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A web-based DSS for fuzzy distribution network optimization

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Abstract

Purpose – Distribution network design (DND) has become an important strategic decision for supply chain managers with increasing competitive nature of the industry nowadays. The purpose of this paper is to propose a web-based decision support system (DSS) for fuzzy distribution network optimization. For this purpose, a web-based DSS using fuzzy linear programming model is proposed to solve DND problem under uncertainty and a framework is created to optimize a distribution network.

Design/methodology/approach – In this study, the fuzziness in distribution network optimization is addressed. Fuzzy linear programming is used in a DSS to consider the uncertain and imprecise data. A web-based DSS architecture is presented. Furthermore, as an application, distribution network optimization is conducted for a company in the ceramics industry.

Findings – By using this DSS, the optimal transshipment amounts in the distribution network and the required facility and distribution centers can be determined for different fuzziness levels. In fact, for different uncertainty levels of input parameters, the planner can understand the range of optimum network planning costs. Based on the results of this study, planners will be able to decide how to develop the distribution network under uncertain demand.

Originality/value – Reviewing previous research in the related literature revealed that there are no studies presenting a web-based DSS using fuzzy linear programming model to solve this type of problems under uncertainty.

Keywords Supply chain, Distribution network optimization, Fuzzy linear programming, Web-based decision support system

Paper type Research paper

1. Introduction

A supply chain consists of a series of activities and organizations in which materials move through in their journey from initial suppliers to final customers (Waters, 2012). Due to increasing competitive nature of the industry today, it is very critical for organizations to have supply chains work as planned, with smooth and uninterrupted flows of materials from initial suppliers to final customers. Supply chain network design deals with the structure of a chain's cost and performance values and determine important decisions such as distribution, transportation and inventory management policies (Farahani *et al.*, 2014). Nowadays, customers are tightening their requirements in terms of throughput time and perfect-order delivery while demanding continuous reductions in supply chain costs. Distribution network is a branch of supply chain that is designed to bring a set of final products from the producers to the final customers (Costantino *et al.*, 2013). At this point, distribution network design (DND) emerges as a major problem faced by the supply chain managers. DND is an important strategic decision that companies must make to ensure that required raw materials and

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components can be distributed efficiently from their suppliers to their manufacturing plants and warehouses as well as the final products to their customers (Michelle, 2005). DND problem consists of selecting locations to build factories, warehouses, and distribution centers; assigning customers to serving facilities; and interconnecting facilities by flow assignment (Miranda and Garrido, 2009). While analyzing a distribution network, two important points should be considered (Ambrosino and Scutella, 2005):

(1) Optimization of the flows of goods: in this case, an existing distribution network is considered and the flows of goods through the network are optimized.

(2) Improvement of the existing network: in this case, the best configuration of the facilities is chosen in the network in order to satisfy the goals of the company, while minimizing the overall costs.

High complexity and multiple factors have to be considered simultaneously when making such a decision. To help decision-makers when dealing with highly complex decisions, several decision support tools, methods and systems (DSS) have been developed (Olmez and Lindemann, 2014). Decision support system (DSS) is a useful tool that makes DND decisions effectively and efficiently. DSSs assist decision makers to obtain data, documents, knowledge or models, increase the number of alternatives examined, achieve better understanding of the business, provide fast response to unexpected situations, offer capability to carry out ad-hoc analysis, facilitate improved communication, achieve cost and time savings, achieve better decisions, facilitate more effective teamwork, achieve better use of data resources, and present graphical information (Subsorn *et al.*, 2008).

The global internet and the world wide web are now the primary enabling technologies for delivering computerized decision support. They have transformed the design, development, implementation, and deployment of DSSs. There are many on-going efforts to develop and implement web-based DSS in various areas such as health care, private companies, government, and education (Bhargava *et al.*, 2007).

