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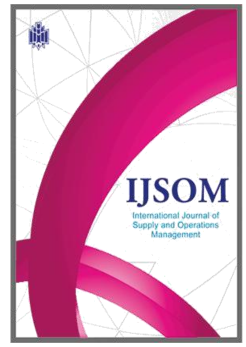

Optimizing Supply Chain Sustainability through AI-Driven Policies and Integrator Facility

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Abstract

Supply chains play a pivotal role in shaping a nation's economic landscape, making their sustainability a paramount concern. However, there is a notable lack of comprehensive policy frameworks addressing this crucial issue. This research aims to fill this gap by introducing two novel policy approaches. Our study focuses on optimizing supply chain networks through the application of AI-driven policies. We analyze the effectiveness of two specific policies: one involving subsidies for suppliers and the other entailing government intervention via an integrator facility for packaging and coordination. To assess these policies, we develop mathematical models and optimize them using the Firefly Algorithm (FA). The research outcomes distinctly reveal that subsidies confer a discernible advantage upon the first model, underscoring their role in shaping its efficacy. Intriguingly, the second model emerges as a formidable contender, particularly when untethered from the support of subsidies. This illuminates the inherent robustness of the second model's design, standing resilient even without the crutch of financial incentives. Beyond the realm of subsidies, the research imparts a profound insight into the essence of holistic policy paradigms, underpinned by AI-driven methodologies. It champions the necessity for a comprehensive approach that extends beyond mere financial aid, advocating for the installation of regulatory frameworks that galvanize publishers' accountability. This multifaceted approach ensures that the trajectory of social welfare is seamlessly woven into the very fabric of the supply chain's functioning, securing a sustainable and equitable distribution of benefits.

Keywords: Supply Chain Management; AI-Driven Policies; Firefly Algorithm; Integrator Facility; Sustainability.

1. Introduction

Social justice stands as an enduring concern that resonates deeply within societies. It encapsulates the pursuit of equitable attention across diverse realms encompassing socio-economic, political, social, and cultural dimensions. These dimensions, intertwined with core values such as wealth, power, commitment, and knowledge, manifest in the aspiration for freedom of action, parity of opportunities, and conditional disparities in the production and dissemination of values (Hou et al., 2023; Pourhassan et al., 2023; Goli et al., 2023; Rezaee, 2013). In modern societies, the discourse of social justice is particularly relevant amid the backdrop of evolving urbanization and its intricate relationship with the urban environment. Within this context, Harvey's conceptualization of societal and spatial justice for cities assumes significance: it delineates the equitable allocation of urban amenities and resources, nurturing an environment where individuals are endowed with an acute awareness of their rights, minimizing disparities and discontent, and effectively meeting diverse demographic needs across strata (Salimifar et al., 2014).

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The essence of promoting social justice lies in the strategic planning and implementation of programs that enhance the well-being of society. This noble pursuit, encompassing a wide range of initiatives and engagements, has long been a subject of contemplation and discussion among intellectuals and authorities in various societies. Developed nations provide a valuable blueprint, where the provision of social services is optimally achieved through a dual-tier approach. In this approach, comprehensive government-led initiatives are complemented by targeted interventions (Goli & Tirkolaee, 2023; Lesotho, 2005). This synergistic relationship establishes governments as the primary drivers of comprehensive social welfare, underscoring their pivotal role in realizing social welfare mandates (Wood & Gough, 2006).

Within the realm of government actions lie the mechanisms to influence a multitude of economic factors, including welfare and poverty, through the lens of cost policies, tax structures, and regulatory frameworks (Allameh et al., 2014). This sphere of influence has spurred a recent surge in studies examining the landscape of government intervention in the realm of social welfare. Research in this domain can be categorized into two distinct strands: the first delves into the impact of macro-level policies, such as fiscal strategies (Dai et al., 2018), government budgets (Esmaeili & Zandi, 2018), and subsidy reforms (Farahani et al., 2014; Govindan et al., 2017), on the landscape of social welfare. Meanwhile, the second strand is centered around the exploration of the roles and initiatives undertaken by governments within supply chains closely intertwined with the enhancement of social welfare. It is within this latter category that the present study finds its focus and relevance.

In this field, Heydari et al. (2017) was performed to evaluate the role of government in the design of reward mechanisms for electric cars based on a news-vendor model with pricing. The goals of government interventions included coordinating the price and increase the accessibility to the good to increase social welfare. In another research, Luo et al. (2014) evaluated an electric car supply chain involving a manufacturer, a retailer and heterogeneous customers. One of the assumptions of the foregoing study was the use of a price-discount incentive scheme by the government to increase electric car purchase rates and reduce air pollution.

Goli and Tirkolaee (2023) evaluated competition in an open and closed-loop supply chain (CLSC) with government intervention. Mardani and Rasti-Barzoki (2017) and Mahmudi and Rasti-Barzoki (2018) modeled the conflict between government and manufacturer’s objectives and used the game theory method for the first time. They considered three scenarios of government profit optimization and setting an upper bound for environmental impacts, environmental effect optimization and setting a lower bound for government profit and creating a balance between government profit and environmental impacts.

In another study, Xie et al. (2016) assessed the recycling supply chain of China's color TVs market. They introduced a Duopoly market of color TV recycling, where the government sells its old TVs to one of the two sellers both as a subsidy provider and as a large seller. By creating a game among two recyclers and a processor in a Duopoly market of color TV recycling, they concluded that as government spending increases, the amount of social welfare as well as the amount of recycling and profits of the two seller’s decreases. Esmaeili and Zandi (2018) evaluated two green and non-green three-layer supply chains based on the intervention of the government in the amount and price of green and non-green goods. They saw the government as a leader in reducing economic and environmental costs and increasing the social welfare index by setting tariffs. In a study, Aghighi et al. (2021) presented a competitive mathematical model, in which they considered the leader role for the government and the follower role for two green and non-green supply chains, both encompassing a manufacturer and a retailer. By doing so, they assessed the policies of pricing, greening strategies and government tariffs by considering the direct supervision of the government (2017).

