A New Model for Supply Chain Quality Management of Hospital Medical Equipment through Game Theory

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Abstract. The need for high-quality medical equipment in the hospital supply chain has more than ever demonstrated the necessity and importance of quality management to be implemented by administrators in line with the Iranian health reform plan. In this study, the Game Theory was used to model the strategies chosen by companies supplying medical equipment to hospitals. Considering the process of self-learning through the Markov chain on the part of medical equipment enterprises involved in market competition, the equipment supply chain environment was simulated. Finally, the importance of reward and penalty system implemented supply chain quality management of medical equipment for hospitals was discussed by analyzing the behavior of the simulated model and calculating the revenues, so as to propel the firms to adopt high-quality strategies.

Keywords: Quality Management, Hospital Supply Chain, Medical Equipment, Game Theory

1. Introduction

The health care sector specifically focuses on the issue of quality. It could be argued that the supply chain quality management in the health sector has been widely embraced. The main reason can be the extreme complexity of systems in health institutions compared to other industries, importance of the effectiveness of these organizations, pressure to reduce costs and ultimately, the trend of specialization and strengthened status of patients [1].

The health care sector in any country is one of the essential areas where the supply chain is of utmost strategic importance, because the costs of supply chain leave a direct impact on the costs of medication. Besides, although most literature discusses supply chain management as the production of physical products, not all industries have the same supply chain characteristics [2]. By regulating and adjusting the supply chain, the quality management strategies based on the production and performance can be strengthened. In other words, the quality of performance and management need to be simultaneously put into concentration and practice, so as to achieve a significant and safe competitive advantage [3].

Nevertheless, supply chain in many parts of the hospital has been traditionally separated. Hospitals need to address a large number of suppliers with different expertise and care sciences. Thus, the supply chain management at a hospital is exclusively more complex and requires greater knowledge than the traditional supply chain industry. The industry experts estimate that the supply chain management practices in the healthcare industry is 10 years behind industries such as retail and production [4]. Many hospitals employ only certain vendors for medical equipment. This will lead to isolation in the equipment supply because the retailers and suppliers with higher capabilities remain unknown. Deployment of applications and tactics of supply chain quality management is a fundamental step forward, enhancing competition and leadership inside the hospital supply chain markets. A significant reduction in patients referring out of the hospital for providing medical supplies, lower price of drugs and medical equipment, preventing the contraband and poor supply items can be the most important achievements of the health reform plan and correct implementation of the supply chain of medical equipment in hospitals. The utilization of high-quality medical equipment directly brings about patient safety and reliability of health care. This paper intends to extend a strategy of supply chain quality management of medical equipment under environmental changes and simulate the behavior of hospital medical equipment suppliers in choosing different strategies through Game Theory.

2 Literature Review

The costs of medical equipment and hospital consumables constitute 45% of the operating budget [5]. With the predicted growing trend, hospitals and health systems may need to spend even more money on the supply chain [6]. Thus, the supply chain management has become one of the most important areas for CEOs and executive leaders of hospitals [7]. Jahantigh and Malmir [8] develop a supply chain model for healthcare industry. The value of their study arises from providing a detailed analysis of a healthcare supply chain in the developing world and diagnosis the parameters involved in inventory. Articles about supply chain management have been historically focused on industries such as manufacturing and retail products. Researchers are striving to develop theories of supply chain with special considerations in the industry and operating environment, particularly in the service sector [9 - 11]. Quality management is an important factor for sustainable supply chains. In order to understand the basic principles of quality management in manufacturing and service networks by decision-makers, understanding and simulating the environment according to Game theory by Stiller et al, the behavior and strategies of human factor was discussed in the success of supply chain quality management. Based on the results of their research, the integrated cognitive skills of players (human factors) in the structure of the supply chain left a significant positive impact on the game performance [12]. Zamparia et al. [13] extended the multi-objective optimization problem in the supply chain so as to achieve multiple optimization criteria through the Pareto solution space as well as the Game Theory for decision support dealing with uncertainty. Qiu et al. adopted the Game Theory to search for customers buying products in the market, where two retailers buy from one manufacturer of products in the supply chain together with customer behavior to cope with the changing policies of retailers [14].