Web-based DSS provides benefits to decision makers in terms of wide accessibility, ease of use, portability, effectiveness, and time reduction (Shim *et al.*, 2002). Furthermore, web-based DSS can eliminate limitations such as poor maintainability, poor flexibility, and less reusability (Xie *et al.*, 2005).

Uncertain and imprecise data increase the complexity of decision-making problems. Fuzzy set theory, which has been widely applied in different disciplines such as operations research, management science, control theory, and artificial intelligence, is one of the solutions to deal with uncertainty in decision making (Shih, 1999). Fuzzy mathematical programming is one of the most popular decision-making approaches based on fuzzy set theory.

The purpose of this study is to present a web-based DSS for distribution network optimization with fuzzy mathematical programming basis. The rest of this paper is organized as follows. In Section 2, the literature on DND is reviewed. In Section 3, fuzzy linear programming method is explained. In Section 4, web-based DSS architecture and fuzzy mixed integer linear programming model (MILP) are described. Application of a company in Turkish ceramics industry is given in Section 5. Finally, conclusions are made in Section 6.

2. Literature review

Network design mathematical models have been constructed based on facility location theory. Recent literature reviews on supply chain management and facility location are presented by Arabani and Farahani (2012), Van der Vaart and van Donk (2008), Gebennini *et al.* (2009) and Melo *et al.* (2009). Literature presents several studies on models and methods for the design and control of complex distribution systems.

Pyke and Cohen (1993) developed a mathematical programming model by using stochastic sub-models to design an integrated supply chain that involves manufacturers, warehouses and retailers. The model minimizes the total cost under a service level constraint and replenishment batch sizes. Ozdamar and Yazgac (1997) developed a distribution/production system, which involves a manufacturer center and its warehouses. The proposed model minimizes the total costs such as inventory and transportation costs under production capacity and inventory equilibrium constraints. El-Sayed *et al.* (2010) developed a multi-period multi-echelon forward-reverse logistics network design under risk model. The problem is formulated in a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program. The objective is to maximize the total expected profit. Pishvaee *et al.* (2010) proposed a model for integrated logistics network design to avoid the sub-optimality caused by a separate, sequential design of forward and reverse logistics networks. Schütz *et al.* (2009) presented a supply chain design problem modeled as a sequence of splitting and combining processes. They formulated the problem as a two-stage stochastic program. The first-stage decisions are strategic location decisions, whereas the second stage consists of operational decisions. The objective is to minimize the sum of investment costs and expected costs of operating the supply chain. Ahumada and Villalobos (2009) reviewed the main contributions in the field of production and distribution planning for agri-foods based on agricultural crops. Through their analysis of the current state of the research, they diagnosed some of the future requirements for modeling the supply chain of agri-foods.

Most of the previous studies focusing on uncertainty in logistics network design used stochastic programming methods. Nonetheless, this approach is not appropriate for real-life cases due to insufficient historical data of uncertain parameters and high computational complexity of stochastic programming models. To handle this issue, fuzzy mathematical programming method, which is an efficient tool for handling uncertainty, has been recently used in logistics network design problems. Pishvaee and Torabi (2010) proposed a model which integrates network design decisions in both forward and reverse supply chain networks and also incorporates strategic network design decisions along with tactical material flow ones to avoid sub-optimalities led from separated design in both parts. To solve the proposed possibilistic optimization model, an interactive fuzzy solution approach was developed by combining a number of efficient solution approaches. Qin and Ji (2010) employed a fuzzy programming tool to design the product recovery network. Based on different criteria, three types of optimization models were proposed and some properties of them were investigated. To solve the proposed models, they designed a hybrid intelligent algorithm which integrates fuzzy simulation and genetic algorithm. Liang (2008) developed a fuzzy multi-objective linear programming model with piecewise linear membership function to solve integrated multi-product and multi-time period production/distribution planning decisions problems with fuzzy objectives. Paksoy *et al.* (2012) applied fuzzy sets to integrate the supply chain network of an edible vegetable oils manufacturer. The proposed fuzzy multi-objective linear programming model attempted to simultaneously minimize the total transportation costs. In fuzzy mathematical programming, several models have been proposed to incorporate fuzziness of the objective and constraint functions. Percin and Min (2013) created a fuzzy decision-making methodology for the selection of third part logistics provider (3PL). Creazza *et al.* (2012) proposed a MILP to solve a real networks with multiple-layer, single location-layer, multiple-commodity, and time-constrained logistics. Xu *et al.* (2008) proposed a multi-objective mixed-integer non-linear programming model for the network design problem of Luzhou Co. Ltd. that operates in Chinese liquor industry. Ozgen and Gulsun (2014) designed a two-phase possibilistic linear programming approach and a fuzzy analytical hierarchical process approach and attempted to optimize two objective functions – minimum cost and maximum qualitative factors benefit in supply chain network. Kengpol (2008) developed a DSS for logistics distribution network by combining MILP and AHP. Manzini (2012) designed a DSS for multi-echelon multi-stage multi-commodity and multi-period production, distribution and transportation system.