Integration of location-inventory problem in a supply chain network is one of the classic topics in the area and has been covered by researchers such as Dai et al. (2018), who developed an optimization model with fuzzy capacity and carbon emission limitations. The mentioned scholars formulated a mixed-integer non-linear model and used a hybrid genetic algorithm (GA) and harmony algorithm to minimize costs. The issue of logistics and supply chain design is one of the most important strategic decisions that has been considered by many researchers. In this type of design problem, the number of types, locations, capacity levels and technology level of the facilities in the network are determined. In addition, transport channels and material flow rates between facilities are specified. Given that operational and tactical decisions are often executed following the implementation of strategic and long-term decisions, strategic decisions are an important factor influencing short-term decisions such as tactical and operational decisions (Pourhassan, 2023).

Comprehensive studies have been conducted in this area in the past few years, which have been able to present a comprehensive classification of supply chain network design models. In this respect, some of the studies in the area have been performed by Melo et al. (2009), Farahani et al. (2014) and Govindan et al. (2017).

Today, three welfare modes of "informal supply", "non-supply" and "welfare state" can be identified depending on various development levels of different countries (Asemota & Igweagbara, 2023). There is a formal legal system in companies with an informal supply system, and even democratic principles are properly adhered to in countries such as India. Nonetheless, lack of balanced development of capitalism and existence of large rural areas and staggering poverty in urban areas have caused poor welfare and the prevalence of insecurity. In this respect, institutional arrangements are the most important cause of a non-supply system, which results in extreme insecurity. This is a core reality in most poor countries in the world, including Sub-Saharan Africa, the West Bank and the Gaza Strip (Asemota & Igweagbara, 2023). The welfare state is a type of welfare organization in which governments play a pivotal role. This military-related term refers to the provision of residents' welfare by the government through service provision and income transfer in order to meet their basic needs and adhere to their social rights. There is a relatively independent government in a welfare state system (Xie & Ma, 2016).

In recent times, there has been a growing interest in the implementation of AI-driven policies to enhance supply chain performance. Notably, Dey et al. (2023) conducted a study to evaluate the adoption of AI in small- and medium-sized enterprises, with a particular focus on its subsequent impact on sustainable practices and supply chain resilience (SCR). This area of research has been relatively underexplored. The study employed a novel structural model that incorporated theoretical perspectives from resource orchestration and the knowledge-based view to examine the factors influencing SCR and AI adoption. Similarly, Tsolakis et al. (2023) delved into the combined use of Artificial Intelligence and Blockchain Technology within supply chains, aiming to extend the boundaries of operational performance and promote sustainable development and data monetization. Their research underscores the potential of leveraging these technologies for a broader and more sustainable approach to supply chain operations.

In the field of decision making for supply chains which has a significant importance for the managers (Hosseini et al., 2022; Babaeinesami et al., 2022; Goodarzian et al., 2023), a critical knowledge gap emerged from our extensive literature review. Previous research predominantly concentrated on the legislative aspects and financial subsidies to enhance social welfare within supply chains, often overlooking the significant role governments play as integral members of these chains. This void in the existing body of knowledge prompted our study, which seeks to bridge this gap by comparing two distinct government approaches. The first approach involves subsidizing and providing direct financial support to supply chain members, while the second, more innovative approach, entails active government participation within the supply chain. In this approach, governments assume roles in management and coordination, necessitating the development of supply chain designs tailored to this unique strategy. By clearly defining the problem, presenting detailed mathematical models, introducing a specific case study, and conducting a rigorous comparison of the two government approaches, our research pioneers an exploration of government involvement in supply chain network design and strategic decision-making. This not only contributes novelty to the field but also underscores the relevance of our paper's goals in shedding light on this unexplored dimension of supply chain management and its profound implications for social welfare.

The significance of our research lies in its capacity to fill a critical void in the understanding of government interventions within supply chains, offering unique insights into the impact on social welfare. By examining the uncharted territory of government involvement, we strive to provide a deeper understanding of how these policies and strategies influence the sustainability and effectiveness of supply chains, with potential implications for societal well-being. Our study offers a fresh perspective on the synergy between government policies and supply chain dynamics, ultimately contributing to the ongoing discourse on how to optimize social welfare through innovative government interventions within the complex web of supply chain networks.

2. Problem Statement

This research aims to comprehensively examine the complexities of a publication subscription supply chain. This intricate supply chain comprises three essential layers: suppliers, distributors, and customers. Each supplier operates as an independent manufacturing entity, responsible for producing distinct products. Following this, distributors play a crucial role as intermediaries, receiving shipments from suppliers and overseeing their distribution. Ultimately, customers place orders and serve as the final recipients of the products. Figure 1 illustrates the structure of this studied supply chain.

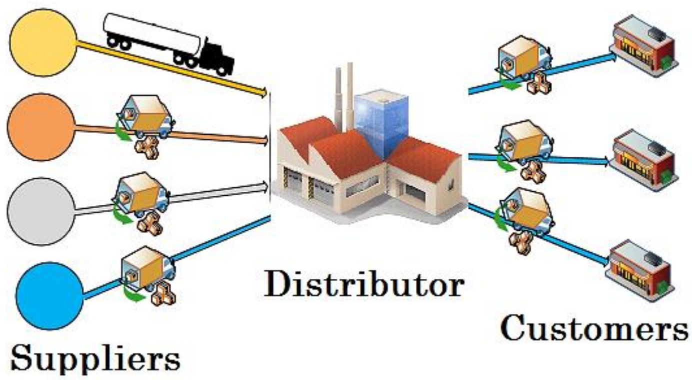

Figure 1. The structure of the studied supply chain

In this supply chain process, when customers place orders for publications, the order details go to the right suppliers. The suppliers then prepare the orders and send them to the distributors. The last step is when the distributors make sure the packages reach the customers on time.