There are numerous studies conducted in the field of supply chain at hospitals and pharmaceuticals. For instance, Chen et al. determined the factors affecting hospitals and the importance of supply chain information integration in the supply chain [15]. In connection with the supply chain consumables in hospitals, Arya et al. examined the problems in the field of cooperation in the supply chain of the equipment, so as to reduce costs of health care products including dental implants requiring high-end technology [16]. Gupta and Ramshba adopted the approach to the supply chain as a dynamic system through interpretive systems modeling (ISM) for interacting factors contributing to the health care supply chain in India [17]. Musazadeh et al. used the multi-objective planning to minimize costs and orders unmet at the same time within the pharmaceutical supply chain. Moreover, the uncertainty of unknown parameters for the design of the supply chain of pharmaceuticals was discussed through the strong contingency planning approach [18]. However, given the need of hospitals for medical equipment and the importance of high-quality medical equipment, this paper attempted to employ the Game Theory to model and simulate the behavior of suppliers through different supply chain quality management strategies.

3 Proposed Model

This paper employed the assumptions of Game Theory, i.e. the players were selected from the medical supply chain businesses. In this case, the behavioral changes of medical equipment firms were explored through strategies of competitors for the supply of equipment using rules of Game Theory. To facilitate the analysis, Vi represents medical equipment firms, i=1, 2, 3, ... , N, Sj is the type of medical equipment firm, where j=1,2,3 are the types of business strategy. The environment in which such a decision and interaction between people's decisions take place is a strategic environment in which each decision-maker is also a player. The basic premise is that each player behaves wisely depending on the type of strategy adopted by the opposing player to gain the most benefit possible.

Every hospital can find a supplier of medical equipment for its needs in less than 24 hours, but it is debatable that the hospital supply chain system consists of various components from suppliers of raw materials to final customer or patients. Therefore, it is essential to select the best supplier of medical equipment among many suppliers. In this article, it was assumed that different types of medical equipment firms have been accidentally scattered in the space of M cells where R refers to space. Each cell is occupied by a medical equipment firm and empty cell means that the cell is not occupied by any medical equipment firm. In this case, the distribution density of medical equipment companies in the space is equal to p. Therefore, the contribution of each of three types of enterprises in various supply strategies is p1, p2, p3. Hence, the sum of probability of each firm will be equal to p1+p2+p3=1 and each equipment company can play other businesses inside the cell.

Based on the above assumptions, the medical equipment enterprises are entitled with the right to choose from three types of strategies, i.e. low quality, high quality and impartial. According to each strategy adopted by the first firm, the second firm shall select a coping strategy likely to adopt similar decisions in the game against the first firm. In this article, firms i=1,2, ..., n can select their strategies between three types of strategies j=1,2,3.Here, the strategy is to choose a variety of strategies by firms in set Sj. It is very important that the decision by both firms will influence the result or outcome of the game called "revenue". The firm selects a strategy or adopt decisions for gaining different revenues composed of positive integers indicated through equation 1 and revenue function Yi [19]:

$$Y(i)=Y^{i}(S1,S2,..,Si,...,Sn) \quad \textbf{(1)}$$

It is essential to note that the revenue of the firm i depends not only on the business strategy (Si), but also on other strategies selected by other firms operating in the supply of medical equipment.

In the proposed model as well as the Game Theory, different revenues are gained as companies adopt various strategies. For example, if firm A selects a high-quality strategy in a game against firm B, the revenues received by firm B in the game, regardless of the probability of selected players, is as follows: 4+1+5. The more a strategy is of higher quality, there will be greater revenue for firms. The logical relationship shall be Y(S1)> Y (S3)> Y (S2) where, Y (S1) represents the revenues of medical equipment firm with high-quality strategy, Y (S3)represents the revenues of medical equipment firm with impartial strategy and Y (S2) represents the revenues of medical equipment firm with low-quality strategy. The payoff from electing different strategies by the medical equipment businesses in competition with each other has been displayed in Table 1.

Table 1: Matrix for the payoff of medical equipment firms.