Reviewing the related literature reveals that there is insufficient number of papers handling the distribution network optimization problem with fuzzy parameters. Additionally, there has not been any published study presenting a web-based DSS using fuzzy linear programming model to solve this problem under uncertainty. In this study, imprecise parameters and fuzzy situation in distribution network optimization is addressed. A web-based DSS architecture is presented. Furthermore, as application, distribution network optimization is conducted for a company in ceramics industry with the consideration of vagueness in customer demand, opening costs of distribution centers and production plants.

3. Fuzzy linear programming method

The difference between fuzzy and conventional mathematical programming approaches is at the point where a fuzzy model exists between a real world optimization problem and usual mathematical model (Inuiguchi and Ramik, 2000). In real world problems, there are usually uncertainties in parameters. Additionally, qualitative constraints and objectives are almost difficult to represent in mathematical forms. In such conditions, a fuzzy solution satisfying the given mathematically represented requirements are very useful in a sense of weak focus in the feasible area. The decision maker can select the final solution from the fuzzy solution considering implicit and mathematically weak requirements (Inuiguchi and Ramik, 2000).

Fuzzy linear programming can be derived by using fuzzy sets as coefficient values in the objective function, constraints or right hand sides of the constraints. There are several methods in the literature to solve fuzzy linear programming models (Verdegay, 1982; Chanas, 1983; Zimmermann, 1991; Julien, 1994; Negoita and Sularia, 1976; Carlsson and Korhonen, 1986; Werners, 1987; Buckley, 1989). In this study, Julien's method is used in the DSS since it provides convenience in computation compared to the other methods. Also, it has less complexity and easy to apply and adapt to problems and takes into account the decisions of the decision makers without creating confusion. The outputs can easily be compared for different uncertainty levels of input parameters. The optimistic and pessimistic perspectives can be considered by decision makers. Zimmerman's method is often used in the literature however, it has disadvantages such as difficulties in application and high complexity.

Julien (1994) transformed fuzzy linear programming problem with the best and the worst linear programming problem at different α-cut levels and obtained the possibility distribution of the optimal objective value. The author associated the α-cut concept with Buckley's (1989) possibility programming to resolve the maximization problem in Equation (1) including fuzzy objective and fuzzy right hand side. Therefore, the crisp linear programming problems in Equations (2) and (3) are solved where the superscript represents an α-cut of the fuzzy parameters and the subscripts L and U are the corresponding lower and upper cuts (Allahviranloo and Afandizadeh, 2008):

$$\widetilde{\text{Max}}\ \ cx \tag{1}$$

s.t.

$$a_i x \underset{\sim}{\leqslant} b_i \quad i = 1, \ldots, m$$

$$x \geqslant 0$$

$$\text{Max}\ \ c_L^\alpha x \tag{2}$$

s.t.

