Policy Analysis with Simulation: Centralization of Blood Supply Chain

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Abstract: Incessant increase of human population and environmental factors increase patients' need for blood, so research on this topic is a crucial necessity. A blood supply chain starts with the donation of blood and ends with transfusion to patient, and configuring blood supply chains as a whole has become a major requirement. In this research, blood supply chain system centralization and decentralization policies are compared for a specific setting in Turkey. Effects of these policies on performance measures like number of expired blood products in regional blood bank and, in each hospital and total cost of the blood supply chain system are observed using simulation modeling. Results show that under the given conditions the best policy is maintaining a decentralized blood supply policy which leads to a lower blood expiration rate and lower total cost.

1 INTRODUCTION

The incessant increase of the population and environmental factors results in the appearance of some health issues. Some of these issues are taken care through ambulatory treatment and some others are treated through inpatient care (admitted to the hospital). Blood is a human fluid which delivers vital substances such as nutrients and oxygen to the body cells and transports metabolic waste away from same cells. The inpatients may need blood supply from outsources due to operations and blood loss. Blood is composed of many different kinds of components and patients may need one or more of these component(s) depending the treatment. In general, blood is collected as a whole in donation centers or in hospitals and, after donation, blood is decomposed into different components such as red blood cells, platelets and fresh frozen plasma which are perishable. Hospitals may prefer to supply their demand by their own production, if they have necessary infrastructure, or by regional blood banks.

In hospitals, blood inventory levels of blood products are monitored based on a determined period and when they reach to the determined base stock level new replenishments from the regional blood centers are done. Orders are delivered to the hospitals at the beginning of the day in which the orders are made. In cases, which demanded blood products do not match the existing blood groups and characteristics in stock, hospitals make effort to afford the blood product. In such a situation, hospitals first search for the proper blood product in the regional blood bank and nearby hospitals, if it is not found, they try to satisfy the demand by letting donations occur.

As the process of supplying blood at the right time is extremely vital on patients' side, blood supply chain network and blood center locations play an important role in efficient demand satisfaction as well as economic scale. There are many decisions that are effective in the pursuit of these objectives. One of the major decisions is centralizing the blood supply chain or decentralizing the blood supply chain by hospital based blood banks which affects objectives with a huge impact.

In Turkey, according to the new law about the national blood banking system, the blood demand from all hospitals is satisfied from Turkish Red Crescent Society (TRCS). None of the hospitals are authorized to collect blood donations by themselves anymore though it costs more to supply blood products from TRCS. Neither the tests for patient and product match can be done by hospitals. Centralizing blood supply chain with TRCS has positive and negative effects as other decisions. For instance, judging from hospitals point supplying blood products from TRCS costs more than producing these products by their own production. On the other hand, in the centralized system all donations can be collected at a single location and production process can be standardized.

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Existing literature on blood supply chain is generally focused on different main parts of the supply chain with different purposes and includes different levels of detail. However, each part and each property of the supply chain effects objectives which exist in the literature, therefore the supply chain must be taken into account from donation to transfusion as a whole with sufficient details. Besides, different scenario analyzes exist in literature but a strategic decision that will affect every aspect of the system like centralization has not been analyzed from a broad perspective. Different versions of this scenario analysis exist in literature but blood products and blood groups were not included and system was not modelled from donation to transfusion as a whole.

In this research, the impact of centralization and decentralization policies on blood supply chain network's total cost and blood wastages/expired blood products are investigated. Points that were not considered in previous studies in the literature are taken into account and in this research. For this purpose, each blood product and blood group is included in the blood supply chain network which is modelled from donation to transfusion as a whole.

In addition, blood supply chain structure, standards and policies vary for different countries and locations and in Turkey or in a country with similar infrastructure, no similar research exists.

In order to make the analysis on a realistic testbed, data is collected from TRCS and own blood banks of the hospitals in Ankara, and a simulation model is generated based on this information.