However, the fluidity of this sequence is marred by a deficiency in coordination among the stakeholders at each tier. This lack of intercommunication perpetuates a scenario where suppliers and distributors function autonomously, unencumbered by cross-tier synchronization. This setup allows for individualized, swift delivery of products to customers, irrespective of other simultaneous orders placed by the same customer. This decentralized operation can lead to instances where two products from a single customer reach them on the same day, dispatched by two disparate suppliers and facilitated by distinct distributors.

The government intervenes in this intricate supply chain, driven by its obligation to uphold social welfare imperatives. Here, social welfare encompasses not only the quantity of individuals and geographic regions whose demands are effectively met but also the quantum of fulfillment achieved per individual or region. The government's intervention manifests in two distinct approaches:

Indirect Influence: The government's role in the supply chain is marked by the provision of subsidies, financial relief for chain constituents, allocation of government funds, and staff insurance. This approach augments social welfare through indirect influence, nurturing an environment where supply chain operations align with broader societal well-being. This model currently finds implementation in real-world scenarios.

Integrated Engagement: The second model posits a heightened government engagement, positioning it as an active participant within the supply chain. This involvement can take the form of assuming a chain member's role or orchestrating alterations at various chain levels, all with the overarching objective of enriching social welfare outcomes.

In essence, this research delves into the intricate interplay of stakeholders within a publication subscription supply chain. It critically assesses the prevailing coordination deficit, the multifaceted government interventions, and their profound ramifications for the augmentation of social welfare on both macro and micro scales.

2.1. First Model: Granting Public Subsidies to Suppliers

The distribution costs include packaging, delivery to distributor and delivery to customer costs. With regard to the age of publications, there is no inventory or warehouse in the model. The subsidies granted to suppliers include insurance subsidies, paper currency subsidies, and cash subsidies. Over a contract, the supplier obtains a part of the distributor’s capacity and must pay the penalty for empty capacity in case of a lack of filling the warehouse. Due to its long-term goals, the government allocates an amount as a budget for the subscription plan, and the total amount of subsidies in all periods is less than this amount. If the amount of demand is more than the capacity of the facility, the model will face a shortage and its cost will be considered.

Indices

s = {1,2,...,S} : Set of suppliers
d = {1,2,...,D} : Set of distributors
c = {1,2,...,C} : Set of customers
t = {1,2,... ,T} :Set of time periods

Parameters

p_s : The sales price of each unit from of supplier s
r_{ps} :Production cost per unit of supplier s
mdd_s :Distributed capacity allocated from distributor d to supplier s
$y1_d$:Insurance subsidy of supplier s
$Y2_d$:Paper subsidies per unit sent from supplier s
$Y3_d$:Cash subsidies per unit sent from supplier s
sd_{ds} :Shipping cost per unit of product s to distributor d
dcs_{ds} :The cost of transporting each unit of product s from the distributor d to the customer c
bd_d :Cost per unit of empty capacity of the distributor d
de_{stc} :Customer demand c in period t of product s
g :Maximum budget allocated by the government

Decision Variables

xb_{Ddst} :The amount of empty capacity of distributor d for the product and in period t
xs_{sdtc} :Amount sent from supplier s to distributor d in period t for customer c
b_s :The amount of subsidy allocated to each supplier in the first model
f_{st} :Delivery percentage of each supplier s in each period t which will be the coefficient of welfare of each supplier in each period.

Objective Function and Constraints

In a situation where the government intervenes in the supply chain through cash subsidies, employee insurance, and government currency provision, where the supplier's profit will be equal to the amount of the difference between the revenue from the sale of a product unit and the cost of the production unit in the total amount of demand met, to which must add government subsidies and from which distribution costs (packaging and delivery to distributor and distribution to customer) and cost of excess distribution capacity must be subtracted. Excess capacity cost means that the supplier has acquired some of the distributor's capacity under a contract with the distributor. However, a penalty must be paid for lack of use of the empty capacity. Therefore, the first model is as follows:

$$\pi 1_s = \sum_d \sum_s \sum_c \sum_t (p_s - rp_s) \times xs_{sdtc} - \sum_d \sum_s \sum_t bd_d \times xbd_{dst} - \sum_d \sum_s \sum_c \sum_t sd_{sd} \times xs_{sdtc} - \sum_d \sum_s \sum_c \sum_t dc_{sdc} \times xs_{sdtc} + \sum_s y1_s + \sum_d \sum_s \sum_c \sum_t (y2_s + y3_s) \times xs_{sdtc} \quad (1)$$

Subject to:

$$\sum_d xs_{sdtc} \le de_{stc} \quad \forall s,t,c \quad (2)$$

$$\sum_c xs_{sdtc} + xbd_{sdt} = md_{ds} \quad \forall s,d \quad (3)$$

$$b_s = \sum_d \sum_c \sum_t (y2_s + y3_s) \times xs_{sdtc} + y1_s \quad \forall s \quad (4)$$

$$\sum_d \sum_c xs_{sdtc} = \sum_c de_{stc} \times f_{st} \quad \forall s,t \quad (5)$$

$$\sum_s b_s \le g \quad (6)$$

$$f_{st} \le 1 \qquad \forall s,t \quad (7)$$

$$xbd_{dst}, xs_{stc}, b_s, f_{st} \ge 0 \qquad \forall s,t,c,d \quad (8)$$

In this model, Eq. (1) is the objective function, the details of which are described. Constraints (2) guarantee that the amount sent for each customer in each period for each supplier is less than or equal to the amount of customer demand. Constraints (3) show that the capacity placed by the distributor for the supplier is either used by sending to the customer or remains as excess capacity. Constraints (4) demonstrate the amount of subsidy of each supplier, which is equal to the amount of insurance subsidy of each supplier plus the total paper and cash subsidies, which is allocated to the total demand met by each supplier. In addition, Constraint 5 calculates the welfare coefficient related to each supplier in each period based on the total amount delivered by each supplier and the amount of demand. Constraints (6) ensure that the total subsidy allocated to suppliers must be less than the budget. Constraints (7) determine the maximum welfare coefficient value and Constraint 8 show the positivity of the variables.

