Jurnal Teknologi

Full paper

Improving the Inventory Levels of a Blood Supply Chain Through System Dynamic Simulation

Jafar Afshar*, Narjes Sadeghiamirshahidi, Ali Reza Firouzi, Seyed Mojib Zahraee, Syed Ahmad Helmi Syed Hassan

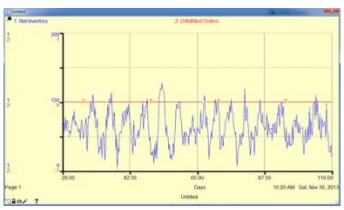
Faculty of Mechanical Engineering, Department of Industrial Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: amir_1065@yahoo.com

Article history

Received :1 January 2014
Received in revised form :
15 February 2014
Accepted :18 March 2014

Graphical abstract



Abstract

The blood supply chain is a complex system with a multi-echelon structure. Hence, the integration of various interconnected elements, which should be synchronized appropriately, is a necessity to meet the patients' requirements. The performance of the blood supply chain is a function of different variables that are dependent of each other. Therefore, the main aim of the chain is the optimization of the overall supply chain by considering the dynamic behavior of the system. The purpose of this study is to develop a system dynamic simulation model for a complex blood supply chain in order to improve the average level of inventories. The developed model is based on three echelons with a centrality on a regional blood center. The performance of the supply chain network in the current condition is investigated and based on the objectives, 17 scenarios were experimented for improving the average level of inventories to avoid outdates while there are not any backlogged orders. In addition, the best values of the investigated parameters (safety stock, supplier preparing lead time, in transit time and separation time) were determined.

Keywords: Blood supply chain; system dynamic; regional blood center, backlogged order

■1.0 INTRODUCTION

Nowadays, the uncertainty of supply and demand leads to a dramatic augmentation in the complexities of supply chain systems. This issue brings about many controversial challenges in the supply chain of perishable products [1] particularly with regards to blood supply chain where the shortage and vitality of this perishable product can make such supply chain crucial [2]. According to Baesler *et al*., the blood supply chain is a complex system as well, because it should consider various interconnected elements which have to be coordinated and synchronized correctly to satisfy the ultimate patient requirements from the quality and quantity points of view [3]. Therefore, the main goal of a regional blood center is to satisfy the patients demand by supplying an adequate amount of blood bags needed in an uncertain environment. According to Katsaliaki and Brailsford, when the supply and demand for blood products are approximately balanced, lacking of harmonization between supply chain echelons can cause a shortage in one region whereas blood units are wasted in another region [4]. Therefore, this shortage could be risky because of the vitality of the blood for life related emergencies. Moreover, the wastage of blood products is also very detrimental for the environment. Nagurney and Masoumi, believe that, in order to achieve a sustainable blood supply chain, the outdating of blood components should be minimized whereas satisfying the uncertain demands in the best possible manner [2]. Since the blood demands are stochastic and the number of patients are enhancing, maintaining an optimum level of inventories is a critical issue in blood banks. In other words, maintaining inventories which are too high or too low in the stocks could lead to blood wastages or customer dissatisfaction respectively.

System dynamics modeling is a methodology to investigate the dynamic nature of the complicated supply chain networks [5]. According to Rabelo *et al*. a system dynamic model replicates the dynamic manner of the supply chain environment because of taking causal relationships, feedback processes, and several time delays which is a need to pursue precisely the behavioral improvement of the system [6]. Based on the literature, Barlas and Aksogan have investigated various production policies under different levels of inventories and order trends [7]. Their investigations show that the order policies which are applied in continuous systems don't meet the requirements of partly continuous and discrete stock systems. Huang and Liu have proposed a model through using system dynamic and APIOBPCS (Inventory and Order Based Production Control System) to reduce the inventory levels of a two supply chains [8]. To do so, they have simulated the transmission and replenishment processes when a third party logistics provider applies vendor managed inventory in order to make a relation between the two supply chains [8]. According to Bell *et al*., the different policies related to discounting lead to inventory oscillation in supply chain and as a result incurring higher inventory costs [9]. So, they have recommended an approach for supply chain in order to return the maximum amount [9]. In this paper, the inventory level of an echelon in blood supply chain has been improved through system dynamics modeling.

■2.0 MATERIALS AND METHODS

System dynamic simulation model which is known as the Stock and Flow Diagram (SFD) for the blood supply chain is constructed. A Regional Blood Center (RBC) located in Malaysia has been considered as the case study. The supply chain of blood is consisted of three main echelons: suppliers which are mobile blood collection units, producer which is RBC and the distributors which are public and private hospitals. The assumptions of the proposed model are: (a) modeling is implemented in an operational level; (b) the proposed model is focused only on the producer (RBC) and Red blood cell is considered as the product; (c) all the stages considered in the chain do not have any interactions with the stages that are out of the system; (d) the demand is stochastic and follows a normal distribution; and (e) the simulation model is run for 110 days in which the first 20 days have been considered for the model to reach to a stable state. The simulation model is constructed using iThink v9.0 software.