This paper is organized as follows: Section two presents existing work in literature, Section three defines the problem and the method. The fourth section includes the numerical results and, in the last section conclusion and suggestions for future work are presented.

2 LITERATURE

Existing literature which are related to the problem are investigated and categorized into two groups as studies handling blood supply chain issues and policies by means of simulation methods and studies considering blood as a perishable good and tackling the issues occurred in blood supply chain.

Starting from the first category, Cohen and Pierskalla (1975) considers management strategies for a regional blood bank. The research focuses on the impact of centralized and decentralized control and also various scenarios on the transfused blood, shortages, number and percentage of the outdated blood. In Özgen (2007), three echelon supply chain configurations which has been defined in the new Turkish Law of Blood and Blood products has been considered for regional blood center in Antalya. Katsaliaki and Brailsford (2007) is a case study of a blood center of a hospital which is located in United Kingdom. This research aims minimizing the wastage and shortages in blood supply chains. In Beliën and Forcé (2012) all the researches of blood supply chain till 2011 are categorized based on the modeling and solution approaches they used and the ideas for future works are presented. In Katsaliaki (2008) blood donation in blood bank, donated bloods' storage, blood distribution systems, hospitals' ordering, stocking, blood- component user's performance and costs are analyzed based on the data gathered from UK blood bank and hospitals where the donations take place. Zahraee et al. (2015) aim to increase the efficiency of the blood supply chain by applying the dynamic simulation and Taguchi method and monitor the resulted change on simulation software. In the work done by Baesler et al. (2014) the focus is on storage of blood components. In this paper, process between blood donations till its delivery is analyzed. In Rytilä and Spens (2006) the increasing importance of the blood supply chains and the strategic decisions which can be made in order to afford the most efficient blood utilization is negotiated. Different inventory strategies, different transportation methods, different ranking approaches and different production control approaches are considered. Kamp et al. (2010) considers blood availability and management in case of epidemic diseases such as H5N1 and H1N1 instead of considering the optimal inventory levels. In Pegels et al. (1977) four different scenarios/strategies are compared. The scenarios applied to the simulation model can be listed as utilization of frozen blood cells, utilization of techniques for extending blood and blood components shell lives, application of improved donation strategies and utilization of improved inventory strategies. Simonetti et al. (2014) aim at investigating the impact of various blood management policies on the availability of the blood and its distribution in USA. The utilized model simulates the impact of different blood management applications which are used in blood transfusion on the demand. In Osorio et al. (2016) simulation is used to support the strategic and operational decisions made in production planning. Discrete event simulation is used to show the supply chain flows incorporating collection, production, stocking and distribution. This research is a case study taken place in Colombia and is based on the real-world data taken from the blood bank. In J. Blake et al. (2015) a simulation study is used to assess the network performance when distinct blood centers are consolidated into one unique blood center located in Calgary, Alberta. Yuzgec et al. (2013) has suggested a simulation model of blood network operations for determining the inventory levels and distribution plan of specific region having a regionalized blood banking system. Vlachos et al. (2012) has considered a methodology to estimate the required inventory level of umbilical cord blood units in Greece. The paper aims at ensuring an adequate probability that a Greek patient find a Human Leukocyte Antigen. J. Blake and Hardy (2013) have again studied the impact that consolidation of blood production and distribution facilities have on customer service. Xu et al. (2013) has suggested a three-dimensional simulation model which simulates the deformation and aggregation of red blood cells by coupling the interactions between the fluid and the deformable solid membrane of the red blood cells using continuum mechanics. In Onggo (2014) the elements of a hybrid simulation model are explained using a case study of blood supply chain simulation model for low and middle-income countries that has different characteristics and challenges in comparison to the typical blood supply chain in high-income countries. Baesler et al. (2014) have used a discrete event simulation model for analyzing and proposing inventory policies to a regional blood center. Haijema et al. (2009) have developed a new approach which combines stochastic dynamic programming and simulation to provide practical order up to rules that are nearly optimal formal theoretical support for blood platelets. The proposed approach has been applied to a Dutch regional blood bank. Mustafee et al. (2009) has described an investigation into using conventional and distributed approaches to simulating the supply chain of blood from the UK Southampton NBS Center to hospitals in this area. Blake and McTaggart (2016) used simulation for resolving the impacts of modernization configure-tions on blood distribution network of Canadian Blood Services.