$$A_U^\alpha x \leqslant b_L^\alpha \quad i = 1, \ldots, m$$

$$x \geqslant 0$$

$$\text{Max}\ \ c_U^\alpha x \tag{3}$$

s.t.

$$A_L^\alpha x \leqslant b_U^\alpha \quad i = 1, \ldots, m$$

$$x \geqslant 0$$

When Julien's method is applied to a minimization problem given in Equations (4)-(6) should be considered to determine the interval of the objective value:

$$\widetilde{\text{Min}}\ cx \tag{4}$$

s.t.

$$a_i x \underset{\sim}{\geqslant} b_i \quad i = 1, \ldots, m$$

$$x \geqslant 0$$

$$\text{Min}\ \ c_U^\alpha x \tag{5}$$

s.t.

$$A_L^\alpha x \geqslant b_U^\alpha \quad i = 1, \ldots, m$$

$$x \geqslant 0$$

$$\text{Min}\ \ c_L^\alpha x \tag{6}$$

s.t.

$$A_U^{\alpha} x \leqslant b_L^{\alpha} \quad i = 1, \ldots, m$$

$$x \leqslant 0$$

4. DSS architecture

The DSS called as "Portneo Optimizer" is based on the distribution operations of a production company that provides raw materials from suppliers and sends the products to customers through distribution centers. Production is carried out at production plants using raw materials supplied from different suppliers. The products produced in the plants are sent to distribution centers using different transportation means. The supply chain network is described in Figure 1. The effective supply chain management system involves the following functions:

- planning raw materials supply from suppliers with different transportation means;
- planning product distribution from production plants to distribution centers with different transportation means;
- planning product distribution from distribution centers to customers with different transportation means; and
- demand planning for customers.

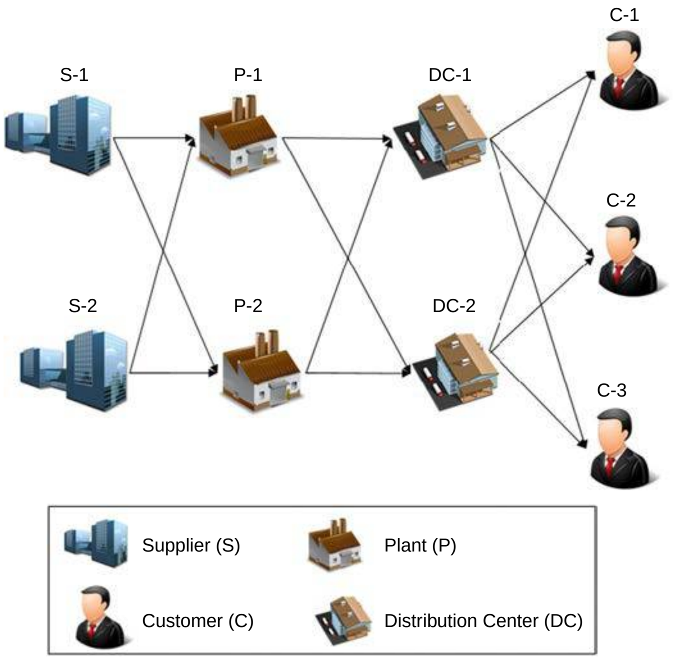

Figure 1. Supply chain network

The DSS components involve database, optimization engine, GIS engine, and user interface. The architecture for the DSS is shown in Figure 2. In the web-based DSS, the databases are built by using MySQL and the user interfaces are created by using Microsoft Silverlight technology. Google maps is used as the GIS engine; in addition, COIN-OR Symphony is used as the open-source optimization solver in the DSS (COIN-OR Symphony Project). The user interfaces are used for data imputation, reporting, and querying as seen in Figures 3 and 4. The fuzzy mixed integer linear model is constructed using the input data and then converted into an .mps file. By using web-based DSS

