

## Uncertain Supply Chain Management

homepage: [www.GrowingScience.com/uscm](http://www.GrowingScience.com/uscm)**Optimizing government costs of supporting periodical publications through robust supply chain network redesign with the consideration of social welfare****Ali Asghar Emadabadi<sup>a</sup>, Ebrahim Teimoury<sup>a\*</sup> and Fahimeh Pourmohammadi<sup>a</sup>**<sup>a</sup>*School of Engineering, Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran***CHRONICLE***Article history:*

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*Keywords:**Social welfare**Periodical publication**Subsidy payment**Supply chain network redesign**Magazines' subscription***ABSTRACT**

In this paper, two policies are considered for supporting periodical publications by the government: direct subsidy payment to these publications and opening new facilities which could help with integration and reduce delivery costs. For this aim, a mixed-integer linear mathematical model is presented that minimizes total costs while considering social welfare. The robust programming approach developed by Bertsimas and Sim is used to cope with uncertain parameters. In order to validate the model and investigate its applicability and advantages, the magazines' subscriptions in Tehran is selected as a case study. The output of the model demonstrates that when social welfare is not considered, the risk-averted supply chain will focus on low-cost areas of the chain, which are the central areas of Tehran. However, when minimum social welfare is assured, the supply chain pays attention to all areas. Also, the government should increase supply capacity by opening new facilities, and it should differentiate between areas when paying direct subsidies.

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**1. Introduction**

Social justice has been one of the critical issues in societies for centuries. Social justice means to pay equal attention to all aspects of social life (economic, political, social, and cultural), and their main values (wealth, power, and commitment, as well as knowledge) in terms of freedom of actions, equality of opportunities, and conditional inequality in producing and distributing of main values (Rezaei, 2012). One of the issues that must be addressed in today's societies due to the expansion of urbanization is social justice concerning urban public space. David Harvey defines social and spatial justice as a fair allocation of public resources and facilities, in a way to make an awareness among people about their rights, and their various demographic needs (Harvey, 2009; Zarrinpoor et al., 2018). Social justice is succeeded through planning and implementation of social welfare programs. Due to the wide range of activities and programs that take into account social welfare, it has been a controversial issue among experts in different societies. Given the experience of developed countries, the supply of social services must first be implemented by the government, and then followed with more targeted interventions (Un.millennium.project, 2005). Therefore, it can be said that the government is the main provider of social welfare, and social welfare programs are state-owned affairs (Salimi Far et al., 2015). Government policies, including cost policies, tax policies, and laws and regulations could affect various

\* Corresponding author

E-mail address: [teimoury@iust.ac.ir](mailto:teimoury@iust.ac.ir) (E. Teimoury)

economic variables, particularly welfare and poverty (Un.millennium.project, 2005). In this regard, various studies have focused on the role of the government in enhancing social welfare in recent years. These studies can be divided into two categories: first, investigating the impact of macro policies such as fiscal policies (Salimi Far et al., 2015. Rafeei et al., 2018) and Targeted subsidies (Pirace & Seif, 2010) on social welfare; and second, investigating the relationship between the role of the government in the supply chain and social welfare. These studies are reviewed in Section 2. As newspapers and other periodical publications can inform and educate at the same time, supporting magazine publications can help to achieve social and political goals of social welfare. In this paper, two policies are considered for supporting magazine publications by the government: direct subsidy payment and opening new facilities which could help with integration and reduce delivery costs. The proposed model is a mixed-integer linear mathematical model that reduces total costs while guaranteeing a minimum level of social welfare. Also, a robust programming approach developed by Bertsimas and Sim (2004) is employed to cope with uncertainties.

The remainder of the paper is organized as follows: The related literature is reviewed in the following section. In Section 3, the Robust Programming approach developed by Bertsimas and Sim (2004) is introduced. In Section 4, the problem is defined. Section 5 introduces the case study (magazine subscriptions of Tehran). In section 6, the proposed model is solved, and the results, as well as the sensitivity analysis, are presented. Finally, Section 7 is dedicated to conclusions and future research suggestions.

## 2. Literature review

The most relevant work to this paper includes the study of Ovchinnikov and Raz (2011) that examined the pricing problem of electric cars by considering the role of the government in designing incentive mechanisms based on the newsvendor model. Also, Luo et al. (2014) have studied the supply chain of electric cars; in their research, the government employs a discount incentive to encourage customers to buy electric cars and consequently to reduce the air pollution. Xie and Ma (2016) have studied the supply chain of color television recycling in China. They have introduced a duopoly market in which the government plays the roles of both a subsidy provider and a wholesaler for the two firms in the market. To the best of our knowledge, Mahmoudi and Rasti-barzoki (2018) are the first researchers to model the contradiction between the government goals and the producers' goals using the Game Theory approach. Their research shows that government policies affect producers' behavior, competitive markets, the emission of greenhouse gases, and imposing tariffs is the most effective way to minimize environmental effects. Heydari et al. (2017) studied the coordination of the reverse and closed loop supply chain components by considering the government's role. The supply chain is intended to sustain consumption by offering a discount or a direct fee in exchange. The primary purpose of the supply chain network design is to determine the location and capacity of supply chain facilities as well as the mode of transportation among them. Network design decisions are strategic decisions that have long-term effects on the supply chain's performance (Ghavamifar, 2015). Strategic decisions are made for three to five years in the future, during which many parameters such as demand, capacity, and costs of the supply chain network could change, significantly. Furthermore, the parameters associated with the design of the supply chain network include a large amount of data which are often accompanied by rough estimates due to incorrect predictions, or poor measurements occurred during the modeling process (Govindan et al., 2017; Wood & Gough, 2006). Researchers such as Mula et al. (2006) and Klibi et al. (2010) have introduced different categories of data uncertainty. Mula et al. (2006) proposed that the uncertainty of data can be due to 1) randomness, that comes from the random nature of parameters or 2) epistemic uncertainty that comes from a lack of knowledge of the parameter values. Klibi et al. (2010) proposed that data uncertainty can be due to normal business conditions or disruptions. There are also different approaches to deal with uncertainties. Govindan et al. (2017) introduced three categories for these approaches: random planning, fuzzy planning, and robust planning (optimization). Zarinpour et al. (2018) presented a location-allocation hierarchy model to design a

