaviour of the simulated model was tested, while the raw materials were priceless, and the results are presented in *Table 9*, which indicates that whilst the raw material are free, the supply chain's overall profit increases exponentially. It should be noticed that the other situations were as well analysed, and it was eventually concluded that the proposed model alongside with the simulated one is performing correctly.

Table 9. Results While the Raw Material is Priceless by Supplier

Players	Maximum Average
Manufacturers' Profit	5640
Retailers' Profit	3622
Suppliers' Profit	4000
Supply Chain's overall profit	13262

Source: created by authors.

Jia *et al.* (2013) and Amoozad Mahdiraji *et al.* (2014) solved the similar problem by using Stackelberg and Nash equilibrium methods. Considering this new proposed model, the situation of the supplier's raw material price (C_p) and manufacturer's mass selling price for the retailer (P_n) are comparable among trio aforementioned methods, and the results are illustrated in *Table 10*. Nonetheless, other decision variables are not comparable, thus, are not considered.

Table 10. Comparing decision variables

C	N	S	P_n	C	N	S	C_p
>	=		Stackelberg (S)	>	=		Stackelberg (S)
>			Nash (N)	>			Nash (N)
			Cooperative (C)				Cooperative (C)

Source: created by authors.

As *Table 10* indicates, the raw material and the mass selling price are equal between Stackelberg and Nash equilibrium. In addition, this new coordination proposed model leads to the minimum amount of raw material and mass selling price decision variables compared with other methods.

Conclusions

To sum up, in this research, the coordination in multi echelon supply chains were considered, in which the revenue sharing contract between several types of contracts based on the game theory approach was used as a suitable tool for coordinating pricing, inventory and marketing expenditure policies as three main decision variables. The authors of this article proposed a coordinated model and examined it by the use of simulation and ARENA software. The simulation preformed correctly, and the verification of the coordination model was testified and guaranteed.

In spite of the recent mathematical achievement regarding supply chain coordination, there are many determining factors missing while performing them in the actual situations. As a case in point, the proposed model was assumed to employ in Iranian Sugar industry chain; however, the lack of informational and cultural infrastructures impeded the procedure. Hence, the authors of this article propose a preparation process prior to using the proposed coordination method. First, cater the informational, relational, and cultural requirements, afterwards, analyse the chain, players, situation, availability of information, and so forth to realize and employ the prominent game theory approach and related tools. Eventually, determine the demand and other parameters and apply the most suitable coordination contract.

The situations and assumptions used in this paper are the key for the future researches. Considering more levels in the supply chain will lead the researchers to a comprehensive model of coordination in the future. In addition, as the competency of information and sharing in different levels of supply chain seems to be impossible in reality, applying the incomplete or imperfect game theory approaches, such as, signalling or Nash Bayesian game, will solve this problem and attain to more realistic options in the future. The coordination mechanism employed in this paper is based on revenue sharing contract. It is worth noting here that other kind and coordination options, such as: profit sharing, buyback, and option contract, are all possible solution for this matter. Ultimately, OPT QUEST application in ARENA software is a suitable tool to estimate the best amounts of nonlinear model parameters; therefore, by identifying the optimal amount of the proposed model parameters the optimal solutions will be acquirable.

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DAUGIAPAKOPIŲ TIEKIMO GRANDINIŲ KOORDINAVIMAS TAIKANT LOŠIMŲ TEORIJOS METODĄ

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SANTRAUKA

Siekiant įvykdyti visus tiekimo grandinės (TG) tikslus, buvo pastebėta daugybė prieštaravimų tarp komponentų ir skirtingų pakopų, o šie trukdžiai gali sumažinti svarumą ir kompetenciją. Šiame straipsnyje aptariami tokie pagrindinai prieštaravimai, kaip inventorius, kainodaros ir rinkodaros sąnaudos neribotoje trijų pakopų tiekimo grandinėje. Lošimų teorijos pagrindai daro šį metodą tinkamą ir patikimą, sprendžiant prieštaringas situacijas, atsižvelgus į visas pakopas ir žaidėjų tikslus. Tam, kad būtų galima išspręsti minėtas problemas, pirmiausia reikia atsižvelgti į neribotą trijų pakopų tiekimo grandinę, kurioje yra S tiekėjų, M gamintojų ir K mažmenininkų. Remiantis tuo, siūlomas netiesinis matematinis kooperatinis modelis, grindžiamas atitinkamomis prielaidomis, lošimo teorijos metodu, Nasho ekvilibriumo apibrėžimu, Pareto efektyvumo ir pajamų pasiskirstymu. Tada pasiūlytas modelis pritaikomas skaitmeniniame pavyzdyje, o rezultatai iliustruojami pagal genetinį algoritmą. Paskui siūlomo modelio jautrumas analizuojamas planuojant eksperimentą. Galiausiai pateikto kooperatinio modelio patikrinimas yra vertinamas pagal modeliavimą.

REIKŠMINIAI ŽODŽIAI: tiekimo grandinė, lošimų teorija ir koordinavimo sutartis, eksperimento planavimas, genetinis algoritmas, modeliavimas.