		Strategy of firm B		
		High quality	Low quality	Impartial
Strategy of firm A	High quality	(u,u)	(w,x)	(z,z)
	Low quality	(x,w)	(y,y)	(z,z)
	Impartial	(z,z)	(z,z)	(z,z)

Where (A, a) indicates the revenues obtained through different strategies. For example, (x, w) means that the revenue gained through a poor quality strategy is w, while revenue gained through a high-quality strategy is x. Based on the classic Game Theory, if 1) x> u> y> w and 2) 2u > x+w, then the Nash equation would be unique [20]. Nash equation is a status of strategies where if any of the players choose other than the Nash equation strategies, there will be higher likelihood of losses. The model above assumes that 5=z, 1=w, 3=y, 4=u, 7=x where z refers to the amount of revenue that will accrue to firms adopting an impartial strategy.

4 Model Algorithm

In the proposed algorithm, medical equipment firms are defined by [name, type, location, history, profitability].Accordingly, name refers to the name of the firm (Vi is used to refer to firm i where i=1,2,3, ..., k is true).The type represents the kind of medical equipment business (in this model Sj refers to the type of medical equipment firm and j=1,2,3.Location refers to the place where a medical equipment firm is situated in point R {1,2,3, ..., N}.Moreover, M represents the total number of cells, records for the data of the previous game between medical equipment companies (i.e., selected strategies in the game) and profitability to the values of revenues at the medical equipment firms.

In this model, the reinforcement learning algorithm was an effective way to solve chainlike Markov problems for random and successive decisions [21]. Using this algorithm can determine the best decisions for each equipment medical firm in the game. To understand the model, the game algorithm of medical equipment firms is divided into three separate steps: Game exchange, self-learning of medical equipment institutions and enterprises to re-adjust positioning. Figure 1 shows step by step the modeling algorithm for hospital medical equipment supply chain. The algorithm is implemented from T=1 with the first firm (game start) all the way to t=k (game end) by the last one based on Figure 1.

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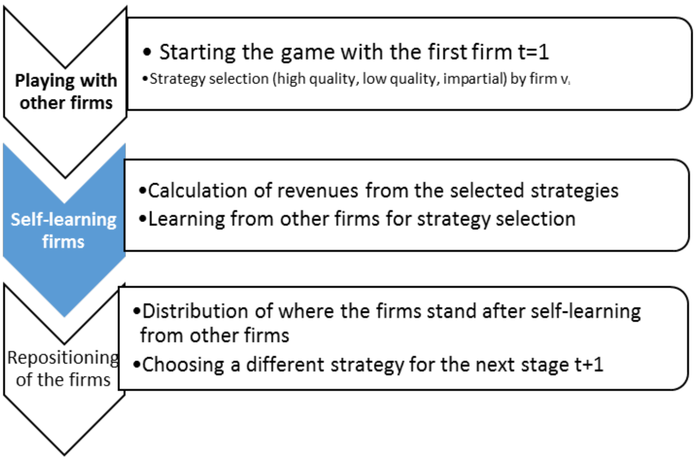

Figure 1: Designing the supply chain modeling algorithm for hospital medical equipment

4.1. Business Game

Starting the game from a random V_1, V_1 provides other firms in the medical equipment. Revenues of the game can be calculated by Strategy Matrix and revenues of two players (see Table 1). Adding the current revenues, backgrounds and historical data on the game, it continues until V1 and other medical equipment enterprises operate in space R. The next game between V_2 and other medical equipment enterprises takes place except for V_1 and the procedure is repeated on V_3. This trend will continue until all medical equipment firms play the game.

4.2. Self-learning Firms

As medical equipment supply chain modeling algorithm (Figure 2) illustrates, different medical equipment firms gain a specific amount of revenues in the game. The reward and punishment system was considered for the medical equipment supplying enterprises, assuming the strategies of the firms are S1, S2, S3 which is a sequence of independent random variables and the distribution/probability density of revenues function for Y_js is S_j. Revenue is expected to increase as enterprises with lower revenues learn a strategy from other types of businesses based on the following steps.

Step 1: It determines the type of medical equipment firm. In this case, it is assume p1, p2, p3 indicate the probability of S1, S2, S3 selected by V_i and P1+P2+P3=1, as well as pj= {p1+p2+p3} represent the probability of strategy selected by V_i. When t=0, p1={1,0,0}, p2={0,1,0} and p3={0,0,1}, the probability of the medical equipment firm's primary Sj is equal to 100%.