health service network. Cui et al. (2016) studied the design of a two-level supply chain in which a set of suppliers serve a set of terminals with uncertain demand. In particular, they considered the possibility of a transportation disruption that might stop a reliable supplier. Yahyaei and Bozorgi-Amiri (2018) investigated the design of a disaster relief logistics network under uncertainty and disruptions. In the paper above, an integer linear programming model is proposed. Kamalahmadi and MellatParast (2017) studied the effectiveness of incorporating three types of redundancy practices (pre-positioning inventory, backup suppliers, and protected suppliers) in a supply chain that faces both supply and environmental risks. They demonstrated that regionalizing a supply chain is an effective way to reduce the negative impacts of environmental disruptions. The design of hub transportation networks is a strategic issue that has been explored by Rostami et al. (2018). Their model was designed for large-scale problems based on the branch and bound framework of the Benders Decomposition technique. Hasani et al. (2012) presented a general comprehensive model for the strategic design of a closed-loop supply chain network under data uncertainty. The proposed model is multi-period, multi-product, and multi-level. Also, it considers the uncertainties associated with demand quantities and purchase costs. The integration of location and inventory problems in the supply chain is one of the standard topics in this field that Dai et al. (2018) have addressed. They developed an optimization model with fuzzy capacity and carbon emissions constraints for perishable products.

Reviewing the literature regarding supply chain management and social welfare reveals that the existing studies have investigated the role of legislation or financial subsidies in social welfare. However, to the best of our knowledge, no study considers the role of the government in designing the supply chain network and strategic decisions. In this study, the government's goal is to minimize its costs while providing social welfare through granting subsidies and direct interference in the supply chain by establishing new facilities under uncertainty. Among the existing approaches for dealing with uncertainty, a robust optimization method is employed in this study, and among the methods of robustness, the method developed by Bertsimas and Sim (2004) is used for two reasons: First, it provides a more realistic approach that can be adjusted to various levels of risk taking. Second, it retains the linearity state of the model.

### 3. Bertsimas & Sim robust optimization approach (2004)

Consider the following linear optimization problem:

$$p(1): \max z = c \cdot x \quad (1)$$

subject to

$$AX \leq b \quad (3)$$

$$l \leq x \leq u \quad (4)$$

Constraint (3) includes  $|I|$  constraints. Constraint number  $i \in I$  is showed as  $a_i \cdot x \leq b_i$ . The set of coefficients  $\tilde{a}_{ij}, j \in J_i$ , which is subject to uncertainty, is named  $J_i$ . The term  $\tilde{a}_{ij}, j \in J_i$  is based on a symmetric distribution with the mean of  $a_{ij}$ . The  $\tilde{a}_{ij}$  takes values in  $[a_{ij} - \hat{a}_{ij}, a_{ij} + \hat{a}_{ij}]$ . For every constraint  $i \in I$ , we introduce a parameter  $\Gamma_i$ , which is not necessarily an integer, and can take values in the intervals  $[0, |J_i|]$ . The linear model  $p(1)$  can be rewritten in  $p(2)$  using the approach provided by Bertsimas & Sim.

$$p(2): \max z = c \cdot x \quad (5)$$

subject to (6)

$$\sum_j a_{ij} x_j + z_i \Gamma_i + \sum_{j \in J_i} p_{ij} \leq b_i \quad \forall i \quad (7)$$

$$z_i + p_{ij} \geq \hat{a}_{ij} y_j \quad \forall i, j \in J_i \quad (8)$$

$$-y_j \leq x_j \leq y_j \quad \forall j \quad (9)$$

$$l_j \leq x_j \leq u_j \quad \forall j \quad (10)$$

$$p_{ij} \geq 0 \quad \forall i, j \in J_i \quad (11)$$

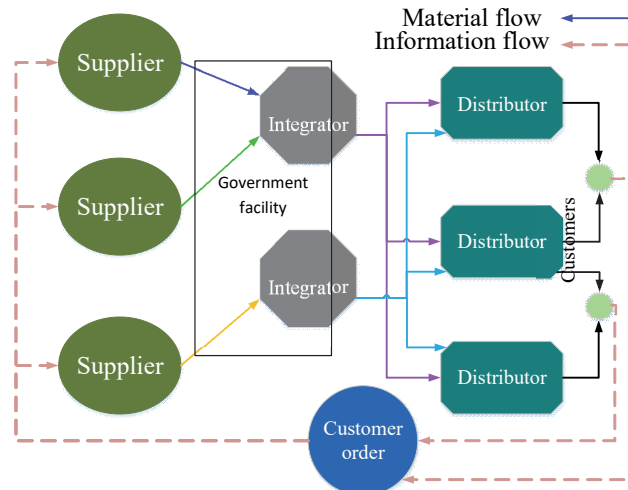
$$y_j \geq 0 \quad \forall j \quad (12)$$

$$z_i \geq 0 \quad \forall i \quad (13)$$

The role of the parameter  $\Gamma_i$  is to adjust the robustness of the proposed method against the level of conservatism of the solution. Speaking intuitively, it is unlikely that all of the  $a_{ij}, j \in J_i$  will change. Our goal is to be protected against all cases that up to  $\lfloor \Gamma_i \rfloor$  of these coefficients are allowed to change, and one coefficient  $a_{ij}$  changes by  $(\Gamma_i - \lfloor \Gamma_i \rfloor) \hat{a}_{ij}$ .