The product considered in this research is known to be highly perishable and due to this characteristic, the second category includes the literature for existing papers on the perishable inventory theory. Sonnendecker and Millard (1960) are the researchers who have suggested the application of general inventory control methods and policies to the blood supply chain and in this way the perishable inventory theories has been applied to blood supply chain problems. In Kopach et al. (2008) focus is on meeting the trade-off between different demand levels (emergency and ad-hoc), service levels, costs and also the classic shortage and wastage minimizing objective function factors by revising a queuing model with utilization of cross level techniques. Stanger et al. (2012) offered the best application that minimizes the wastage occurring due to expiration of the normal blood inventory holding durations. In this paper, main focus is on the management of red blood cells stock management in hospitals' transfusion laboratories. In J. T. Blake et al. (2003) the methods which can be used in platelet suppliers' regional inventory ordering policies are discussed. In Hardy (2015) four simulation models are used to evaluate the impact of a reduced red blood cell shelf life on outdate, shortage, and emergency order rates.

Literature analysis shows that blood products and blood groups were not included and system was not modelled from donation to transfusion as a whole in previous researches despite their crucial effects on objectives.

3 METHOD

In this section the functioning blood supply chain in Ankara, centralization scenario and decentralization scenario is summarized and then the simulation model established is described in detail.

3.1 Problem Summary

In Turkey, a centralized blood bank system is used and TRCS supplies blood products to hospitals regardless of hospitals’ capabilities. In this research the performance of centralized and decentralized regional blood supply chain policies are compared and the objective is to monitor the changes occurring in number of expired blood products of hospitals and TRCS and total cost of the system under centralized and decentralized scenarios.

In this research, there are two types of hospitals: Type 1 and Type 2. Hospital types are determined based on their ability to afford their own blood when demanded. According to the investigation of this subject, some large and facilitated hospitals which are referred as Type 1 hospitals own their own blood bank infrastructure and some smaller hospitals which are referred as Type 2 hospitals need to satisfy their demand from the regional blood bank.

The supply chain performance is assessed under two different policy scenarios: Central supply chain policy and decentral supply chain policy. In central supply chain policy, all demands of both hospital types are satisfied from the TRCS which plays the