At stage T in the game, after observations Y1, Y2, .., Yt, i.e. revenue from the different strategies chosen by the first firm (Vi) in competition with other firms in the supply of equipment, if>$\hat{Y}(i,t)Y(i,t)$, the optimized strategy selection policy stops and the firm's revenue $Y(i,t)$ will indicate the values of revenues for Vi at the end of stage t, or it may calculate $\hat{Y}(i,t+1)$the amount of revenue expected at stage t+1 so as to earn more money in the game. It will arrive in next step to observe Yt+1. Details are as follows:

Step 2: It calculates the expected revenue value in the game's stage 1.$\hat{Y}(i,t)$It represents the value of expected revenue in stage *t* of the game and its equation is as follow:

$$\hat{Y}(i,t) = \lambda\hat{Y}(i,t-1) + (1-\lambda) \times Y(i,t-1) \tag{2}$$

Under conditions where 0 << 1, it is a constant value assessing the current average impact of previous revenues on the current revenues. At t=1, Y (i, t-1)=0. This means that medical equipment firm has no revenues before the first game.

Step 3: At this stage, the revenue is calculated, assuming that n (i, t) represents the value of the rate of revenue when choosing strategy *i* at stage *t*, then the equation will be as follows:

$$r(i,t) = \frac{Y(i,t)-\hat{Y}(i,t)}{\hat{Y}(i,t)} \tag{3}$$

Step 4: It calculates the adjusted value of medical equipment firms It is assumed that $p_b(i,t)$ is the corrective value of medical equipment firm at *t* of the stage game. The Markov decision process, there is a theorem $p_2(i,t), p_3(i,t)$ and $p_2(i,t) > p_3(i,t)$ based on probabilities j on various strategies so that if equation $p_3(i,t) > p_1(i,t)$ is true, i.e. in the density of the first strategy is more than the impartial one, the optimal policy in strategy selection stops, and if firm V_i selects strategy S1 to compete in the supply chain and end the game, and if $p_1(i,t) > p_2(i,t)$, then algorithm will select strategy S_2 for the first firm to continue the game, and if the probability if out of both the scenarios above, algorithm will continue according to Figure 3 [21].

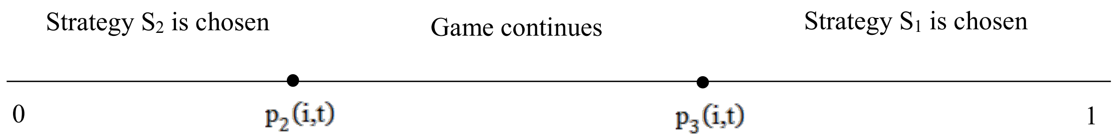

Figure 2: Combining the optimal policies in selecting strategies

Equation 4 was used to calculate the adjusted values of the type of medical equipment firm:

$$p_b(i,t) = p_b(i,t) + a \times r(i,t) \tag{4}$$

Where *a* is a positive constant that determines the speed of learning. It is considered equal to 0.1=a. As such, the value of revenues in steps after learning from other firms will not be infinite.

Step 5: It determines the adjusted value for different types of firms at different stages of the game as shown in Figure 2 and calculated through Equation 5:

$$\sum_{b=1,2,3} P_b(i,t) = 1 \tag{5}$$

Step 6: It selects the type of medical equipment firm according to $p_b(i,t)$.

If $p_b(i,t) = \mathrm{Max}\left(p_1(i,t), p_2(i,t), p_3(i,t)\right)$, the type of medical equipment firm is selected based on $p_b(i,t)$.

Organizations in the strategy based on quality of supply chain need to adopt quality strategies so as to survive in competition and economic life. However, a common strategy in the entire supply chain focuses on customer value and product quality.

4.3. Repositioning of medical equipment firms

All the medical equipment firms finish the self-learning process and are then randomly distributed in the environment, prepared for the next step.

5 Simulation Model

The purpose of supply chain modeling is to identify the different components of supply chain and how the structure dominate in such a way that optimum performance is achieved in the entire chain. The optimization-simulation models intend to anticipate and accurately simulate the application of mathematical methods. In this method, the system is modeled through simulation software, solved by an optimization algorithm. The advantages of this model can be accuracy and robustness of optimization [22].