#### 4. Problem definition

The supply chain studied in this paper has four levels: Suppliers, each produces a unique product and receives the order's information; Integrators who receive the orders' information from the registration system and package the orders; Distributors who receive the prepared packages from integrators and deliver them to customers; and Customers who are the final receivers.



**Fig. 1.** The structure of the supply chain considered in this study

The flow of information and goods in the supply chain is as follows: the orders are registered by the customer; the orders' information is sent to the suppliers based on the goods being requested; the suppliers send the customers' orders to the integrators; the integrators wrap the packages and send them to the distributors. The distributors, then, deliver the packages to the customers. Note that each customer is allocated to one integrator. The government wants to intervene in this supply chain for assuring social welfare goals. The social welfare of each region is measured by the demand that is met in that region. The government has two means for providing social welfare: first, by granting subsidies to suppliers (magazine publishers), which has an indirect effect on the supply chain; and second, by establishing new facilities for integrating and distributing customers' orders, which reduces total supply chain's costs and helps all members of the chain. This research aims to minimize the government's costs through a well-designed supply chain network. Also, we investigate the impacts of supply chain network redesign on social welfare. For this aim, a mathematical model is presented in which both types of interference by the government are considered (subsidy payment and facility establishment). The supply chain's profit is guaranteed through adding a constraint which considers a minimum level

that must be met. Moreover, the level of social welfare is calculated based on the percentage of demand quality that is met in each region. The mathematical model is presented after introducing the notations.

#### 4.1. Sets and Indexes

Suppliers' index:  $s \in \{1, 2, \dots, S\}$

Index related to the Integrator:  $o \in \{1, 2, \dots, O\}$

Index related to the Distributors:  $d \in \{1, 2, \dots, D\}$

Index related to the Customer:  $c \in \{1, 2, \dots, C\}$

Index related to the Period:  $t \in \{1, 2, \dots, T\}$

Index related to the Candidate integrator:  $ko \in \{1, \dots, Ko\}$

Index related to the Candidate distributor:  $kd \in \{1, \dots, Kd\}$

#### 4.2. Parameters

Transportation Cost from Distributor  $s$  to Integrator  $o$ :  $cshs_{so}$

Transportation Cost from Supplier  $s$  to Candidate Integrator  $ko$ :  $cshsk_{sko}$

Transportation Cost from Integrator  $o$  to Distributor  $d$ :  $csho_{od}$

Transportation Cost from Integrator  $o$  to Candidate Distributor  $kd$ :  $cshok_{okd}$

Transportation Cost from Candidate Integrator  $ko$  to Distributor  $d$ :  $cshkd_{kod}$

Transportation Cost from Candidate Integrator  $ko$  to Candidate Distributor  $kd$ :  $cshkk_{kokd}$

Transportation Cost from Distributor  $d$  to Customer  $c$ :  $cshd_{dc}$

Transportation Cost from Candidate Distributor  $kd$  to Customer  $c$ :  $cshkc_{kdc}$

Production Cost of Product  $s$  (per unit):  $csp_s$

Cost of the vacant capacity of distributor  $d$ :  $cshbnd_d$

Cost of the vacant capacity of candidate distributor  $kd$ :  $cshbnkd_{kd}$

Cost of the vacant capacity of integrator  $o$ :  $cshbo_o$

Cost of the vacant capacity of candidate integrator  $ko$ :  $cshbko_{ko}$

Deficiency penalty coefficient (based on kg deficiency):  $bb$

Amount of budget required to establish a candidate integrator  $ko$ :  $f\hat{o}_{ko}$

Amount of budget required to establish a candidate distributor  $kd$ :  $f\hat{d}_{kd}$

Big number:  $m$

The capacity of Integrator  $o$ :  $capo_o$

The capacity of Candidate Integrator  $ko$ :  $capko_{ko}$

The capacity of Distributor  $d$ :  $capd_d$

The capacity of Candidate Distributor  $kd$ :  $capkd_{kd}$

The demand of Customer  $c$ , in Period  $t$  for Product  $s$ :  $de_{stc}$

Minimum Profit of Supply Chain at Period  $t$ :  $had_t$

Subsidy Coefficient Allocated to Supplier  $s$ :  $zy_s$

Selling Price of Product  $s$  (per unit):  $p_s$

### 4.3. Decision Variables

Quantity sent from Supplier  $s$  to Integrator  $o$ , in Period  $t$  for Costumer  $c$ :  $xs_{sotc}$

Quantity sent from Supplier  $s$  to Candidate Integrator  $ko$ , in Period  $t$  for Costumer  $c$ :  $xsk_{skotc}$

Quantity sent from Integrator  $o$  to Distributor  $d$ , in Period  $t$  for Customer  $c$ :  $xo_{odtc}$