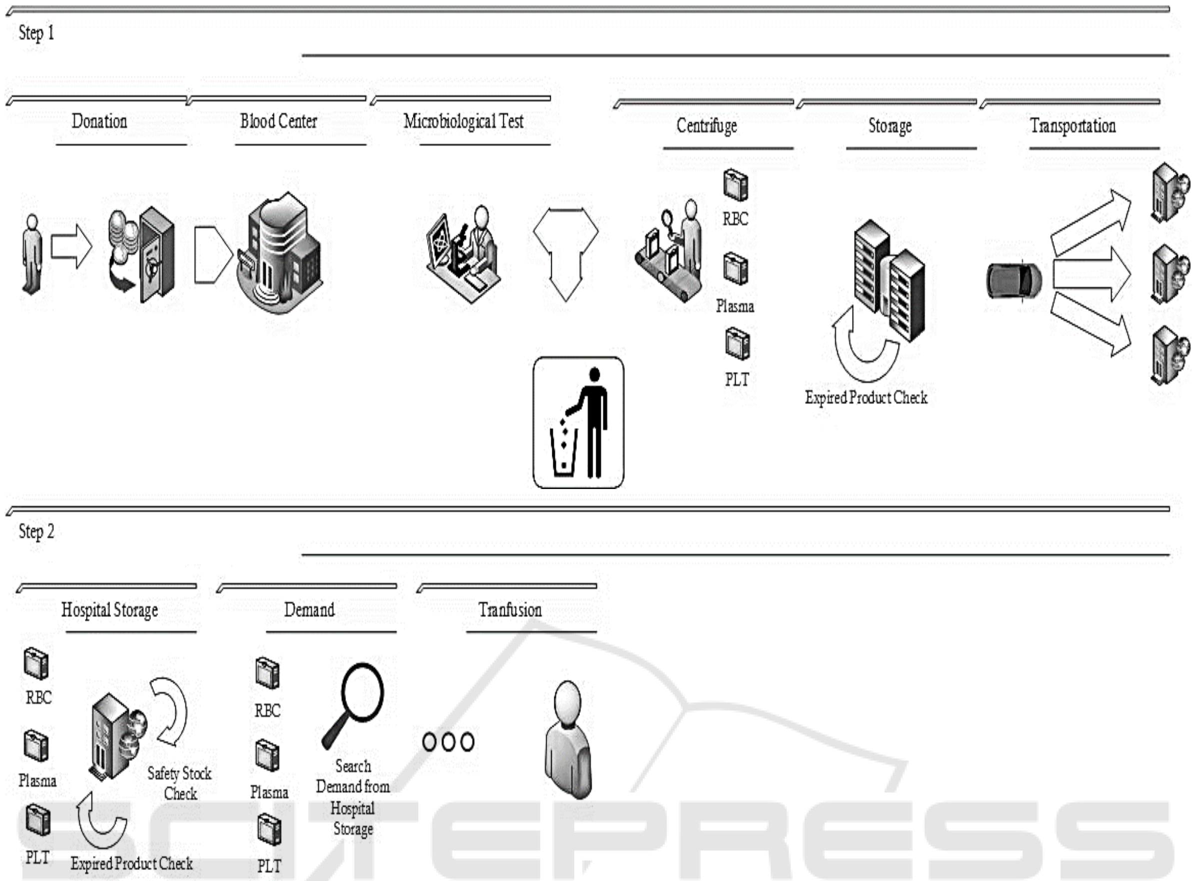

Figure 1: Centralized blood supply chain - Step1: within TRCS from donation to transportation - Step2: within hospitals from storage to transfusion.

role of regional blood bank. TRCS collects, tests and processes all blood donations within the city. Hospitals keep an inventory and this inventory is replenished by TRCS daily. The base stock level of each hospital is determined by TRCS. When there is a blood product demand, the hospital inventory is checked, if it is not available in the hospital TRCS is checked, if there is no blood product of the requested type in TRCS banks, other hospitals are checked. Also, blood cross match tests are done by TRCS. Centralized blood supply chain is generalized into two steps in Figure 1, the first step illustrates flow from donation to TRCS storage and the second step illustrates flow from hospital storage to transfusion. In the decentralized supply chain policy, Type 1 hospitals produce their own blood components but Type 2 hospitals still order from TRCS. In decentral system, Type 1 hospitals collect, test and process their own blood inventory. Type 2 hospitals order their blood from TRCS and their inventory is replenished daily by TRCS. If the required blood product is not available in the inventory of a Type 1 hospital, hospital first asks other Type-1 hospitals, if blood is not available in other hospitals they ask TRCS. If the hospital is a Type 2, they ask TRCS when the required blood type is not in their inventory.

Outdated blood disposal is a crucial operation both at TRCS and at hospitals. Both decentral and central systems need to check their inventory periodically for determining expired products. Blood and all its components are perishable products which have different shelf lives. To illustrate, red blood cells can stay alive for a 42-day period of time, frozen plasma cells can stay alive for 2 years while platelets live for 5 to 7 days, once the facility that collected them has completed their tests. The responsible personnel check the blood products' expiration date and dispose the ones which are outdated.

