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A Fuzzy Multi-objective Optimization Model in Sustainable Supply Chain Network Design Considering Financial Flow

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A B S T R A C T

The integrated and coordinated planning of the primary functions within the supply chain, including procurement, production, and distribution, often results in enhanced economic efficiency and, consequently, increased profitability for the entire supply chain. Conversely, the financial flow, as well as the flow of goods and information, are pivotal and influential elements within any supply chain. This paper aims to make a significant contribution by integrating the planning of procurement, production, and distribution within a multi-product supply chain to maximize the producer's profit while minimizing deviations in the producer's financial indicators, taking into account both the physical and financial flow. The studied supply chain encompasses multiple suppliers, a single producer, and numerous customers. As the presented mathematical programming model is bi-objective, two fuzzy multi-objective interactive methods, Selim and Ozkarahan (SO) and Torabi and Hassini (TH), have been employed to adjust the degree of satisfaction of the objective functions. Subsequently, the model is optimized using the goal programming method. The numerical results of optimizing the proposed fuzzy model demonstrate the efficiency, high-quality performance, and applicability of the model. A key finding in the numerical results is that the total value of the distribution in the two models is equal. However, the SO method yields more unbalanced solutions when the decision maker prioritizes the first objective function.

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1. Introduction

In today's business landscape, traditional management practices characterized by limited integration in their processes have lost their effectiveness, giving way to new integrated approaches. This shift towards integration is also evident in supply chain management, as the industry seeks to address its challenges through an integrated approach for managing the flow of materials, goods, information, and finance, while also adapting to dynamic environmental conditions [14]. Supply chain management encompasses a collection of methods aimed at effectively integrating suppliers, manufacturers, warehouses, and stores. The management of inventories plays a crucial role in the success or failure of the chain, making the coordination of inventory levels throughout the supply chain a significant concern [1]. The primary objective of supply chain management is to efficiently control the flow of materials between suppliers, warehouses, and customers in order to minimize the total cost of the supply chain [3,17]. A substantial portion of the research in this field has focused on developing optimization models for integrating various activities such as purchasing, production, and distribution. The central concept of this approach involves the simultaneous optimization of decision variables across different activities, a departure from the traditional sequential optimization method [24].

In the realm of supply chain management, one of the primary challenges lies in the master planning of the supply chain. Master planning is tasked with determining the quantities of supply, production, and distribution for facilities at various levels of the supply chain over a medium-term period [33]. Historically, these activities were managed independently or sequentially, leading to excessive inventory and subpar chain performance. However, in today's competitive environment, the development of an effective tactical plan capable of integrating supply, production, and distribution plans within an efficient framework is crucial [11]. Financial flows, alongside goods and information flows, are fundamental components within all supply chains. Given the significant impact of financial performance on the overall supply chain performance, managing financial flows is critical [21]. While many successful integrated models have been proposed for tactical supply chain planning, most have overlooked decisions related to revenue, marketing activities, capital planning, and other financial aspects of the firm [11].

Financial factors play a pivotal role in influencing the planning of procurement, production, and distribution within the supply chain. Global financial factors such as exchange rates, customs, and insurance costs greatly influence the tactical decisions of the supply chain. Therefore, it is imperative to consider these factors in the master planning of the supply chain. Integrating financial factors into tactical supply chain models allows for a systematic assessment of the impact of production decisions on financial operations and facilitates the selection of an optimal combination of financial and production decisions, ultimately creating a competitive advantage for the company [9,5]. Hence, it is crucial to consider financial flow in supply chain models, particularly in scenarios involving capital-intensive activities, as financial operations complement production operations.

Financial operations are indeed crucial as they ensure the necessary financial resources for production and distribution activities [15]. Furthermore, financial resources are essential for investing in new production processes, equipment, innovative products, and expanding into new markets. Public sources of financing encompass loans from financial institutions and funds raised through the issuance of equity shares, with or without an initial public offering. To attract capital from these investment groups, companies must maintain a clear and satisfactory financial situation [29]. Evaluating a company's future investment and creditworthiness involves a process based on statistical and comparative analysis of financial statements [20]. Additionally, the analysis of financial statements allows financial institutions to assess companies operating in the same industries using specific criteria [35].