Quantity sent from Integrator  $o$  to Candidate Distributor  $kd$ , in Period  $t$  for customer  $c$ :  $xok_{okdte}$

Quantity sent from Candidate Integrator  $ko$  to Distributor  $d$ , in Period  $t$  for Costumer  $c$ :  $xkd_{kodic}$

Quantity sent form Candidate Integrator  $ko$  to Candidate Distributor  $kd$ , in Period  $t$  for Customer  $c$ :  $xkk_{kokdte}$

Quantity sent from Distributor  $d$  to Costumer  $c$ , in Period  $t$ :  $xd_{dte}$

Quantity sent from Candidate Distributor  $kd$  to Costumer  $c$ , in Period  $t$ :  $xkc_{kdte}$

Vacant Transportation Capacity from Integrator  $o$ , in Period  $t$ :  $xbo_{ot}$

Vacant Transportation Capacity from Distributor  $d$ , in Period  $t$ :  $xbd_{dt}$

Vacant Transportation Capacity from Candidate Integrator  $ko$ , in Period  $t$ :  $xbko_{kot}$

Vacant Transportation Capacity from Candidate Distributor  $kd$ , in Period  $t$ :  $xbkd_{kdt}$

Allocation Variables: Equals 1 when (Candidate) Integrator  $o$  ( $ko$ ) is assigned to Customer  $c$ , otherwise zero:  $a1_{oc}$   $a2_{koc}$

Equals 1 if Candidate Integrator ( $ko$ ) is opened, otherwise 0:  $z_{ko}$

Equals 1 if Candidate Distributor ( $kd$ ) is opened, otherwise 0:  $zz_{kd}$

Welfare Coefficient of each Region (Costumer)  $c$ , in Period  $t$  for Product  $s$ :  $zref_{stc}$

The subsidy paid by the government for Customer  $c$  in Period  $t$  for Product  $s$  (This subsicy is paid to suppliers):  $yar_{stc}$

Gama (Level of protection against uncertainties in period  $t$ ):  $ga_t$

Variables of the Robust Model:  $zr_t$

Variables of the Robust Model:  $pr1_{sotc}, \dots, pr15_{kdt}$

Variables of the Robust Model:  $y1_{skotc}, \dots, y14_{kdt}$

### 4.4. Mathematical model

The mathematical model is as follows based on the problem definition and the model components:

$$\min GO = \sum_{ko} fo_{ko} \times z_{ko} + \sum_{kd} fd_{kd} \times zz_{kd} + \sum_s \sum_c yar_{stc} \quad (14)$$

subject to

$$\begin{aligned} & \sum_c \sum_o \sum_s cshs_{so} \times xs_{sotc} + \sum_c \sum_o \sum_s pr1_{sotc} + \sum_c \sum_{ko} \sum_s cshsk_{sko} \times xsk_{skotc} \\ & + \sum_c \sum_{ko} \sum_s pr2_{skotc} + \sum_c \sum_d \sum_o csho_{od} \times xo_{odtc} + \sum_c \sum_d \sum_o pr3_{odtc} \\ & + \sum_c \sum_{kd} \sum_o cshok_{okd} \times xok_{okdte} + \sum_c \sum_{kd} \sum_o pr4_{okdte} + \sum_c \sum_d \sum_{ko} cshkd_{kod} \times xkd_{kodic} \\ & + \sum_c \sum_d \sum_{ko} pr5_{kodte} + \sum_c \sum_{kd} \sum_{ko} cshkk_{kokd} * xkk_{kokdte} + \sum_c \sum_{kd} \sum_{ko} pr6_{kokdte} \end{aligned} \quad (15)$$

$$\begin{aligned}
 & + \sum_c \sum_d cshd_{dc} \times xd_{dtc} + \sum_c \sum_d pr7_{dtc} + \sum_c \sum_{kd} cshkc_{kdc} \times xkc_{kdtc} + \sum_c \sum_{kd} pr8_{kdtc} \\
 & - \sum_c \sum_o \sum_s (p_s - csp_s) \times xs_{sotc} + \sum_c \sum_o \sum_s pr9_{sotc} - \sum_c \sum_{ko} \sum_s (p_s - csp_s) \times xsk_{skotc} \\
 & + \sum_c \sum_{ko} \sum_s pr10_{skotc} + \sum_o xbo_{ot} \times cshbo + \sum_o pr12_{ot} + \sum_d xbd_{dt} \times cshbnd + \sum_d pr13_{dt} \\
 & + \sum_{ko} xbk_{kot} \times cshbo + \sum_{kd} xbk_{kdt} \times cshbnd + \sum_{ko} pr14_{kot} + \sum_{kd} pr15_{kdt} \\
 & - \sum_s \sum_c yar_{stc} + (ga_t \times zr_t) \leq had_t \quad \forall t
 \end{aligned}$$

$$\sum_s xs_{sotc} = \sum_d xo_{odtc} + \sum_{kd} xok_{okdtc} \quad \forall o, t, c \tag{16}$$

$$\sum_s xsk_{skotc} = \sum_d xkd_{kodtc} + \sum_{kd} xkk_{kokdtc} \quad \forall ko, t, c \tag{17}$$

$$xd_{dtc} = \sum_o xo_{odtc} + \sum_{ko} xkd_{kodtc} \quad \forall d, t, c \tag{18}$$

$$xkc_{kdtc} = \sum_o xok_{okdtc} + \sum_{ko} xkk_{kokdtc} \quad \forall kd, t, c \tag{19}$$