In blood processing centers at first each donor's suitability is tested, if a donor is not suitable (2% probability) the donation is disposed; otherwise the blood is divided into its components and sent to appropriate storages. In addition to the division of blood to different components, blood can be categorized into 8 subgroups based on blood groups which have varying frequencies from population to population. Blood demands of patients can be satisfied in case that the blood group and other blood characteristics match. These demands are satisfied from hospitals' blood stocks, so it is crucial to keep sufficient stock in hospitals.

Preparation process varies between different blood products. RBC demands are prepared one day prior to transfusion but when the time comes for transfusion the product may not be needed anymore with 60% probability. If RBC is not used product can be returned to the relevant storage. Plasma demands are prepared instantly with a 20 minutes defrosting process. PLT demands are prepared instantly and it does not require any special process. In contrary to the red blood cells case all other products are disposed if they are not used when being demanded.

Typically, before transfusion, the red blood cells have to pass the cross-match tests which determine the blood availability for a specific patient. In this research, cross match tests are ignored. The ratio of the blood which is considered as waste as a result of the cross-match test is approximately 1% - 2% which is a negligible percentage in comparison to other components in the system. This 1% - 2% waste will not affect the internal circulations of the system, number of wasted blood and total cost by a significant amount.

The blood donation amount is highly stochastic due to its nature. Sometimes the natural disasters impulse the empathy of human beings and the donation ratios grow up sharply while in some other cases considered as normal cases these ratios fall down. In addition to donation ratios, the demand amounts and frequencies are also stochastic values and to the best of the knowledge one cannot say the demand would be exactly equal to some amount on a specific day. In order to study this highly stochastic system a simulation approach is preferred. The simulation model is used to assess the number of unsatisfied demand due to blood shortages, wastages and also the total system cost under different scenarios and different donation levels.

3.2 Simulation Model

Ankara, Turkey is taken as the base of our simulation model. The data set used in this research is gathered from different resources. The information about the demand values and process durations are collected from a Type 1 Hospital's annual reports that contain daily amount of demands for a year. This demand data contains the data for all the possible blood products which includes blood groups. The process durations, TRCS prices and blood product production costs are taken based on the information taken from experts. Ratios of blood group demands are adopted from TRCS's statistics. In Ankara, hospitals to meet their demand by their own stocks, is a more expected situation which is approved by experts. In other words, usually there is no need for hospitals to search blood products from different sources, stocks can usually meet demand. In addition, in Ankara Type 1 hospitals are located close to each other which make the transfer time between Type 1 hospitals short enough to not affect the expiration time of a blood product. Therefore, in the decentral case Type-1 hospitals share one depot and Type-2 hospitals share another depot (TRCS depot). Information about the number of donations per day is adopted from TRCSs' reports which contain the monthly donation numbers for a period of 6 years. The distribution of daily donation amounts is generated through this monthly data and expert opinion. Ratios of blood group donations are adopted from TRCS's statistics. In addition to the data mentioned above, the blood bank process durations are utilized which were presented in Baesler et al. (2014). Blood product production process distributions are generalized with the generated data from the simulation model which is established with process distributions presented in Baesler et al. (2014).

The simulation model is developed in ARENA 14.0 and solved based on the real-life data gathered from different resources as illustrated in Section 3.1.

The simulation model of centralized blood supply chain network is shown in Figure 2 below. The simulation model starts with donations, and then each donation is transferred from donation points to regional TRCS center where biological tests and centrifuge occurs. Because of different processing needs each blood product is modeled with a sub-model and the sub-model of RBC is shown in Figure 3 below. Also in the simulation model, each blood type of each product is stored in a different storage, and for daily replenishments and shortages products are transferred from TRCS to hospital storages where they are stored in the same way. When demand occurs, it is tried to be matched if there is enough stock at hospital's storage. If there is not enough product with demanded properties, other storages, TRCS and other hospitals' storages, are investigated. If demand can be matched with the requested blood product transfusion process begins, and each transfusion process is modeled with a sub-model.