2.2. The Second Model: Direct Interference of Government

As mentioned in the section of the statement of the problem, one of the defects of a supply chain is the lack of coordination of its members. In such situations, the government must establish supply chain coordination by entering the chain and developing integrators that are responsible for coordination among the members. In these situations, a supply chain is converted into a four-layer chain, where information of orders made by a customer is delivered to the supplier based on the required goods, and the information of all customer demands along with their address and data are given to the integrator. Suppliers deliver customer orders to the integrator, and each integrator packages and send the product to the distributor. Afterwards, the distributor deliveries the prepared package to customers.

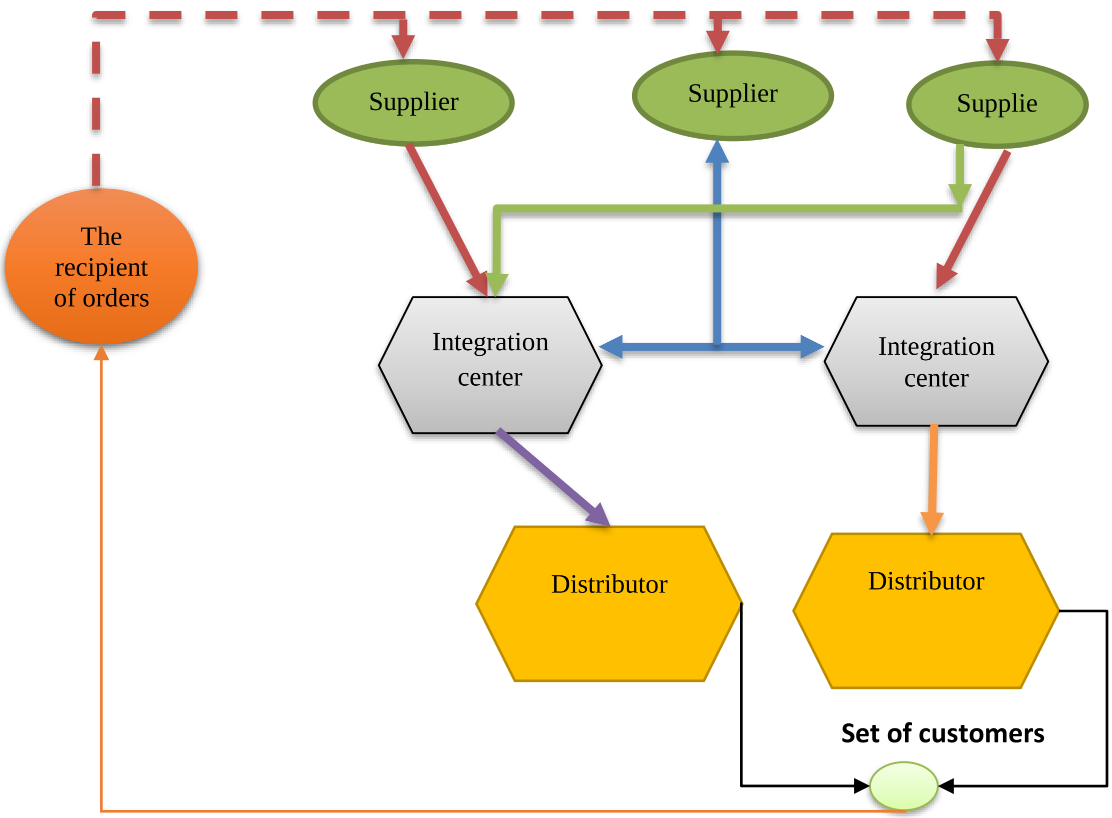

Figure 2. A schematic presentation of the supply chain network with direct interference of the government

2.3. Methods of Subscription and Delivery

The subscription of publications in each period is independent of other periods and the customer can choose a publication from any group of products and receive it until the end of that period. However, the two models of government intervention will have different delivery modes. In the first model, each publication is delivered to the customer with one delivery, whereas in the second model, the number of deliveries depends on the customer choosing or not choosing the newspaper. If the newspaper is selected, since the newspaper is delivered to the customer on a daily basis, other publications will be sent next to the newspaper as well if ordered. However, if the newspaper is not selected, the number of deliveries will be equal to the total number of orders of the publications. Moreover, it is assumed in the research that a maximum of two publications are delivered to the customer in each delivery. The stated conditions are calculated outside the presented models and according to the customers' demand and are entered into the model as a demand parameter. The rest of model assumptions are presented as follows:

Assumptions

- Each customer is allocated to an integrator so that all of their information is given to one integrator.
- The integrator decides based on the period of publication and delivery or accumulation of ordered products of the customer.
- The government exploits the available facilities to create the integrator. As a result, the establishment cost is considered zero.
- In this model, the government is responsible for packaging costs as subsidies.
- Given the age of the publications, there is no inventory or warehouse in the model.
- Since the government builds the integrators and these facilities are regarded as subsidies, the empty capacity cost is not calculated for the integrators. However, it is calculated for distributors similar to the first model.
- Due to its long-term goals, the government allocates an amount as a budget for the subscription plan, and the total amount of subsidies in all periods is less than this amount.
- If the amount of demand is more than the capacity of the facility, the model will face a shortage and its cost will be considered.
- 9. The number of merging facilities that must be established is announced by the government and among its candidates. The symbols used in the model are presented below based on the type of indices and sets of parameters and decision variables.