$$\forall s, o, t, c \quad xs_{sotc} \leq m \times a1_{oc} \tag{20}$$

$$\forall s, ko, t, c \quad xsk_{skotc} \leq m \times a2_{koc} \tag{21}$$

$$\forall c \quad \sum_o a1_{oc} \leq 1 \tag{22}$$

$$\forall c \quad \sum_{ko} a2_{koc} \leq 1 \tag{23}$$

$$\sum_o a1_{oc} + \sum_{ko} a2_{koc} = 1 \quad \forall c \tag{24}$$

$$\sum_c \sum_s xs_{sotc} + xbo_{ot} = capo_o \quad \forall o, t \tag{25}$$

$$\sum_c \sum_s xsk_{skotc} + xbk_{kot} = capko_{ko} \times z_{ko} \quad \forall ko, t \tag{26}$$

$$\sum_c \sum_o xo_{odtc} + \sum_c \sum_{ko} xkd_{kodtc} + xbd_{dt} = capd_d \quad \forall d, t \tag{27}$$

$$\sum_c \sum_o xok_{okdtc} + \sum_c \sum_{ko} xkk_{kokdtc} + xbk_{kdt} = capkd_{kd} \times zz_{kd} \quad \forall kd \tag{28}$$

$$de_{stc} \times zref_{stc} \leq \sum_o xs_{sotc} + \sum_{ko} xsk_{skotc} \leq de_{stc} \quad \forall s, t, c \tag{29}$$

$$yar_{stc} \leq zy_s \times \sum_o xs_{sotc} \times p_s \quad \forall s,t,c \quad (30)$$

$$pr1_{sotc} + zr_t \geq cshs1_{so} \times y1_{sotc} \quad \forall s,o,t,c \quad (31)$$

$$pr2_{skotc} + zr_t \geq cshsk1_{sko} \times y2_{skotc} \quad \forall s,ko,t,c \quad (32)$$

$$pr3_{odtc} + zr_t \geq cshol_{od} \times y3_{odtc} \quad \forall o,d,t,c \quad (33)$$

$$pr4_{okdtc} + zr_t \geq cshok1_{okd} \times y4_{okdtc} \quad \forall o,kd,t,c \quad (34)$$

$$pr5_{kodic} + zr_t \geq cshkd1_{kod} \times y5_{kodic} \quad \forall ko,d,t,c \quad (35)$$

$$pr6_{kokdtc} + zr_t \geq cshkk1_{kokd} \times y6_{kokdtc} \quad \forall ko,kd,t,c \quad (36)$$

$$\forall d,t,c \quad pr7_{dtc} + zr_t \geq cshd1_{dc} \times y7_{dtc} \quad (37)$$

$$\forall kd,t,c \quad pr8_{kdtc} + zr_t \geq cshkc1_{kdc} \times y8_{kdtc} \quad (38)$$

$$\forall s,o,t,c \quad pr9_{sotc} + zr_t \geq csp1_s \times y9_{sotc} \quad (39)$$

$$\forall s,ko,t,c \quad pr10_{skotc} + zr_t \geq csp1_s \times y10_{skotc} \quad (40)$$

$$pr12_{ot} + zr_t \geq cshbol \times y11_{ot} \quad \forall o,t \quad (41)$$

$$pr13_{dt} + zr_t \geq cshbnd1 \times y12_{dt} \quad \forall d,t \quad (42)$$

$$pr14_{kot} + zr_t \geq cshbol \times y13_{kot} \quad \forall ko,t \quad (43)$$

$$pr15_{kdt} + zr_t \geq cshbnd1 \times y14_{kdt} \quad \forall kd,t \quad (44)$$

$$-y1_{sotc} \leq xs_{sotc} \leq y1_{sotc} \quad \forall s,o,t,c \quad (45)$$

$$-y2_{skotc} \leq xsk_{skotc} \leq y2_{skotc} \quad \forall s,ko,t,c \quad (46)$$

$$-y3_{odtc} \leq xo_{odtc} \leq y3_{odtc} \quad \forall o,d,t,c \quad (47)$$

$$-y4_{okdtc} \leq xok_{okdtc} \leq y4_{okdtc} \quad \forall o,kd,t,c \quad (48)$$

$$-y5_{kodic} \leq xkd_{kodic} \leq y5_{kodic} \quad \forall ko,d,t,c \quad (49)$$

$$-y6_{kokdtc} \leq xkk_{kokdtc} \leq y6_{kokdtc} \quad \forall ko,kd,t,c \quad (50)$$

$$-y7_{dtc} \leq xd_{dtc} \leq y7_{dtc} \quad \forall d,t,c \quad (51)$$

$$-y8_{kdtc} \leq xkc_{kdtc} \leq y8_{kdtc} \quad \forall kd,t,c \quad (52)$$

$$-y9_{sotc} \leq xs_{sotc} \leq y9_{sotc} \quad \forall s,o,t,c \quad (53)$$

$$\forall s,ko,t,c \quad -y10_{skotc} \leq xsk_{skotc} \leq y10_{skotc} \quad (54)$$



$$-y11_{ot} \leq xbo_{ot} \leq y11_{ot} \quad \forall o,t \tag{55}$$

$$-y12_{dt} \leq xbd_{dt} \leq y12_{dt} \quad \forall d,t \tag{56}$$

$$-y13_{kot} \leq xbk_{kot} \leq y13_{kot} \quad \forall ko,t \tag{57}$$

$$-y14_{kdt} \leq xbk_{kdt} \leq y14_{kdt} \quad \forall kd,t \tag{58}$$

$$a1, a2, z, zz \in \{0,1\}$$

$$xsk_{skote}, xo_{odtc}, xbk_{kdt}, xok_{okdte}, xkd_{kodte}, xkk_{kokdte}, zr_t, \tag{59}$$

$$All pr, All y, xd_{dte}, xkc_{kdtc}, xb_{stc}, xbo_{ot}, xbd_{dt}, xbk_{kot}, xs_{sotc} \geq 0$$