The primary objective of this research is to establish financial indicators for designing a sustainable supply chain. To achieve this, a multi-echelon and multi-product mathematical model is proposed to maximize profit and minimize deviations of financial indicators from their desired limits. Furthermore, the research integrates and coordinates procurement, production, distribution, and financial decisions (such as investment, debt, equity, etc.) based on operational resource constraints and financial limitations arising from factors such as exchange rates, value-added tax, income tax, and insurance, optimizing these aspects effectively.

The rest of the paper is organized as follows. In Section 2, an overview of the theoretical foundations of the subject is provided. In Section 3, the definition of the problem and the assumptions, the mathematical model by considering the financial and physical flow, as well as the description of the proposed solution method are provided. In Section 4, the numerical results of the model are analyzed. Finally, Section 5 is devoted to conclusions and suggestions.

2. Research Background

Several research items have been conducted regarding the simultaneous optimization of production and distribution. Moreover, master planning for production units is a fundamental issue that can affect the distribution of products. In this regard, the most important relevant research works are examined in this section. Moreover, the application of financial metrics in production and distribution planning is assessed.

Cohen & Sangwon [8] attempted to optimize the flow of materials, products, and product production mix within a supply chain network with a fixed structure by introducing a mixed spherical model. Chandra & Fisher [7] introduced a model titled "coordinated production and distribution planning," where the demand for each product in a period for each retailer is known. The objective function of this model aims to minimize the total cost, encompassing setup costs, production costs, transportation of manufactured products to retailers, and inventory costs. Pirkul & Jayarama [27] presented an integrated model of the mixed integer programming type, with an objective function seeking to minimize the costs of the entire chain, including establishment, operations and warehouses, variable production and distribution costs, transportation costs of raw materials from sellers to production centers, and transportation costs of finished products to customers. Patterson & Kim [25] introduced an integrated production-distribution model of probabilistic type, aiming to minimize costs related to production and distribution in the model's objective function, with constraints related to facility demand and capacity. Sabri & Benita [30] presented an integrated multi-objective model for strategic and operational planning in the supply chain, seeking to minimize chain costs at the strategic level and determine raw material purchase amounts and distribution at the operational level using economic scale formulas. Peng et al. [26] introduced a hierarchical model with strategic and tactical levels, focusing on purchasing, production, and distribution planning, with the outputs of the strategic level model serving as inputs for the tactical level model.

Although many researchers have emphasized the importance of financial flow in the supply chain, little research has been done in this field. The research items that have been done in the field of financial flow in the supply chain can be divided into two groups. The first group is those who have considered financial flow items as variables that model financial operations and are optimized like other supply chain planning variables. The second group is those who have considered the financial flow-related items as parameters in the constraints and objective function.

In the first group, Romero et al. [28] introduced a multi-cycle mathematical planning model that integrates planning and scheduling, while also considering financial flow and budget management in the chemical industry. Badell et al. [4] presented a mixed integer programming model for master planning and scheduling, taking into account financial flow and budget in the chemical industry. Burke et al. [6] developed a mixed-integer linear programming (MILP) model for a multi-level, multi-product chemical supply chain that optimizes planning, scheduling, financial flow, and budget variables simultaneously. The model, designed for multiple periods, aims to change the company's equity. Ge et al. [10] presented a two-level optimization model for the optimal design of a batch storage network, where production decisions in each activity are coordinated with financial operations resulting from the financial flow.

In the second group, Melo et al. [22] introduced a limited capacity dynamic location model for multi-product facilitation. The proposed MILP model simulates supply chain operational decisions while considering capital constraints. Vafadar et al. [34] presented a MILP model for the optimal configuration of the production and distribution network. The model aims to minimize the cost of the network according to financial constraints related to the exchange rate and customs fees. Hammami et al. [14] presented a supply chain network design model, which is a multi-product, multi-level, and multi-factory MILP model considering transfer price, supplier deployment cost, and cost allocation. Thevenin et al. [32] introduced a stochastic linear programming model for supply chain planning, similar to an asset and debt management model. The model includes constraints related to financial flow management and debt to maximize the expected value of net cash in the planning horizon.