5.1. Simulation environment

In this section, the results are elaborated through a hypothetical example. It is assumed that Khatam Hospital receives medical equipment from five supplying firms though application contracts. If high-quality goods are provided by the suppliers, the hospital is satisfied to sign a two-year contract for awarding the suppliers. In case dissatisfaction is caused by poor products by suppliers, next contracts will not be involved in supplying the medical equipment. Here, the number of firms was i=5, including firms A, B, C, D, and E. In the first stage of the algorithm, V1 is used as a firm starting the game. To solve this example problem through Markov chain, duration of the planning considered is considered infinite and the space and number of situations adopted by firm A against firm are assumed i=2 and 1, i.e. The is solved for two stages t=2.Regarding each state *i*, there is a limited set of actions or variables of D*i* decisions. In other words, firm A is in the first game (situation i=1) and strategy is selected from three options 3=j (high quality, low quality, impartial). Status transition is displayed by vector [21]:

$$P_{ij}(k) = P\left(X_{n+1} = j \middle| X_n = i, d_i = k \in D_i\right) \quad \textbf{(6)}$$

Where X_n refers to the status of firm in step *n*, as stated earlier. The sum of $P_{ij}(k)$is one. The revenues from action *j* in status *i* is displayed by $r(i,t)$.Each of the strategies chosen by the firm is a probability P1+P2+P3=1. When there are t=0, p1={1,0,0}, p2={0,1,0} and p3={0,0,1}, firm A must choose one strategy from the available options. Firms B, C, D, and E will select one of three types of strategies. The assumptions for selecting different strategies have been shown in Table 2. Status *t* refers to step *i* where firm A can choose a strategy to begin the game. Actions in step 1 include a choice of three types of strategies to continue playing. In Step 2, the actions decline for selecting these strategies, i.e. Firm A at second stage firms will only be able to select a strategy that is high quality or low quality, since it shall not play other firms if the impartial strategy is adopted.$P_{ij}(k)$It refers to the probability of selecting strategies in the next steps of the game, while $\hat{Y}(i,t)$ refers to earning revenue from action *k* in status *i.* For example, it is randomly assumed for numerical solving the problem that firm A in the first game selects high-quality strategy in the game with Firm B. This is an optional procedure for the start of the algorithm. At each step, the algorithm achieves a better procedure and this action continues until the procedure is optimized.

The revenue earned in the previous step for each status *i,* action *k* is selected in a way that the maximum value of $p_b(i,t)$ is chosen for the action in the next step.

Using the procedural steps above, it is assumed r=$\begin{Bmatrix} 2 \\ 1 \end{Bmatrix}$ (the procedure refers to period n when the system is in status *i* and what action is required then the stable procedure is independent of period n). The procedures intended involved when the firm is in status 1 and action 2 is taken or when it is in status 2 and action 1 is taken.

For procedure r=$\begin{Bmatrix} 2 \\ 1 \end{Bmatrix}$, calculation is made for $r(i,t)$.Then, the optional procedure r, both actions and j=1,2 are examined with respect to a=0.1 in Equation (7) until the maximum value is obtained:

$$p_b(i,t) = p_b(i,t) + a \times r(i,t) \quad (7)$$

$$p_b(i,t)=\text{Max}\left(p_1(i,t),p_2(i,t),p_3(i,t)\right) = \{0.75, 0.25, 0\} \quad (8)$$

$$\hat{Y}(i,t) = 4.5Y(i,t)= 16 \quad (9)$$

The equation $\hat{Y}(i,t)>Y(i,t)$ is not established, i.e. the end of the algorithm for firm A and selecting the second firm to restarting the game.

Table 2: Assumptions on strategies selected by firm A in the game.

$Y(i,t)$	$\hat{Y}(i,t)$	$P_{ij}(k)$		Action k	Status i
		2	1		
16	8	0	1	1	1
9	4.5	$\frac{1}{2}$	$\frac{1}{2}$	2	
15	7.5	$\frac{3}{4}$	$\frac{1}{4}$	3	
16	8	$\frac{1}{2}$	$\frac{1}{2}$	1	2
9	4.5	$\frac{1}{4}$	$\frac{1}{4}$	2	

As the results suggest, firm A with strategy 1 at the start of a game earns the same earning values in step 6. It will not go to step 2 to continue the game, because the optimal strategy 1 (high-quality strategy) has been obtained and the algorithm will stop. It should be noted that first strategy selected by the firms at the start of game will have a significant role on the final result of the change or maintaining the optimal strategy, satisfaction or non-satisfaction of the hospital.