Indices

s = {1, 2,... ,S}:s Supplier index
o:{1,2,...,O} = o Integrator index
d = {1, 2,... ,D}:d Distributor index
c = {1,2,..., C}:c Customer index
t = {1,2,...,T}:t Time-related index

Parameters

hs_{so} :Shipping cost from supplier s to integrator o
ho_{od} :Shipping cost from integrator to distributor d
hd_{dc} :Shipping cost from distributor d to customer c
rp_s :The cost per unit of product s including production costs
nd_d :Distributor empty capacity costs
m :A desired large number
ed :Packaging unit cost
mo_o :The capacity of integrator o
md_d :The capacity of distributor d
de_{stc} :Customer demand C in period t of product s
α :Number of government integrator facilities to be established
g :Maximum government budget allocated

Decision Variables

xs_{sotc} :Amount sent from supplier s to integrator and in period t for customer c
xo_{odtc} :Amount sent from integrator o to distributor d in period t for customer c
xd_{dtc} :The amount sent from distributor d to customer c in period t
xb_{stc} :The amount of product shortage s for customer c in period t
xbo_{ot} :The amount of empty capacity of the integrator o in period t
xbd_{dt} :The amount of empty capacity of distributor d in period t;
$a1_{oc}$: 1, if integrator o is assigned to customer C; otherwise, 0.
z_o : 1, if integrator o is established; otherwise, 0.
f_{st} :Percentage sent by each supplier in each period, which will be the coefficient of welfare of each supplier in each period
v :The amount of subsidies allocated in the second model of government intervention.

Objective Function and Constraints

According to the definition of the problem and the components of the model that were stated, the objective function and constraints of the second model are as follows:

$$\max z = -\sum_c\sum_t\sum_o\sum_s hs_{so} \times xs_{sotc} \quad (9)$$

$$-\sum_c\sum_t\sum_d\sum_o (ho_{od} - ed) \times xo_{odtc} \quad (10)$$

$$-\sum_c\sum_t\sum_d hd_{dc} \times xd_{dtc} \quad (11)$$

$$+\sum_c\sum_t\sum_o\sum_s (p_s - rp_s) \times xs_{sotc} \quad (12)$$

$$-\sum_d\sum_t xbd_{dt} \times nd_d + \sum_s y1_s \quad (13)$$

Subject to

$$\sum_s xs_{sotc} = \sum_d xo_{odtc} \qquad \forall o, t, c \quad (14)$$

$$xd_{dtc} = \sum_o xo_{odtc} \qquad \forall d, t, c \quad (15)$$

$$xs_{sotc} \le m \times a1_{oc} \qquad \forall s, o, t, c \quad (16)$$

$$\sum_o a1_{oc} = 1 \qquad \forall c \quad (17)$$

$$\sum_c\sum_s xs_{sotc} \le mo_o \times z_o \qquad \forall o, t \quad (18)$$

$$\sum_c\sum_o xo_{odtc} + xbd_{dt} = md_d \qquad \forall d, t \quad (19)$$

$$\sum_o z_o = \alpha \quad (20)$$

$$\sum_o xs_{sotc} \le de_{stc} \qquad \forall s, t, c \quad (21)$$

$$\sum_c\sum_o (xs_{sotc}) = \sum_c de_{stc} \times f_{st} \qquad \forall s, t \quad (22)$$

$$v = \sum_c\sum_t\sum_d\sum_o ed * xo_{odtc} + \sum_s y1_s \quad (23)$$

$$f_{st} \le 1 \qquad \forall s,t \qquad (24)$$
$$v \le g \qquad (25)$$
$$a1_{oc}, z_o, \in \{0,1\} \qquad \forall o,c \qquad (26)$$
$$xo_{odtc} xd_{dtc}, xb_{stc}, xbd_{dt}, xs_{sotc} \ge 0 \qquad \forall o,s,d,t,c \qquad (27)$$

In this model, Eqs. (9-13) pertain to the objective function. Specifically, Eq. (9) encapsulates the expense associated with conveying items from the supplier to the integrator. Eq. (10) accounts for the expenses incurred in both packaging and delivery to the distributor. Notably, the packing cost necessitates subtraction from the overall chain costs due to governmental intervention. Further elucidation arises from Eq. (11), which delineates the delivery cost from the distributor to the customer. Meanwhile, Eq. (12) represents the discernible distinction between revenue from sales and the costs incurred in production. Lastly, Eq. (13) encapsulates the amalgamation of excess distributor capacity costs and total insurance subsidies granted to each supplier. It's pertinent to note that, due to governmental intervention, the excessive integrator cost doesn't contribute to the chain costs.

The constraints (14-17) serve as the bedrock of the model's structural constraints. Among these, constraints (14) and (15) are anchored in the delicate equilibrium maintained in the quantity transference across levels. This entails ensuring that the quantum dispatched from one level corresponds harmoniously with the quantum received at the subsequent tier. Contrarily, constraints (16) and (17) are focused on allocation dynamics, wherein each customer becomes tethered to an integrator. Importantly, a customer's affinity to an integrator remains primary, yet predicated on problem cost conditions, interconnections between multiple facilities could also manifest. Stepping further, constraints (18) assume the mantle of facility capacity considerations, explicitly mandating the establishment of an integrator facility (Constraint 18) and fostering an equilibrium (Constraint 19) to gauge the superfluous capacity of each facility and subsequently incorporate it as a cost within the overarching objective function.

Constraints (20) serve as the enabler for facility establishment within the realm of the stipulated candidates, a quantity presided over by the government's announcement. Constraints (21) weave a fabric of restraint, compelling the dispatch for each customer within each temporal period per supplier to be incommensurate with the customer's demand volume. Notably, Constraints (22) unfurl a formulaic assessment, conjuring the welfare coefficient pertinent to each supplier for each period. This coefficient materializes from a composite evaluation of the total volume supplied by each supplier against the backdrop of demand quantities.