2.1 Developing the Model

The stock and flow diagram of the blood supply chain in Malaysia consisted of five different important parts. In the simulation model, the actual customer order refers to the patients' demand and follows the Normal distribution with a mean of 135 and standard deviation of 15. The first part of the model is dedicated to the forecasting demands. One of the important equations in this part is *Expected Customer Demand* which is refer to the forecasted demands in previous periods plus the difference between the actual customer order and the expected customer order in this period multiplied by a smoothing factor coefficient:

Expected Customer Demand (t) = Expected Customer Demand (t - dt) + (Customer Order Adjustment) * dt (1)

In the second part of the model, the order policy of RBC has been shown and the questions of when RBC should place the orders and what the amount of orders are in each period will be answered. The *Order Decision* is calculated based on:

Order decision = IF (Inventory Position-Minimum Red Cell Inventory < 0) THEN (Blood Center Order Up to Level-Inventory Position) ELSE 0 (2)

It means that if the difference between the inventory position and the minimum level of inventories is lower than zero, an order should be placed and the amount of and order is calculated based on the difference between the maximum level of inventories and the inventory position.

The third part of the model is dedicated to the separation of blood components and blood wastage. The *Net Inventory* in this section is the parameter which is investigated in this study:

Net Inventory = (Red Cells Inventory + Finish Separation - Shipping Red Cells) (3)

In the fourth part of the model the blood bags are shipped to the customers. The *Shipping Red Cells* is calculated as follow:

Shipping Red Cells = MIN (Red Cells Inventory + Finish Separation, Desired Shipment rate) (4)

The term shipping red cells refers to the shipment of blood bags to the customers. If the amount of bloods in inventory can respond all of the customer orders, the shipment will be equal to the desired shipment rate, if not; the shipment will be equal to the amount of inventory in hand.

The last part of the model is for calculating the backlogged orders. The term *Unfulfilled Orders* or backlogged orders refer to the customer orders which are not responded. The concept of this equation is that, there were some backlogged orders in the previous period and they have been accumulated in the stock and these amounts are added by the backlogged orders which are generated in the current period:

Unfulfilled Orders (t) = Unfulfilled Orders (t - dt) + (Unfulfilled Adjustment)*dt (5)

■3.0 RESULTS AND DISCUSSION

Inventory control is a vital operation in blood supply chain to respond the customer orders in the best possible manner. Actually the blood supply chain should be responsive in terms of time and satisfaction to fulfill the customer demands. Also this subject is very dominant because of the perishability of blood components in a blood supply chain. Therefore, holding too high level of inventories in the stock brings about blood wastage and at the opposite side, maintaining too low inventory level triggers shortage in satisfying the customer demands. Figure 1 shows the initial behavior of the system in which the inventory level of RBC in the current state is for about 126 blood bags in average and there is not any backlogged order. However, in order to have an optimum level of inventory to avoid wastages and order backlogs, the inventory level is improved in this paper.

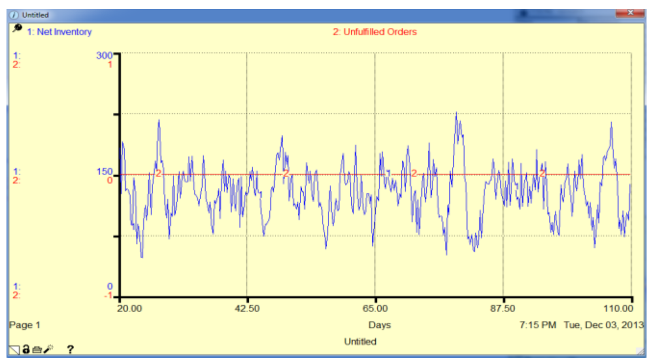


Figure 1 Initial behavior of the system

3.1 What-If Analysis

In order to improve the inventory levels of the current state of the system the method of what-if analysis has been used. Four factors, safety stock, supplier preparing lead time, in transit time and separating time have been considered and 17 scenarios are investigated. After each run the average of inventory levels is calculated and a comparison is made at the end of the experimentations. Table 1 demonstrates all the scenarios which should be investigated. The scenarios have been considered based on the production capacity and the capacity of the system. For example the supplier preparing lead time could not be lower than half a day or higher than 1 day. So this information is achieved with understanding the essence and capacities of the system.

