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Designing and optimizing a sustainable supply chain network for a blood platelet bank under uncertainty

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ABSTRACT

This paper develops a possibilistic optimization model for a multi-period and multi-objective sustainable blood supply chain with uncertain data due to an uncertain condition during a disaster and after it. The components considered in this study are donor groups, blood collection facilities, distribution centers, and hospitals as the demand points. The minimization of the total cost, environmental effects, in addition to the maximization of social effects are considered as the objectives to increase the efficiency of the network. Then ϵ-constraint method is utilized to transfer the multi-objective mathematical model to a mono objective one. In order to validate the proposed model, some test problems are investigated. For large-sized problems, a meta-heuristic algorithm, namely simulated annealing (SA) is provided for solving the model. Some numerical examples are solved and evaluated and the performance of the SA algorithm is compared with harmony search (HS) algorithm. Finally, the obtained results are discussed, and the conclusions are provided.

1. Introduction

Supply chain network design or SCND has a prominent effect on the performance of the supply chain. It deals with many aspects of the network, affecting its qualitative and quantitative performances such as numbers and locations of facilities, capacities of them as well as information and material flow allocations. Network configuration cannot be changed in short terms because of the significant expenses and the required time. The SCND is an important issue in tactical and operational decisions in the supply chain management (Devika et al., 2014; Fu and Fu, 2015; Amin et al., 2017).

The growing concerns to meet environmental, social, and legislative requirements are forcing companies to consider the impacts of sustainable supply chain (SSC) design on the environment and society (Govindan et al., 2014). An important concept in sustainability is Corporate Social Responsibility (CSR). CSR is the effect of corporate activities on diverse groups which includes environmental conservation, workplace safety, human rights, right conditions for workers, etc. (Carter and Jennings, 2002).

Human blood is a vital and rare resource. It is extracted from the human body and currently, there is no other product or superseded chemical process that can be replaced with human blood. In addition, from all donated blood units, only a small amount is usable, and there is a required time interval between a person's blood donation and the next turn. Thus, in the required time, the body can rebuild the lost blood.

Among the various blood products, platelets have a high degree of perishability because they can be saved just five days before deteriorating. For this reason, platelets are valuable resources. They are needed only in particular cases, but when they are required, we face circumstances in which numerous units should be transfused at one time. As a result, the demands of platelets are highly changeable (Abdulwahab and Wahab, 2014).

In several cases, supply chains include uncertain factors which have big impacts on the chains. As a result, it is essential to consider uncertainty in the design and optimization of the supply chains (Bashiri et al., 2012). In a supply chain, a disaster, one of the uncertainty sources, occurs when one or more activities of the members of the chain are interrupted that lead to the major disruptions in the normal flows of the services and the products (Glenn Richey Jr et al., 2009).

The rest of the paper is organized as follows. Section 2 provides a brief literature review on the prior research pertinent to sustainable

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supply chain network and blood supply chain network design problems. Section 3 of this paper includes the definition of the problem and the mathematical formulation. In Section 4, the suggested solution methodology is given. In Section 5, implementation and evaluation of the proposed model are discussed. Finally, the conclusions and future research of the presented model are provided in Section 6.

2. Literature review

Javid and Azad (2010) stated that the design of a distribution network includes location–allocation, vehicle routing, and inventory problems. Some papers in the literature have integrated two of these problems. Some examples include location-routing problems (LRP) (Govindan et al., 2014), location-inventory problems (LIP) (Daskin et al., 2002; Shen et al., 2003), inventory-routing problems (IRP) (Federgruen and Zipkin, 1984). In addition, many studies have investigated healthcare facility location–allocation problems (Daskin and Dean, 2005). It is noticeable that SCND may have different designs including open loop, closed-loop, reverse network, or integrated design (Wei and Zhao, 2011; Ene and Öztürk, 2014; Jabbarzadeh et al., 2014).

To our knowledge, there are still a limited number of organizations that have considered the sustainable operations and processes along economic, environmental, and social aspects which are mentioned as Triple Bottom Line (TBL) in the rest of this article. At the beginning, economic aspects of sustainability were emphasized in the related papers. However, the concept of sustainability in supply chain management has been developed recently focusing on social and environmental sides (Baud-Lavigne et al., 2014). Some review papers have been published in this field such as Hassini et al. (2012), Masoumik et al. (2014), and Williams et al. (2017). Moreover, a few authors (e.g., Fukui and Miyoshi (2017) and Wang et al. (2017)) have investigated the impacts of governmental carbon emission tax decisions on the fuel consumption and carbon emissions caused by organizations operations.

De et al. (2016) presented a sustainable ship routing problem under uncertainty and considered environmental impacts caused by carbon emissions and fuel consumption. They restricted those impacts by defining some constraints and upper limits for the total fuel cost, fuel consumption, and carbon emission level to maintain a sustainable ship routing. De et al. (2017) developed a Maritime inventory routing problem as a mixed integer non-linear programming model incorporating the routing and scheduling constraints. In order to consider the sustainability aspects, the relation between the fuel consumption and vessel speed as a non-linear constraint is defined. Then, they employed an effective search heuristics named Particle Swarm Optimization for Composite Particle (PSO-CP) and validated this approach by using other algorithms such as Differential Evolution (PSO-DE), basic PSO and Genetic Algorithm (GA).