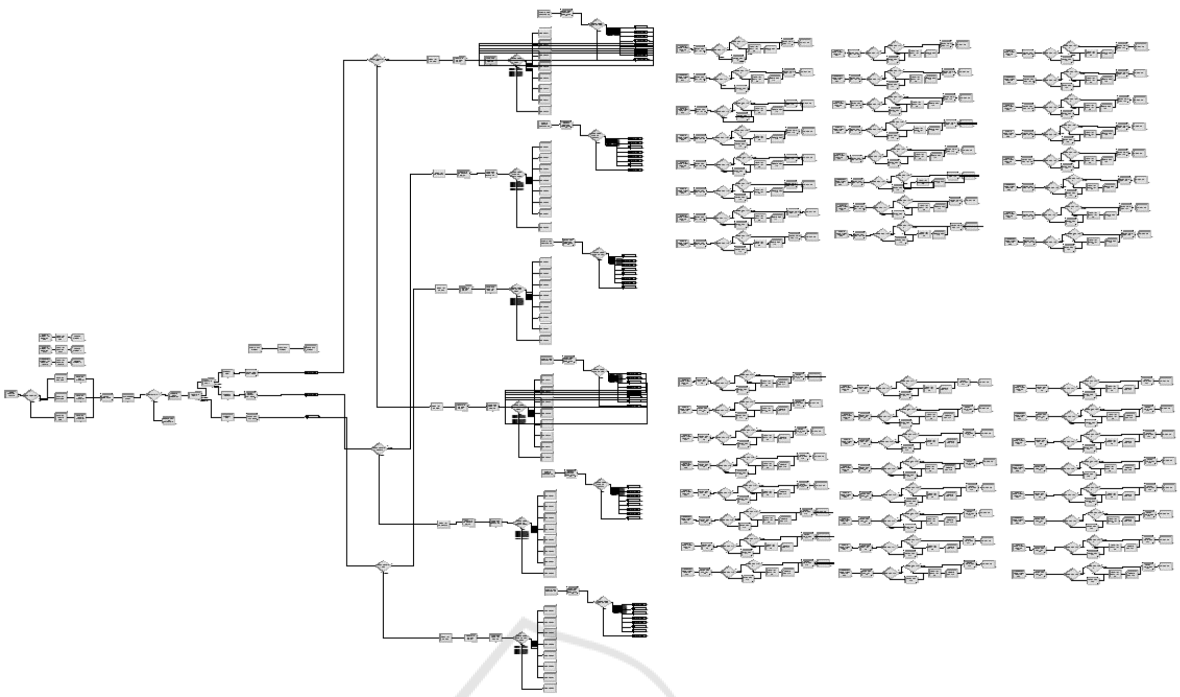

Figure 2: Simulation model for centralized system.

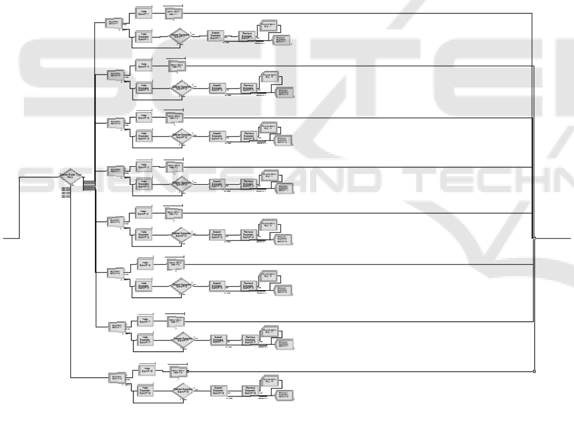

Figure 3: Sub-model for producing RBC.