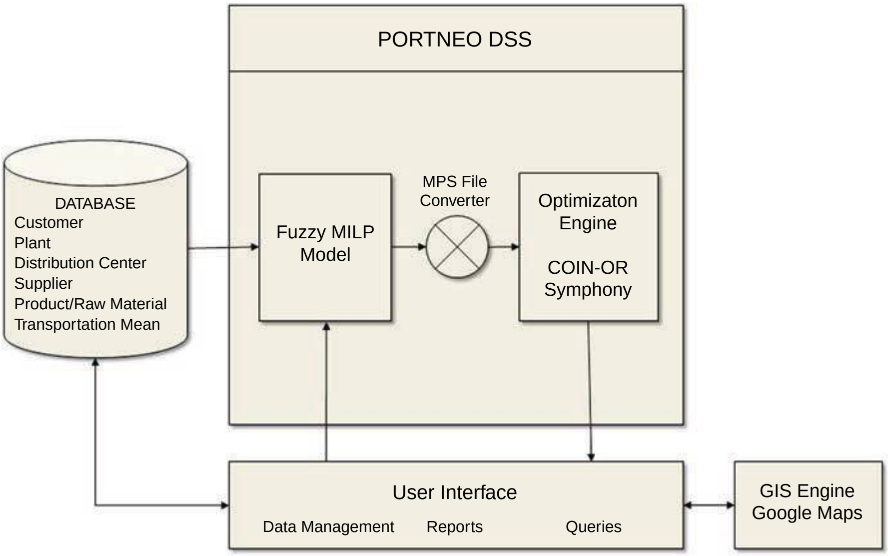

Figure 2.
Portneo DSS architecture

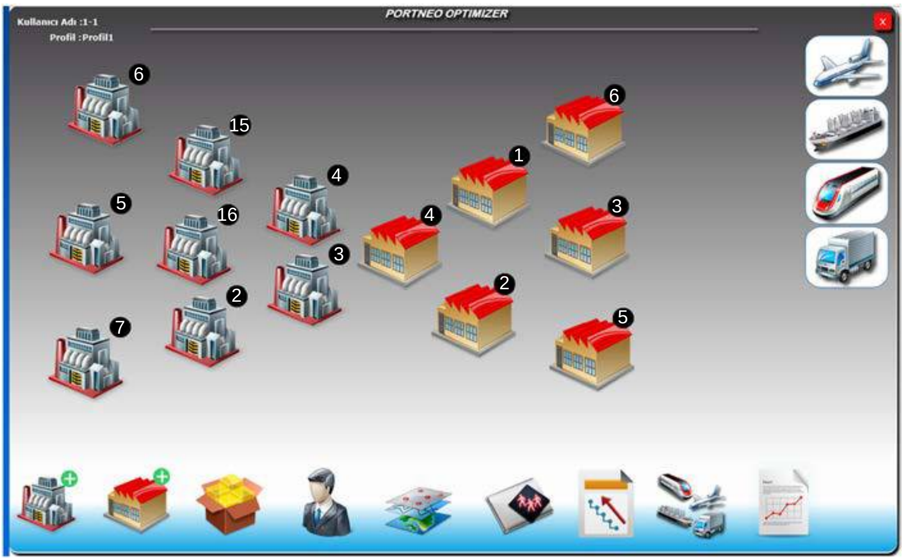

Figure 3.
User interface for network building by drag and drop

Figure 4.
User interface for data input regarding to the plant

framework, it is expected to provide computational performance to users such as, shorter response time to optimize distribution network, higher availability of the computing system in addition, by forming user interfaces and DSS architecture fast data compression is intended.

The .mps file is then used by Symphony and optimization is conducted. The solutions are obtained and the reports are created on the user interface. In the DSS, different scenarios can be conducted using different parameter values. Google Maps is used to determine the exact locations of the facilities and customers and also to calculate the road distance between the two points on the map as seen in Figure 5. It is also used for graphical representation of the supply chain network.