In order to verify the model for the results of the various strategies of the firms against other firms, the following steps of the algorithm should employ the simulated environment through reusable object-oriented language Java so as to examine the realization of the request desire. The five medical equipment firms begin a game 120=! 5 steps along with self-learning and repositioning.

5.2. Simulation analysis

To verify the results and quantification of medical equipment firms competing and playing with other firms, the parameter of probable strategies selected by the firms in step 1 was considered as variable, while the average value of the revenue for medical equipment firm was considered in various probability distributions so as to examine the behavior of firms in competition with other firms.

It is assumed the proportion of selecting one of the three types of medical equipment firms (high quality, low quality, impartial) is p1, p2 and p3. As mentioned earlier, the sum of the probability of each probability should be equal to one. It is better to specify a subset of the set of all policies to determine the probability of selection strategies, because step 1 in the algorithm assumes that any strategy might be selected. This section provides the distribution of various medical equipment firms in selecting the initial strategy. There are 4 types of distribution below to begin algorithm based on Markov chain:

$$\{0.8, 0.1, 0.1\} \text{and } \{0.1, 0.8, 0.1\} \text{and } \{0.1, 0.1, 0.8\} \text{and } \{0.3, 0.3, 0.3\} = \{P_{S3}, P_{S2}, P_{S1}\}$$

The Java programming language was used to change the probability of selecting the first strategy by the medical equipment firms and their revenues through algorithm in Figure 2 as follows:

If there is a fundamental difference in the proportion of distribution for medical equipment companies (initial probabilities), then a series of repetitions and self-learning institutions, the adjusted values approach to one, thus the number of firms with high quality strategy S_1 will be more and more and this means that the number of S_1 is greater than S_3 and the number of S_2 is lower than S_1. Furthermore, a certain fluctuation takes place in the number of each of the three kinds of medical equipment firms at the beginning of the operation. Therefore, it can be concluded that the behavior of medical equipment firms is based on Markov chain after a reasonable trial period of learning, thus giving a sustainable value to the type of medical equipment firm [23].

6 Conclusions and Ongoing Studies

In this article, effort was made to model the behavior of suppliers of medical equipment at high-quality, low-quality and impartial levels in the medical equipment supply chain. Based on the results of the analysis, the proposed reward and punishment mechanism for hospital plays a key role in the treatment of strategies selected by suppliers of medical equipment and ultimately on the quality management and behavior of medical equipment firms. Based on the above analysis, medical equipment firms tend to select high-quality strategies when rewarded for providing top quality medical equipment and punished for providing poor medical equipment.

However, the model is based on the assumption Y(S1)> Y(S3)> Y(S2), meaning that the higher the quality, the higher the revenues. Using the Markov chain rules, if there is a significant difference in the distribution (probability) of the types of medical equipment firms, as the number of games ($n\to\infty$) increase, the revenues of medical equipment firms undergoes a positive trend and will eventually be maintained at a fixed value.

In real markets, due to asymmetric information and lack of proper supervision of the entire supply chain of hospitals, the medical equipment manufacturing firms often operate without authorization and produce low-quality items. For example, “platinum shattering inside the foot of the patient” and “fake heart stents” and thousands of other accidents should be taken seriously concerning the medical equipment industry. Some dealers of hospital equipment forge documents so as to sell illegal products to public hospitals. With this explanation, it is recommended that the government adopt the complete and accurate reward mechanism to realize domestically high-quality production and prevent illegal trafficking of poor quality equipment.

Application of reward and punishment mechanism can reduce the asymmetric information in the market of medical equipment in Iran. Moreover, it can set the ground for tracking the origin of production and use of raw materials for medical equipment before it is delivered to the customers (patients) in the supply chain of medical equipment. Finally, it can resolve many of the issues concerning the quality of medical equipment.

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