Resonating with the fabric of subsidies, Constraints (23) unfurl the summative tapestry of the chain subsidy corpus. This aggregate is a confluence of insurance subsidies allocated to individual suppliers and the collective packaging costs encompassing all products and periods. Moving on, Constraints (24) function as architects of an upper bound on the welfare coefficient. Meanwhile, Constraints (25) articulate a mandate, stipulating that the aggregate subsidy outlay bestowed upon suppliers remains circumscribed by the fiscal confines of the budget.

Finally, Constraints (26) and (27) both demarcate and posit fundamental attributes on variable characteristics, encompassing their nature and inherent positivity.

3. Firefly Algorithm

The Frog Leap Algorithm emerges as a refined iteration of the Shuffled Complex Evolution (SCE) algorithm. This algorithm is ingeniously constructed by optimizing a portion of SCE, thereby giving birth to this novel approach. The choice of the Firefly Algorithm as the optimization method for our proposed mathematical model stems from its ability to effectively address complex, multi-dimensional optimization problems. This algorithm draws inspiration from the collective behavior of fireflies and their light-based communication, making it well-suited for supply chain optimization, where numerous interconnected variables need to be fine-tuned for efficiency. The Firefly Algorithm's capacity to adapt and converge towards optimal solutions aligns with the intricate dynamics of supply chains, making it a suitable choice for our research.

At its core, this algorithm serves to partition the primary dataset into a series of smaller subsets. Subsequently, these subsets undergo meticulous arrangement through the Competitive Complex Evolution (CCE) algorithm. By orchestrating this ordered segmentation, the algorithm achieves a pivotal advancement. The amalgamation of these orderly subsets is then carried out, elevating the primary dataset to a more refined state. This iterative process repeats itself assiduously to converge upon the most optimal solutions. The Frog Mutation Algorithm is an evolution of the aforementioned CCE algorithm, undergoing enhancement to engender the novel approach. Notably, much of the fundamental framework aligns with its parent algorithm, SCE.

Within the domain of the Shuffled Frog-Leaping Algorithm (SFLA), the mechanism responsible for subset sorting is referred to as the Frog-Leap Algorithm (FLA). This represents a pinnacle of refinement and optimization, a thoroughbred among CCE algorithms. Unlike its predecessor, where sorting is executed within a complex of subsets within the primary population, FLA diverges in approach. It commences its sorting endeavors within a single Memplex, subsequently cascading this sorting across all Memplexes. This strategy ensures the extraction of the utmost optimal solutions from the realm of possibilities.
Figure 3 presents the intricacies of the FLA's procedural flow, encapsulating the multifaceted process of sorting and refinement.

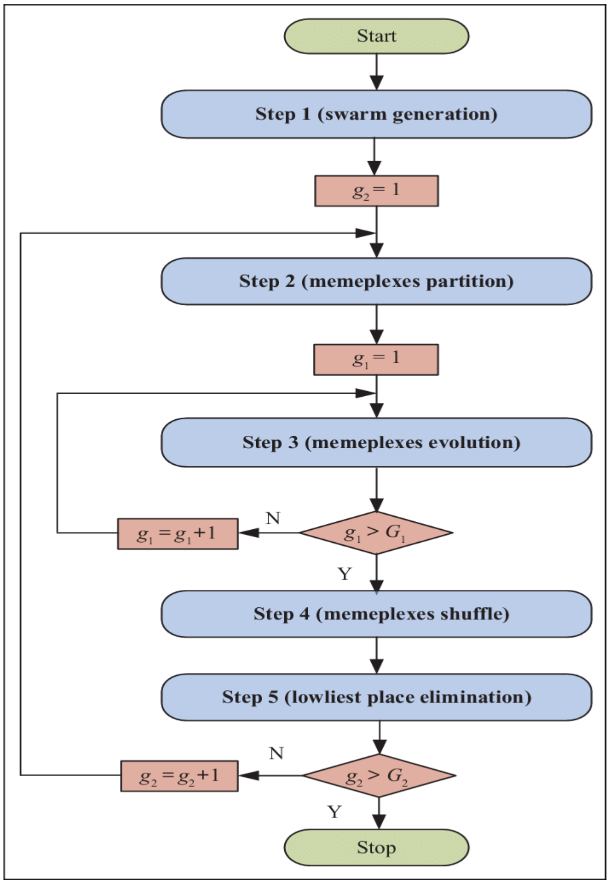

Figure 3. The flowchart of FLA

4. Case Study

In order to validate the models presented in the subscription plan, four journals are evaluated for 6,307 customers in East Asia. For four rounds, customers randomly order publications, and two distributors (east and west distributors) are responsible for the distribution of the publications. In both models, the cost of delivery from the distributor to the customer is assumed to be equal for the customers in one area, and the shipping cost is proportional to the distance dimension. The subsidies paid to suppliers are shown in Table 1.

Table 1. Subsidy amounts paid by product type in the second model

Product Type	Insurance Subsidies	Delivery Unit Paper Subsidies	Delivery Unit Cash Subsidies
Newspaper	26700	100	350
Weekly Journal	34800	80	460
Biweekly Journal	48000	120	540
Monthly Journal	75480	170	510

5. Model Solution and Analysis of Results

The presented models along with the data mentioned in the previous section, are solved by FLA algorithm per four random demands. According to the output of the second model, the east and west integrators must be established among the four candidate integrators. As observed in Table 2, the chain profit is higher in the first model, compared to the second model, which might be due to the profit of chain components (i.e., publications profit). However, considering the amount of subsidies paid to each publication in each model iteration, it is obvious that the paid subsidies are much higher than the profit of publications. For instance, the publication receives about 80 million subsidies for each model iteration, while its profit in each round is less than eight million. In other words, the newspaper has lost more than 72 million in each round. Meanwhile, the amount of loss is estimated at 55 million in the second model supply chain with a subsidy at a lower amount.