In this model, Eq. (14) shows the objective function that represents the total government costs, including subsidy payment and the establishment of new facilities. Eq. (15) to Eq. (59) state the constraints of the model. Eq. (15) shows the supply chain’s profit which is calculated based on the transportation costs, net revenue of selling products, the cost of vacant capacity, and the value of the subsidy, as well as the cost of robustness. Constraints (16) to (19) are balance equations for transportation quantities. Constraints (20) to (24) allocate customers to integrators. Note that each customer should be allocated to one integrator. Constraints (25) to (28) determine the capacity of new facilities. Constraint (29) guarantee that all customers’ demand is met. Constraint (30) demonstrates the maximum subsidy that can be granted to each supplier. Constraints (31) to (58) are the robust constraints of the model. Constraint (59) demonstrates the type of variables and their positivity.

### 5. Case study

In order to validate the proposed model and show its applicability and advantages, the magazines’ subscriptions of Tehran have been selected as a case study. The case study includes four types of magazines (daily, weekly, bi-weekly, and monthly). To cope with Tehran’s diverse and wide urban space, its 22 regions are divided into 119 zones. For each region, the demand quantity is considered 0.1% of the population, which is distributed equally among different zones. The number of customers in each zone is specified in Table 1.

**Table 1**  
demand value in each region

Region No.	Population	Number of zones	Number of customers per zone
1	487,508	10	49
2	701,303	9	78
3	330,649	6	55
4	919,001	9	102
5	858,346	7	123
6	251,384	6	42
7	312,194	5	62
8	425,197	3	142
9	174,239	4	44
10	327,115	3	109
11	307,940	4	77
12	241,831	6	40
13	248,952	4	62
14	515,795	6	86
15	641,279	6	107
16	268,406	6	45
17	273,231	3	91
18	419,882	5	84
19	261,027	4	65
20	365,259	6	61
21	186,821	3	62
22	176,347	4	44

Customers can order 150 daily newspapers, 24 weekly magazines, and 12 bi-weekly magazines, as well as six monthly magazines during four periods. There are two distributors and two integrators, which are placed in the eastern and the western part of the city, and new facilities can be opened if necessary. Therefore, two locations in eastern and central parts of Tehran are considered as candidate locations to open new integrators and distributors (meaning a total of four candidates). The rest of the information is presented in Tables 2, 3, and 4.

**Table 2**

Transportation costs from suppliers to integrators

Supplier	Candidate integrator	Path 1	Path 2	Integrator	Path 2	Path 1
Daily group	Candidate 1 (east)	112	125	East	145	127
	Candidate 2 (center)	75	87	West	95	77
Weekly group	Candidate 1 (east)	112	125	East	132	115
	Candidate 2 (center)	75	87	West	107	90
Bi-weekly group	Candidate 1 (east)	121	130	East	132	115
	Candidate 2 (center)	82	95	West	115	98
Monthly group	Candidate 1 (east)	105	115	East	172	152
	Candidate 2 (center)	82	95	West	145	127

**Table 3**

Transportations costs from integrators to the distributors

Integrator	Integrator's capacity	Distributor	Distributor's capacity	Path 1	Path 2
East	140000	East	200000	57	50
		West	150000	100	90
West	120000	East	200000	100	100
		West	150000	62	72
East	140000	Candidate 1 (east)	100000	100	50
		Candidate 2 (center)	100000	87	75
West	120000	Candidate 1 (east)	100000	88	100
		Candidate 2 (center)	100000	37	55
Candidate 1 (east)	100000	Candidate 1 (east)	100000	50	35
		Candidate 2 (center)	100000	35	55
Candidate 2 (center)	110000	Candidate 1 (east)	100000	40	60
		Candidate 2 (center)	100000	25	37
Candidate 1 (east)	100000	East	200000	100	75
		West	150000	75	75
Candidate 2 (center)	110000	East	200000	75	75
		West	150000	57	75

**Table 4**

The minimum level of social welfare considered for each period

Period 1	Period 2	Period 3	Period 4
70%	80%	90%	95%

## 6. The results

The presented model is solved with GAMS software using the CPLEX solver for two scenarios. In the first scenario (Scenario I), the constraint which guarantees minimum welfare is disabled. As a result, no facilities are opened, and no subsidy is granted. Therefore, the total government costs are equal to zero. In the second scenario (Scenario II), the constraint above is abled. As a result, the government costs are equal to 1.75 billion Rials, which includes the costs of establishing an integrator in the eastern part of Tehran and a distributor in the western part. In this case, the granted subsidy also equals zero.