4.1 Fuzzy MILP model

In the DSS, the DND model is described considering a supply chain composed of suppliers, production plants, distribution centers, and customers. Raw materials are sent from suppliers to production plants with different types of transportation vehicles such as trains, trucks, ships, and aircrafts. Products are transported from the plants to the distribution centers. In this model, location and capacity allocation decisions are made for both production plants and distribution centers. Finally, customer demands are met by the distribution centers. Multiple distribution centers may be used to satisfy the customer demand and multiple production plants may be used to replenish distribution centers. In the model, it is assumed that units have been appropriately adjusted such that one unit of input from a supply source produces one unit of finished product. As for customer demand, fixed costs of opening plants and distribution centers have fuzzy values; the other parameters have crisp values in the model. The parameters of the model are given below:

i is the plant; j is customer; e is distribution center; h is supplier; m is total number of customer demand points; n is total number of potential production plants; l is total number of suppliers; p is total number of transportation vehicle; t is total number of

Figure 5.
User interface for location determination using Google maps

potential distribution center locations; $\tilde{D}_j$ is annual demand from customer j; K_i is potential capacity of production plant at site I; S_h is supply capacity at supplier h; R_p is transportation capacity at vehicle p; W_e is potential distribution center capacity at site e; $\tilde{F}_i$ is fixed cost of opening a plant at site i; $\tilde{f}_e$ is fixed cost of opening a distribution center at site e; c_{hip} is cost of shipping one unit from supplier h to factory i with transportation vehicle p; c_{iep} is the cost of producing and shipping one unit from production plant i to distribution center e with transportation vehicle p; and c_{ejp} is the cost of shipping one unit from distribution center e to customer j with transportation vehicle p.

The goal of the DND model is to identify the locations of production plants and distribution centers as well as transportation vehicles and quantities to be shipped between various points that minimize the total fixed and variable costs. The decision variables are given below:

y_i is the 1 if the production plant is located at site i; 0, otherwise; y_e is 1 if the distribution center is located at site e; 0, otherwise; Q_{hip} is quantity shipped from supplier h to production plant at site i with transportation vehicle p; Q_{iep} is quantity shipped from production plant at site i to distribution center e with transportation vehicle p; Q_{ejp} is quantity shipped from distribution center e to customer j with transportation vehicle p.

The problem is formulated as a mixed integer linear program:

$$\text{Min} \sum_{i=1}^{n} \tilde{F}_i y_i + \sum_{e=1}^{t} \tilde{f}_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n}\sum_{p=1}^{s} c_{hip} Q_{hip} + \sum_{i=1}^{n}\sum_{e=1}^{t}\sum_{p=1}^{s} c_{iep} Q_{iep} + \sum_{e=1}^{t}\sum_{j=1}^{m}\sum_{p=1}^{s} c_{ejp} Q_{ejp} \tag{7}$$

st.

$$\sum_{i=1}^{n}\sum_{p=1}^{s} Q_{hip} \leqslant S_h \text{ for } h = 1, \ldots, l \tag{8}$$

$$\sum_{h=1}^{l}\sum_{p=1}^{s} Q_{hip} - \sum_{e=1}^{t}\sum_{p=1}^{s} Q_{iep} \geqslant 0 \text{ for } i = 1, \ldots, n \tag{9}$$

$$\sum_{e=1}^{t}\sum_{p=1}^{s} Q_{iep} \leqslant K_i y_i \text{ for } i = 1, \ldots, n \tag{10}$$

$$\sum_{i=1}^{n}\sum_{p=1}^{s} Q_{iep} - \sum_{j=1}^{m}\sum_{p=1}^{s} Q_{ejp} \geqslant 0\text{for} \tag{11}$$

$$\sum_{j=1}^{m}\sum_{p=1}^{s} Q_{ejp} \leqslant W_e y_e \text{ for } e = 1, \ldots, t \tag{12}$$