Table 2. Solution of both models in similar and full welfare conditions in all regions and per various demand levels

Random demand set number		1	2	3	4
Demand	Total delivery number	382	382	399	399
	Total newspapers number	312	293	308	304
	Total weekly journals	47	48	49	46
	Total biweekly journals	210	220	295	356
	Total monthly journals	299	208	314	361
The first model (subsidy to the supplier)	Profit amount	235	355	300	353
	Newspaper profit	248	352	307	242
	Weekly journal profit	352	209	252	319
	Biweekly journal profit	279	240	320	337
	Monthly journal profit	331	351	197	254
	Total subsidies paid	343	311	260	368
	Newspaper subsidy	326	361	368	289
	Weekly journal subsidy	357	285	260	202
	Biweekly journal subsidy	261	218	316	265
	Monthly journal subsidy	315	186	360	237
The second model (integrator establishment)	Profit amount	328	371	302	344
	Total subsidies paid	258	273	331	299
Profit of supply chain without subsidies in the first model		360	210	220	202
Profit of supply chain without subsidies in the second model		270	197	359	199
Profit difference between the second model and the first model without subsidies		290	362	289	229

In this regard, the net profit of each chain is calculated without considering the subsidy, the results of which can be observed in the last row of Table (2), according to which the second supply chain has a profit of more than 33 million and has a more favorable performance. Another important point in Table 2 is the existence of approximate stability of the profit difference between the two models. It means that the profit difference in the output of each model implementation period is approximately 33 million due to the changes in the number of demands made each model implementation round. This is primarily due to similar changes in costs and profits of the two models. When the model is implemented with complete welfare, all changes in demand affect the profit of each chain. Given the equality of changes in demand and cost parameters in the two models, profit changes at the same level in both models, which stabilizes the difference between the two models.

Table 3. Output solution of the two models per different welfares

Random demand set number		1	2	3	4
The first model (subsidy to the supplier)	Profit amount	17253	17242	17878	18132
	Total subsidies paid	88370	88968	93877	92219
The second model (integrator establishment)	Profit amount	2029	20476	19908	20318
	Total subsidies paid	3572	3973	3963	1933
Profit of supply chain without subsidies in the first model		72929	73958	71790	74000
Profit of supply chain without subsidies in the second model		23671	23751	24213	22
Profit difference between the second model and the first model without subsidies		47844	52134	48511	49144

In Table 3, optimizations were carried out for both models, with a focus on aspects other than social welfare. As shown in the final row of Table 3, the second model is outperformed by the first in terms of maximizing publisher profits. However, it should be noted that, as depicted in Figure 4, a reduction in overall welfare is observed in the case of a lack of consideration for social welfare within the second model. A comparative analysis of Tables 2 and 3 highlights that a notable 38% increase in profit is achieved by the first model through the reduction of the number of subsidies received by approximately 20%. In contrast, profits are seen to increase by more than 60% with an 80% reduction in subsidies for the second model. These results suggest that the second model exhibits a reduced dependency on subsidies while displaying high responsiveness to enhancements in social welfare. These findings are graphically represented in Figure 4 and Figure 5, illuminating the dynamic relationship between subsidy reduction, profitability, and social welfare considerations within the supply chain.

5.1. Sensitivity Analysis

In this section, the sensitivity of the model to changes in the price parameter of the journal is evaluated in order to examine the models in more detail. According to Table 4, the models are solved three times with an increase of zero, 200 and 300 units of the base price, respectively. Given the 100% welfare, the subsidies paid in both models are a fixed amount (not equal) and supplier profit increases with an increase in the price. According to the first-third columns of Table 4, the profit of the chain in the first model increases about 10 times by increasing 300 units in each price without increasing the amount of subsidy paid. However, this profit increase is different in each publication; newspaper profit increases more than 13 times with a 30% increase in the price, weekly journal profit increases more than 6.5 times with a 15% increase in the price, and biweekly and monthly journal profits increase more than 6 and 3.4 times, respectively. This increase in profit for the second model is more than doubled, showing that the second model is less sensitive to the price range, compared to the first model. In the fourth column of Table 4, both models are solved for different values of the price of each publication. As expected, the amount of profit of each supplier changes depending on the increase or decrease of price. For example, the amount of profit of newspapers decreases due to the decrease of newspaper price.