### 6.1. Results

Table 5 represents the difference between total magazines quantities that are allocated to select zones in Scenarios I and II (in percentage). Since the social welfare of each region is measured by total demand quantity that is met in that region, Table 5 also shows the difference of provided social welfare in Scenarios I and II. As it is shown in Table 5, the level of social welfare in Scenario II is always higher than Scenario I, achieved by establishing new facilities. Note that while establishing a new facility has a significant effect on the quantity of daily newspapers, its effect on monthly newspapers

is almost zero. Another point in Table 5 is the integer behavior of the weekly and bi-weekly magazines; that is, the weekly magazines are not allocated to the zone, or all of their volumes are allocated. We also investigated whether considering social welfare would affect the allocation of customers to facilities. The results are provided in Table 6. As it is shown in Table 6, the allocation of customers to integrators is different (more than 65%) in Scenarios I and II. Since in Scenario II, new facilities are opened, allocating a customer to a new facility might be less costly for the chain.

**Table 5**  
The difference between total quantities allocated to zones in Scenarios I and II (percentage)

Period	Newspapers				Weekly magazines				Bi-weekly magazines				Monthly magazines			
	Period 1	Period 2	Period 3	Period 4	Period 1	Period 2	Period 3	Period 4	Period 1	Period 2	Period 3	Period 4	Period 1	Period 2	Period 3	Period 4
1	-70	-80	-90	-95	-100	-100	-100	-100	-70	-80	-90	-95	-100	-100	-100	-100
5	-100	-100	-100	-100	0	-100	-100	-100	0	-100	-100	-100	0	-100	-100	-100
8	-42	-51	-91	-50	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	-27	-40	-43	-34	0	0	0	0	0	0	0	0	0	0	0	0
24	-100	-100	-100	-100	0	0	0	0	0	0	-100	-100	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	-100	-100	-100	-100	0	0	0	0	0	-100	0	0	0	0	0	0
53	0	-8	-12	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	-100	0	-100	-100	-100	0	0	0	0
65	-20	-34	-37	-28	0	0	0	0	0	0	-100	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	-17	-21	-9	0	0	0	0	0	0	0	0	0	0	0	0
81	0	-18	-22	0	0	0	0	0	0	0	0	0	0	0	0	0
86	-100	-41	0	0	0	0	0	0	-100	0	0	0	0	0	0	0
92	-40	-50	-14	-46	0	0	0	0	-100	0	-100	-100	0	0	0	0

**Table 6**  
The allocation of customers to facilities in Scenarios I and II

zone	SCN I	SCN II	zone	SCN I	SCN II	zone	SCN I	SCN II	zone	SCN I	SCN II	zone	SCN I	SCN II
1	o1	ko1	25	o1	ko1	49	o1	ko1	73	o2	o1	97	o1	o1
2	o2	o2	26	o1	o2	50	o1	ko1	74	o1	o1	98	o1	o1
3	o1	ko1	27	o1	o2	51	o1	ko1	75	o2	o2	99	o1	o1
4	o1	ko1	28	o1	ko1	52	o1	ko1	76	o2	ko1	100	o1	o1
5	o1	o2	29	o1	o2	53	o2	ko1	77	o1	o1	101	o2	o1
6	o2	ko1	30	o1	o2	54	o1	ko1	78	o1	ko1	102	o1	ko1
7	o1	o2	31	o1	o2	55	o1	o1	79	o1	o1	103	o1	ko1
8	o1	o2	32	o1	o2	56	o1	o1	80	o1	ko1	104	o2	o1
9	o1	o2	33	o2	o2	57	o1	ko1	81	o2	ko1	105	o1	o1
10	o1	o2	34	o2	o2	58	o1	ko1	82	o1	ko1	106	o1	o1
11	o1	o2	35	o2	o2	59	o1	ko1	83	o1	o1	107	o1	o1
12	o1	o2	36	o2	o2	60	o1	ko1	84	o2	o1	108	o1	o1
13	o2	o2	37	o2	o2	61	o1	ko1	85	o2	o1	109	o1	o1
14	o1	ko1	38	o2	o2	62	o1	ko1	86	o1	o1	110	o1	o1
15	o1	ko1	39	o2	o2	63	o1	o2	87	o1	o1	111	o2	o1
16	o2	ko1	40	o1	ko1	64	o1	ko1	88	o2	o1	112	o1	o1
17	o1	ko1	41	o2	o2	65	o1	o2	89	o1	o1	113	o1	o1
18	o1	o2	42	o2	o2	66	o1	ko1	90	o2	o1	114	o2	o1
19	o1	o2	43	o1	o1	67	o1	o2	91	o2	o1	115	o2	o1
20	o1	o2	44	o1	ko1	68	o1	o2	92	o1	o1	116	o2	o1
21	o1	o2	45	o1	ko1	69	o2	o1	93	o1	o1	117	o2	o1
22	o1	o2	46	o2	ko1	70	o1	ko1	94	o1	o1	118	o1	o1
23	o2	ko1	47	o1	ko1	71	o2	o1	95	o1	o1	119	o1	o1
24	o1	ko1	48	o1	ko1	72	o1	ko1	96	o1	o1			