$$\sum_{h=1}^{l}\sum_{i=1}^{n} Q_{hip} + \sum_{i=1}^{n}\sum_{e=1}^{t} Q_{iep} + \sum_{e=1}^{t}\sum_{j=1}^{m} Q_{ejp} \leqslant R_p \text{ for } p = 1, \ldots, s \tag{13}$$

$$\sum_{e=1}^{t}\sum_{p=1}^{s} Q_{ejp} = \tilde{D}_j \text{ for } j = 1, \ldots, m \tag{14}$$

$$y_i, y_e \in \{0, 1\}, Q_{hip}, Q_{iep}, Q_{ejp} \geqslant 0 \tag{15}$$

5. Application

A company in Turkish ceramics industry plans to design its distribution network with consideration of vagueness in customer demand and opening costs (Ustundag and Cevikcan, 2012). The goal is to obtain the optimal transshipment amounts among suppliers, production plants, distribution centers and customers as well as making decisions to open alternative production plants and distribution centers using the DSS. Related capacity parameters and required transportation costs for the problem are given in Tables I and II, respectively. Demand levels and opening costs for production plants and distribution centers are expressed as fuzzy triangular numbers since they

Location	Product equivalent capacity
S-1	20,000
S-2	24,000
S-3	25,000
P-1	120,000
P-2	90,000
DC-1	30,000
DC-2	35,000
DC-3	33,000
DC-4	28,000

Table I.
Capacity parameters

	P1	P2	DC1	DC2	DC3	DC4	C1	C2	C3	C4	C5	C6
S1	140	420										
S2	160	400										
S3	500	450										
P1			210	420	570	840						
P2			400	110	220	410						
DC1							180	230	430	420	710	820
DC2							510	230	360	220	470	520
DC3							730	320	650	490	140	360
DC4							890	550	760	580	170	110

Table II.
Transportation costs ($/unit)

cannot be determined precisely. The upper and lower values of opening costs and demand forecasts for different α-cuts are given in Tables III and IV, respectively.

Results are obtained for the α-cut values of 0, 0.25, 0.50, 0.75, and 1. The computational experiments are conducted on a 1.8 GHz PC with i5 processor and 4 GB RAM on the Microsoft Windows XP operating system. It takes about 6 seconds to find the optimum solution for each experiment. The lower and upper bounds of optimum DND and their related non-zero variables are given in Table V.

As seen in Table V, the upper bound of optimal DND increases with the level of fuzziness (highest value: $62{,}797\times10^3$, α-cut = 0). Inversely, lower α-cut values produces smaller lower bounds (lowest value: $33{,}544\times10^3$, α-cut = 0). In fact, α-cut value can be considered as the level of certainty. The range between the lower and the upper bounds is inversely related to α-cut value. The underlying reason of this fact is that the range of

	U/L	P-1	P-2	DC-1	DC-2	DC-3	DC-4
1	–	1,500	1,000	440	320	260	280
0.75	L	1,388	925	407	296	241	259
	U	1,613	1,075	473	344	280	301
0.5	L	1,276	850	374	272	221	238
	U	1,725	1,150	506	368	299	322
0.25	L	1,163	775	341	248	202	217
	U	1,838	1,225	539	392	319	343
0	L	1,050	700	308	224	182	196
	U	1,950	1,300	572	416	338	364

Table III.
Opening costs for production plants and distribution centers (1,000$)

fuzzy parameters (demand and activating costs) gets wider as the level of vagueness increases. The lower bound has a range of ($33,544 \times 10^3$, $44,326 \times 10^3$), whereas the upper bounds has a range of ($51,514 \times 10^3$, $62,797 \times 10^3$). From the distribution quantity aspect, upper bounds provide more non-zero variables of distribution quantity since upper bound models have higher demand values due to the right hand side values in constraints. In addition, activating decisions for plants and distribution centers are not sensitive to fuzzy parameters. All the plants and distribution centers are opened for each scenario, except for distribution center 4. Only for the α-cut value of 0, the distribution center 3 is not opened at the upper bound level. However, the plants 1 and 2 are opened for all the α-cut values. Finally, the results indicate that opening the distribution centers 1-2-3 and plants 1-2 are necessary to minimize the total supply chain costs. The uncertainty in demand forecasts and opening costs does not influence this decision as seen in Table V. In addition, based on a pessimistic view, the total cost value can be considered as $62,797 \times 10^3$. On the contrary, based on an optimistic view, it can be considered as $33,544 \times 10^3$. Thus, it is clear that the cost values cannot go beyond these limits with the given input values.