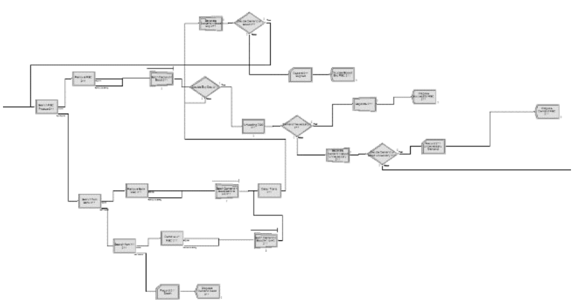

Figure 4: Sub-model for RBC transfusion.

Sub-model of RBC's transfusion process is shown in Figure 4.

The blood donation data gathered from TRCS only includes the donations which are from central Ankara. Computations show that central Ankara donations can only satisfy %50 of the demand for each blood component. The results of the simulation model also confirm this fact. However in reality, TRCS also gathers additional donations which come from the close provinces. Only with the addition of these donations, Ankara can satisfy its blood demand completely.

For further analysis of the system multiple levels of donation ratios (donation/demand) are considered which represent the cases where the demand increase or donations decrease. For each scenario donation rates are gradually increased to fulfill the demand and its effects to objectives are observed. Hourly donation ratios (donation/demand within the same hour) are taken as different percentages that are (100%, 87.5%, 75%, 62% and 50%). Expert opinion was obtained in validation stage and the model showed high face validity. The model was run for 365 days and 6 replications with a warm of period of 1000 hours.

4 NUMERICAL RESULTS

The performance measures which are assessed include number of expired products and the total cost

of the system. In this case study, the demand rate is kept constant while the donation ratios are changed.
The first performance measure is the blood products that expired which may mean that the supply chain is not good structured enough, and it is a problem that needs to be addressed on. In the decentralized system, there are less expired blood products than the centralized system. In the centralized system, Type 1 hospital storages usually contain extra blood product than needed because of the new emergency stock legislation. Due to a high amount of stock held until the blood product is identified by other hospitals and transfer process is completed, the blood can expire. Therefore, blood products may expire before being used and centralization with high amount of base stocks is not a good scenario for this performance measure as shown in Figure 5.
The second performance measure is total cost. This measure is considered for Type 1 hospitals and for the whole system. TRCS produces blood products with the same cost as Type 1 hospitals and sells these blood products with the price of 3 times of its production cost. That's why total cost increase for Type 1 hospitals in centralized scenario is expected while total cost of the system increases as well. The only factor of total cost is not the blood product production; there are disposal costs of expired blood products which is costly because of the type of the product. As previously shown in the decentralized system there is less expired blood products than the centralized system, so total cost of the system is expected to be less in the decentralized system. Decentralized scenario gives better results than centralized scenario in this performance measure which is shown in Figure 6.
For these performance criteria, the best scenario is the decentralized one which has lower expiration rate and lower total cost. So, it is better to have a decentralized system for Type 1 hospitals which are capable of supplying their own demand by their laboratories.