Table 1 Different scenarios

Scenario	Safety Stock	Lead Time	In Transit	Separating Time
1	250	1	0.25	0.5
2	350	1	0.75	0.5
3	250	1	0.75	1.5
4	350	1	0.25	1.5
5	350	0.5	0.75	0.5
6	350	1	0.25	0.5
7	350	1	0.75	1.5
8	350	0.5	0.25	1.5
9	250	0.5	0.75	0.5
10	250	0.5	0.25	0.5
11	250	0.5	0.75	1.5
12	250	1	0.25	1.5
13	300	0.75	0.5	1
14	350	0.5	0.25	0.5
15	250	0.5	0.25	1.5
16	350	0.5	0.75	1.5
17	250	1	0.75	0.5

After running the model and investigation of 17 scenarios, the average level of inventories for each scenario has been calculated. Table 2 provides information on the average level of inventories for each scenario. It can be clearly seen in the table, scenario 11 has had a better response based on the lower average of inventory levels over three month's period. It should be mentioned that all the scenarios have investigated whereas there is not any backlogged orders and therefore the customer satisfaction is at 100%. In scenario 11 safety stock should be at the level of 250, the supplier preparing lead time should be half a day, in transit time should be 0.75 day and the components separating time should be 1 day and a half. The behavior of the system in scenario 11 has been depicted in Figure 2 In this condition, the average level of inventories is for about 93, which is the lowest level rather than the other 16 scenarios.

Table 2 Results of the alternatives

Scenario	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Response	297	328	95	261	328	397	195	262	229	298	93	162	246	398	161	195	229

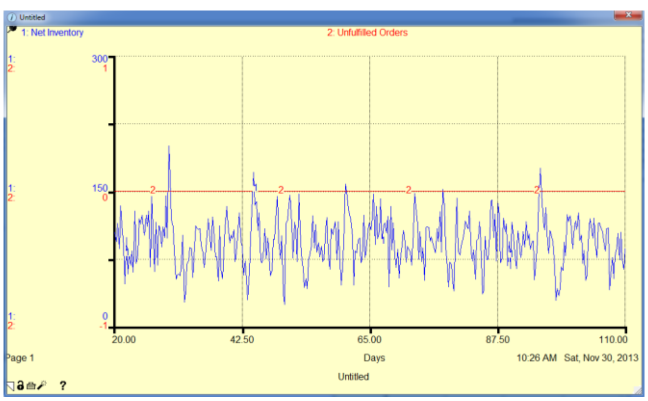


Figure 2 Scenario 11 (SS=250, LT=0.5, IT=0.75, ST=1.5)

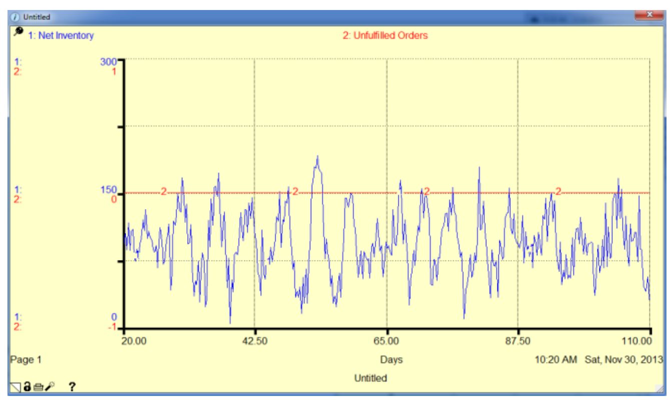


Figure 3 Scenario 3 (SS=250, LT=1, IT=0.75, ST=1.5)

Although scenario 11 has had the lowest quantity, scenario 3 also has a very low inventory and the difference here is only for about 2 blood bags (Figure 3). Likewise, the only difference between these two scenarios (3 and 11) in the amount of their factors is the supplier preparing lead times which are 1 and 0.5 day respectively. So regarding to the little differences between the inventory levels, it is recommended that managers could consider scenario 3, which has the worst condition than scenario 11, in order to decrease the costs related to the lead time.

■4.0 CONCLUSION

This paper has developed a model for blood supply chain with system dynamics. Different scenarios have been investigated based on four various variables (safety stock, supplier preparing lead time, in transit time and separating time). The experimentations have been done to improve the average level of inventories whereas backlogged orders are zero. According to the simulation results, two scenarios with the lowest average level of inventories have been selected. Due to the little difference between these two scenarios, the scenario with the higher supplier preparing lead time has been chosen because of considering the worst condition and decreasing the costs related to the lead time. Finally the inventory level of RBC has been reduced and as a result the inventory holding costs are decreased. In addition, improving the inventory levels prevent blood products to be perished and the availability of blood products is enhanced. Based on these explanations, the customer satisfaction remains at the high level without incurring high costs to the societies.

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