This study provides a risk perspective to the DND problem. The decision maker can integrate the uncertainty into the problem and calculate the upper and lower bounds of cost values. Additionally, different optimum scenarios can be considered regarding to opening new facilities.

6. Conclusion

DSSs facilitate a wide variety of decision tasks including information gathering and analysis, model building, sensitivity analysis, collaboration, alternative evaluation,

α	U/L cut	C-1	C-2	C-3	C-4	C-5	C-6
1	–	14,000	9,000	9,000	12,000	9,000	8,000
0.75	L	12,950	8,325	8,325	11,100	8,325	7,400
	U	15,050	9,675	9,675	12,900	9,675	8,600
0.5	L	11,900	7,650	7,650	10,200	7,650	6,800
	U	16,100	10,350	10,350	13,800	10,350	9,200
0.25	L	10,850	6,975	6,975	9,300	6,975	6,200
	U	17,150	11,025	11,025	14,700	11,025	9,800
0	L	9,800	6,300	6,300	8,400	6,300	5,600
	U	18,200	11,700	11,700	15,600	11,700	10,400

Table IV. Demand forecasts (product units)

	Up./Low. cut	Total cost (1,000$)	Opening DCs	Opening plants
1	–	47,920	1-2-3	1-2
0.75	Lower	44,326	1-2-3	1-2
	Upper	51,514	1-2-3	1-2
0.5	Lower	40,732	1-2-3	1-2
	Upper	55,150	1-2-3	1-2
0.25	Lower	31,138	1-2-3	1-2
	Upper	58,877	1-2-3	1-2
0	Lower	33,544	1-2-3	1-2
	Upper	62,797	1-2	1-2

Table V. Lower and upper bounds of optimized distribution network and decision implementation in daily business activities. They are increasingly integrated into business processes and information systems. Since the progress of internet technology enhances the capability and usability of DSSs, these systems are much more adopted by the managers in different industries.

In this study, a web-based DSS using fuzzy linear programming is proposed for distribution network optimization. Furthermore, an application is conducted for a company in Turkish ceramics industry.

A user friendly, web-based DSS architecture framework is presented. Furthermore, as an application, this system is designed to manage and optimize distribution network for companies under the consideration of α-cut values which indicate vagueness in customer demand, opening costs of distribution centers and production plants. Hence, the decision maker can handle the DND problem with a risk viewpoint using the proposed DSS. The uncertainty can be easily integrated into the problem and the upper and lower bounds of cost values can be calculated. Additionally, by using the web-based DSS, users can easily adapt the system and interpret the results visually.

Its visual capabilities and ease of use are the superiorities of the proposed DSS. The advantage of using fuzzy linear programming is the incorporation of uncertainty of customer demand levels and activating cost for plants and distribution centers. The optimal transshipment amounts in the distribution network and the required facility and distribution centers can be determined for different fuzziness levels.

According to the uncertainties influencing the distribution network, fuzzy numbers are used to model the problems. Fuzzy logic helps distribution network planners to know the value of membership degree of development plan in the optimum set. In fact, the planner can understand the range of optimum network planning costs for different uncertainty levels of input parameters. Based on the results summarized in this study, planners can decide how to develop the distribution network in case of imprecise demand data.

A possible avenue for future research is implementing different fuzzy linear programming methods in the DSS for DND.

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Further reading

The Computational Infrastructure for Operations Research (COIN-OR) Symphony Project: https://projects.coin-or.org/SYMPHONY

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