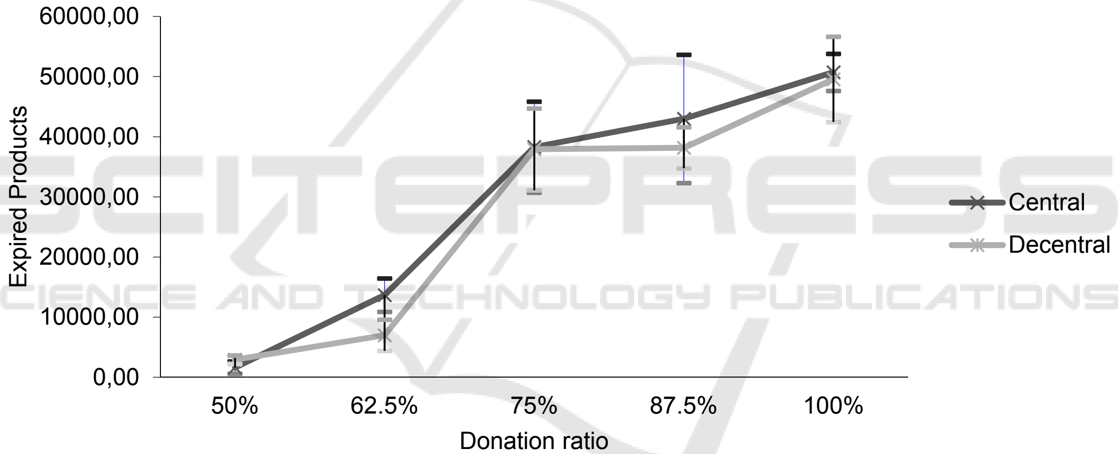

Figure 5: Number of expired products of central and decentral systems.

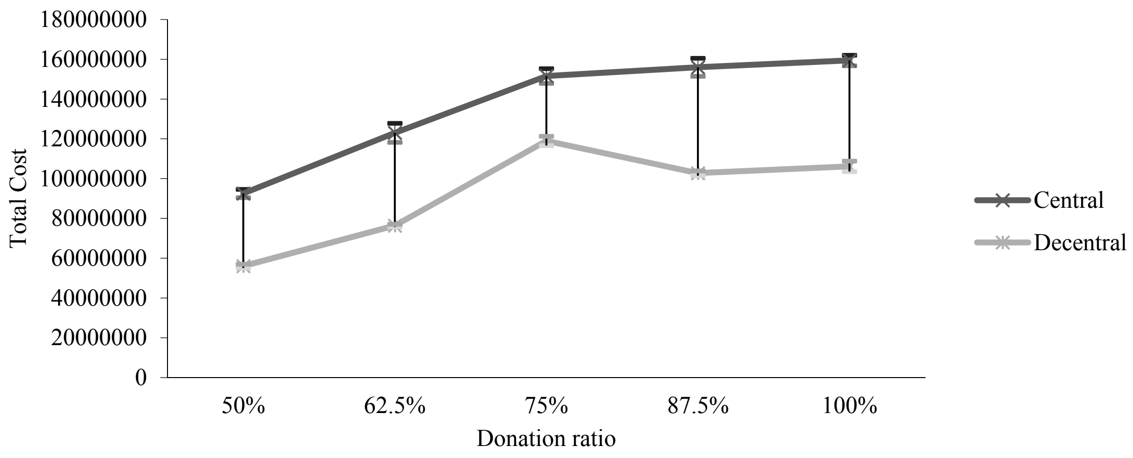

Figure 6: Total cost of central and decentral systems.

5 CONCLUSIONS

Blood supply chain policies become more and more important nowadays, because of the increasing population rate, widespread epidemics, disasters and terrorist attacks which increase the need of blood products. Therefore, centralization policy and its effects on system have great importance in terms on both cost and human life.

In this research, the impact of centralization and decentralization policies on blood supply chain network's total cost and blood wastages/expired blood products are investigated with simulation. Ankara, Turkey blood supply chain system is used as the base of the simulation model. With aim of eliminating deficiencies in previous research each blood product and blood group is included in the blood supply chain network which is modelled from donation to transfusion as a whole

Results showed that decentralized system is better for performance criteria like, number of expired products of hospitals and TRCS, and total cost of the system. Actually, the decentralized scenario is a kind of a semi-decentralization which is also preferred by USA. In USA system hospitals, which are capable of producing blood products from their donations supply blood to system with Red Cross. With adoption of this semi-decentralized blood supply chain system, type 1 hospitals' having idle blood product production facilities can be prevented. Results also showed that base stock levels of the hospitals should be determined carefully in order to the centralized system work efficiently. The current base stock levels lead into a greater number of expired products.

For future work, the effects of different base stock levels on performance measures can be evaluated. Optimal stock levels of different stock policies can be determined with a mathematical programming model and then the impact of centralization and decentralization policies on blood supply chain network can be observed with use of the simulation model which is developed in this research.

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