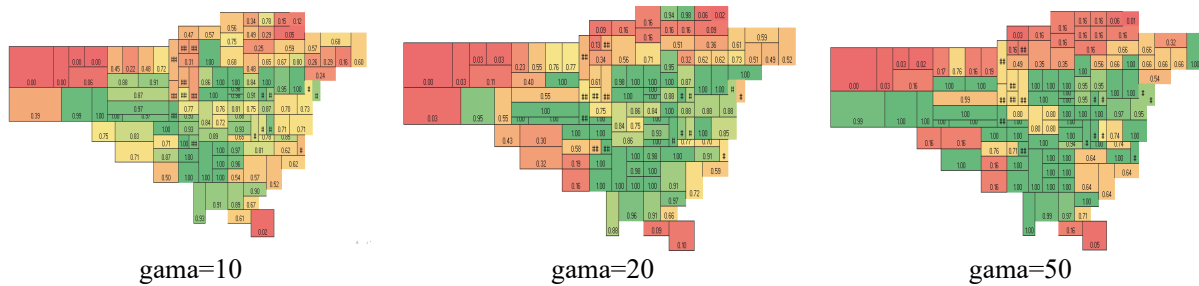
6.2. Sensitivity analysis

Since the level of protection against uncertainties depends on the value of parameter Gama (Ga) in Bertsimas & Sim’s method, here we investigated the effects in Scenarios I and II. Note that this parameter might affect granted subsidies, the establishment of new facilities, and supply chain’s costs. Table 7 represents the social welfare level in Scenario II for selected zones (1 to 10) when Gama is increased from 0 to 40. The increase in the value of Gama has changed the level of social welfare about 0.5% in Scenario II (on average) and about 3% in Scenario I, meaning that the value of parameter Gama

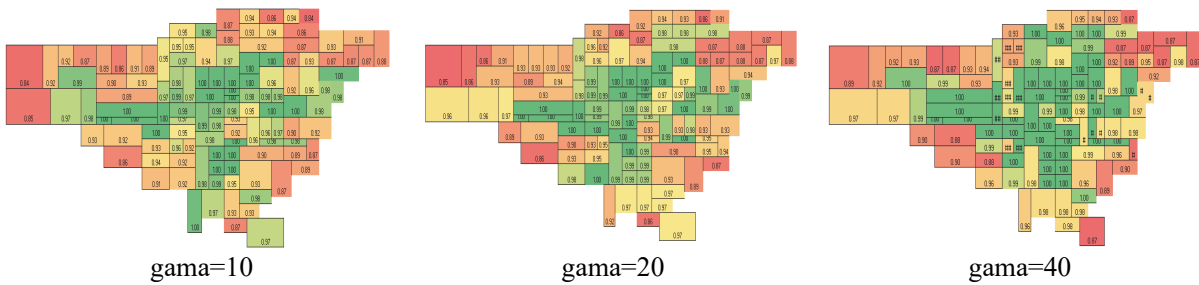
has a negligible effect on average social welfare in both scenarios. However, it should be noted that when the value of Gama is low, the supply chain concentrates on central parts of Tehran. However, when Gama increases, the supply chain also pays attention to non-central parts of the city. The results are represented in Fig. 2 and 3 for Scenarios I and II, respectively. As it is shown, the level of social welfare in non-central parts in Scenario II is better than Scenario I, because in Scenario I social welfare is not guaranteed and since central parts have lower delivery costs, the supply chain pays more attention to them. In Scenario II, the supply chain must pay attention to all regions. Therefore, it takes full advantage of the capacity of new facilities by concentrating on non-central parts of the city. Also, the costs of opening new facilities are partly compensated by changing allocations.

**Table 7**  
The level of social welfare for different values of Gama in Scenario II

Zones/The value of Gama	0	5	10	20	30	40
1	84%	89%	84%	85%	85%	89%
2	84%	85%	92%	86%	95%	92%
3	84%	92%	87%	91%	92%	93%
4	85%	85%	99%	93%	94%	100%
5	84%	85%	85%	96%	97%	97%
6	84%	97%	97%	96%	97%	97%
7	84%	94%	98%	97%	100%	99%
8	84%	92%	89%	93%	87%	87%
9	84%	86%	86%	93%	87%	87%
10	89%	99%	91%	93%	87%	93%



**Fig. 2.** The level of social welfare in different zones for Scenario I



**Fig. 3.** The level of social welfare in different zones for Scenario II

**7. Conclusion**

As mentioned before, providing social welfare is one of the main government's goals, and is closely linked to how the government policies are applied. As newspapers and other periodical publications can inform and educate at the same time, supporting magazines' publications can help us provide cultural and political aspects of social welfare. In this paper, two policies have been considered for supporting magazine publications by the government: direct subsidy payment to the publications and opening new facilities which could help with integration and reduce delivery costs and help all the members of the supply chain of magazine publications. The proposed model is a mixed-integer linear mathematical model that reduces total costs while guaranteeing a minimum level of social welfare. In order to deal with uncertainties, the robust programming approach developed by Bertsimas and Sim

has been employed. The magazines' subscriptions in Tehran was selected as a case study to show the applicability and advantages of the proposed model. The social welfare of each region has been measured by the demand that is met in that region. The results show that when a minimum level for social welfare is guaranteed, the government established two new facilities for integrating and distributing customers' orders. However, no subsidy is granted to publications. In other words, direct intervention in the supply chain is more preferable than granting subsidies. Moreover, the results have shown that when social welfare is not considered, the supply chain concentrates on central parts of Tehran, as these regions have lower delivery costs. Considering social welfare also changes the allocation of customers to facilities. In addition, the sensitivity analysis has shown that the value of parameter Gama, which determines the level of protection against uncertainties, has a negligible effect on average social welfare in both scenarios. The main finding of this study is that the government must increase the capacity for responding to demands by establishing new facilities. Also, it should try to balance delivery costs in different regions by granting different subsidies to regions. Investigating how these subsidies must be allocated to regions can be considered as a path for future research. Applying other approaches for dealing with uncertainties is also suggested.

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