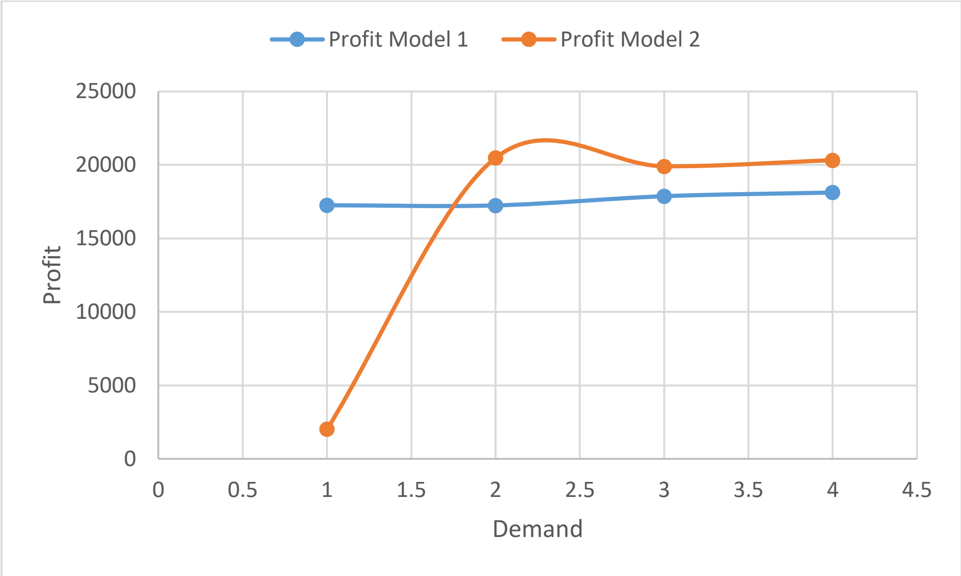

Figure 4. Comparison of profit amount in the two models

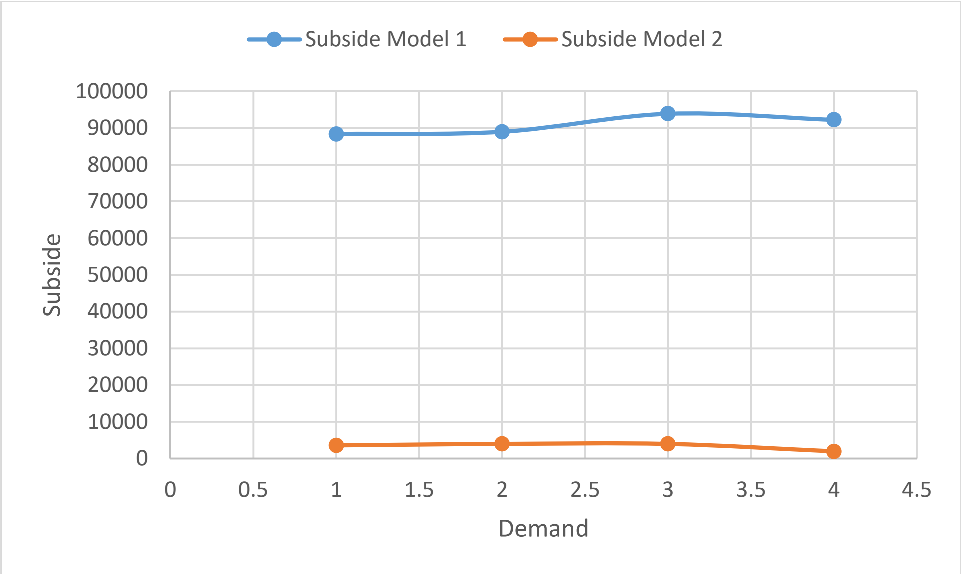

Figure 5. Comparison of subsidy amount in the two models

Table 4. Solution of the two models in equal and full welfare conditions in all regions per different prices and equal demand rates

Column Number		One	Two	Three	Four	Five
Price	Price of each newspaper	1000	1200	1300	900	1475
	Price of each weekly journal	2000	2200	2300	2300	2612
	Price of each biweekly journal	3000	3200	3300	3900	3662
	Price of each monthly journal	3000	300	3300	3600	3625
Demand	Total number of deliveries	406739				406739
	Total newspapers	318225				318225
	Total weekly journals	50444				50444
	Total biweekly journals	25298				25298
	Total monthly journals	12472				12472
The first model (subsidy to the supplier)	Profit amount	13600079	94887879	135531779	19678979	99552108
	Newspaper profit	7916625	71561625	103384125	-23905875	78517250
	Weekly journal profit	2689444	12778244	17822644	17822644	12883572
	Biweekly journal profit	1461676	6521276	9051076	24229876	5259952
	Monthly journal profit	1532334	4026734	5273934	15323334	2891334
	Total subsidies paid	120618850				0
	Newspaper subsidy	80556250				0
	Weekly journal subsidy	20677600				0
	Biweekly journal subsidy	12949000				0
	Monthly journal subsidy	6436000				0
	Profit amount	54880826	26406974	67050874	48801926	133601003
	Total subsidies paid	18089050				0
Profit of supply chain without subsidies in the first model		-107018771	-25730971	14912929	-100939871	99552108
Profit of supply chain without subsidies in the second model		-72969876	8317924	48961824	66890976	133601003

In the fifth column of Table 4, models are solved in the conditions of lack of subsidy payment such that welfare is extremely close to full. Prices are presented in such situations, according to which if, for example, the price of the newspaper is 1475, the newspaper establishes full welfare without receiving subsidy and based on its profit. The amount of subsidy for each newspaper is 250 units (the sum of two cash and foreign exchange subsidies), which, if deducted from 1475, gives the maximum price to which the subsidy must be allocated. In other words, the conditions of the third column of Table 4 must not occur for the newspaper since the price of 1300 price unit for the newspaper is higher than the maximum price (1225 units) which includes subsidy.

6. Conclusion and Recommendations

The promotion of social welfare within the supply chain is a central objective embedded in government policies. This welfare is intrinsically linked to the utilization and nature of these policies. In our research, we examined two distinct government policies aimed at supporting publications. In the first model, the government offers three types of subsidies (cash, paper, and insurance) to each supplier. In the second model, the government takes a more direct role by entering the market and establishing an integrator facility responsible for packaging and coordinating activities among the suppliers. This approach results in reduced packaging costs for suppliers and a decrease in the number of deliveries, thereby bolstering the overall support for the supply chain. Mathematical models were meticulously formulated for each of these scenarios.

The outcomes of these models demonstrated that, when considering subsidies, the first model yielded higher profits for each supplier compared to the second model. However, it is important to note that the total amount of subsidies paid in the first model significantly surpassed that of the second model. By accounting for this and excluding subsidies from the profit calculations of both models, the second model exhibited superior performance in terms of achieving equal and comprehensive social welfare across all regions. Conversely, the first model excelled in scenarios where different regions displayed varying degrees of welfare.

Our findings underscore the need for the government to not only provide subsidies but also establish regulations that compel publishers to contribute to overall welfare. Without such regulations, suppliers tend to optimize their profits in both models, regardless of the social welfare landscape. This can result in uneven distribution of welfare across regions. The first model is better suited for situations in which the government lacks comprehensive oversight of publisher operations but seeks to equalize social welfare across all regions to maximize profits. However, in such cases, the government's actions may inadvertently reduce social welfare due to increased publication prices leading to decreased demand.

In this study, we used the number of journal deliveries per round as a key indicator of social welfare. We recommend that future research consider additional variables such as customer-related factors and the methods of publication reception as indices of welfare. Furthermore, investigating uncertainties related to transportation costs, prices, and price-dependent demand should be explored in further studies.

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