Pishvaee and Razmi (2012) introduced an interactive fuzzy method for solving a multi-objective optimization model based on environmental factors. The model minimizes the total environmental effects and the total cost. Validi et al. (2015) presented an effective method for solving an NP-hard model of a sustainable distribution supply chain and considered a set of real paths between the customers and the plants to minimize carbon dioxide emissions and their network costs. The other good practice in a green supply chain can be found in Wang et al. (2011), who studied an SCND problem with environmental considerations and presented a multi-objective optimization model that considers both total cost and environmental impacts in the supply chain. Zhalechian et al. (2016) presented a new sustainable closed-loop location-routing-inventory model under mixed uncertainty and proposed stochastic-possibilistic programming and hybrid meta-heuristic algorithms to solve the model. Furthermore, Zhalechian et al. (2017a) introduced a new multi-objective model for a hub location problem an $M/M/c$ queuing system under uncertainty that considers economic, responsiveness and social responsibility at the same time.

The initial investigations about the supply chain management of perishable goods in general, and blood products, in particular, began in the 1960s. Some primary studies were published in the 1970s and the 1980s (e.g., Prastacos, 1984; Pegels and Jelmert, 1970). Pierskalla (2005) studied some models for allocating transfusion centers and donor groups to the community blood centers, which aims to specify the quantity of the community blood centers in the area, the geographical locations of them, and meeting the current demand according to the supply. Cetin and Sarul (2009) proposed an optimization model with two objectives to determine the locations of some blood banks in a blood supply network developing a goal programming method. In their model, the entire fixed charge of the blood bank chain, and the summation of the traveling distances among the blood banks and the demand points are minimized. One of the major distinctions between a common supply chain and a blood one is the perishability of the blood products. Proper preparation of blood products for patients requires many steps.

Beliën and Forcé (2012) presented a comprehensive review in this field, and examined some papers up to the year 2010, and categorized them. One of their categories is related to the different kinds of blood products. Whole blood, and red blood cells (Duan and Liao, 2014) which have significant demands, have been mentioned in some articles. They are used in surgery, anemia, and premature children (Haijema et al., 2007; Zhou et al., 2011; Ghandforoush and Sen, 2010). Platelets are used for cancer treatment and have a short lifetime. Plasma is the other product that is almost not perishable and is used for some cases such as surgery, burn, and diseases of the liver. The other part is frozen blood that mainly includes the frozen red blood cells. Few papers (e.g., Arvan et al., 2015) considered four blood products such as red blood cells, plasma, platelets, and whole blood. Gunpinar and Centeno (2015) concentrated on decreasing the shortage of the blood products in the hospitals and used the first-in-first-out (FIFO) policy in decisions related to the inventory. They considered the patient's demands based on the needs for 'young' blood (Platelets with less than 3 days old), or 'any' blood separately. It is noticeable that some studies have considered a regional blood bank instead of a blood supply chain (Şahin et al., 2007; Gregor et al., 1982). Some studies have addressed the sustainable blood bank supply chain network design (Nagurney et al., 2012; Nagurney and Masoumi, 2012).

One of the newly published papers which consider routing aspect is the research of Gunpinar and Centeno (2016). They presented an integer programming model which determines the optimal routings for bloodmobiles. The model aims to simultaneously determine the number of bloodmobiles, and minimize the total distance traveled by vehicles. They used CPLEX solver and branch-and-price algorithm.

Ensafian et al. (2017) developed a stochastic multi-period mixed-integer model in the platelet supply chain. In addition, they incorporated the age of platelet and ABO-Rh priority matching rules in their model. They aimed to increase the quality and safety of platelet transfusion services. Afterwards, they employed a two-stage stochastic programming model. Kazemi et al. (2017) presented a new mixed-integer programming model for a blood inventory-routing problem that delivers blood products from blood centers to demand centers (e.g., hospital blood banks). They proposed branch-and-cut and robust possibilistic programming methods to solve their problem.

The main optimization model of this paper is based on the mathematical formulation of Wei et al. (2015) in the aspect of considering an integrated sustainable supply chain under uncertainty and human relief. Wei et al. (2015) have encouraged actors that are involved in a disaster relief process to utilize the techniques and methods they introduced in their paper, to optimize the operations. We observe that there was a gap in the literature about simultaneous consideration of TBL and studying the blood banking network design before the paper of Wei et al. (2015). In this regard, we have covered some gaps in the blood supply chain network design literature with the following main research contributions:

- Developing a new comprehensive blood platelet supply chain design model (including inventory, location, allocation, routing) by integrating sustainability into the decision-making process.