Compared to other related works, the main contribution and novelty of this research is the simultaneous modeling of financial and physical flow in the supply chain. Moreover, the marginal contributions of this research are as follows:

- Optimizing a master planning model aims to maximize the producer's profit and minimize the deviations of the financial indicators from the optimal limits.
- Realization of the supply chain profit by considering different Financial parameters.
- Implementation of goal programming to handle all objective functions simultaneously.
- Presenting a new solution method approach for multi-objective models by combining mathematical programming and Selim and Ozkarahan (SO) and Torabi and Hassini (TH) approaches

It should be noted that using the fuzzy multi-objective TH and SO approaches, along with goal programming, enables the decision maker to make the final decision by choosing the appropriate solution based on the degree of satisfaction and priority of each objective function. Moreover, this approach is able to produce efficient, balanced and unbalanced solutions according to the decision-maker's preference.

3. Research Methodology

Figure 1 shows the structure of the chain investigated in this research. In this supply chain, a manufacturer produces different products using different raw materials that are provided by a set of suppliers located in foreign countries. Final products are delivered to different customers based on their demands. The manufacturer can order from a limited number of potential suppliers in each period. Therefore, the manufacturer considers factors such as the selling price of raw materials, exchange rates, customs duties, transportation costs, and transportation insurance of purchased materials to allocate orders to suppliers.

The proposed model makes decisions related to the amount of purchase of raw materials, the amount of production, the level of inventory of raw materials and finished products, and the amount of distribution of finished products under the limitation of financial and operational resources with the aim of maximizing the company's profit and minimizing the deviations of financial indicators from their desired limits. One of the prominent features of the proposed model is financial flow modeling with the help of goal programming.

The purpose of this research is to determine the best medium-term (less than one year) multi-period program with the goals of maximizing profits and minimizing the deviations of financial indicators from their optimal limits (defined by decision-makers) by considering operational and financial limitations in a joint and integrated manner for the following issues:

- Supply plan: the purchase amount of each material from each supplier in each period
- Production plan: the amount of production of each final product in each period
- Distribution schedule: the number of each final product to be delivered in each period
- Financial management: determining the amount of investment, the amount of equity, the amount of debt, the number of accounts receivable, the amount of cash, etc., in each period.

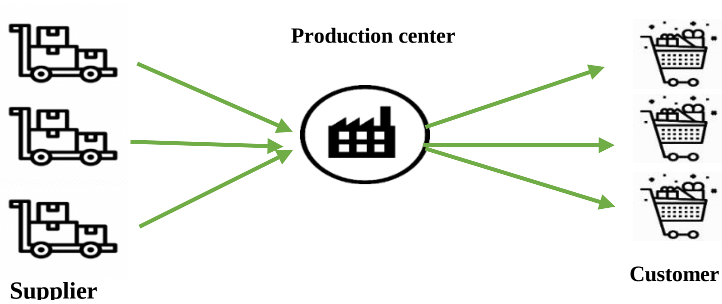

Figure 1. Structure of the investigated supply chain

The assumptions used in modeling the problem are as follows:

1. The supply chain is global, and raw material suppliers are based in other countries.
2. The facility capacity is limited at the producer level.
3. Each of the considered suppliers has the ability to supply all raw materials.
4. Suppliers do not have a supply limit and are able to produce the entire amount ordered.
5. The logistics network is multi-product.
6. The presented model is multi-period.
7. The number and location of customers, suppliers and production center is fixed and known in advance.
8. The production center has a safety stock (SS) of raw materials and finished products.
9. The transportation time between the components of the supply chain is considered insignificant.
10. Customers' demands must be answered at the end of each period, and it is not possible to fulfill them in subsequent periods.
11. Inventory of raw materials and manufactured products are transferred from one period to the next.
12. In each period, the amount of total assets is equal to the amount of total liabilities.
13. Total liabilities in each period are equal to the amount of short-term debt, long-term debt and equity in each period.
14. Current assets in each period are equal to the sum of cash, accounts receivable and inventory value in each period.
15. The total debt rate in each period is lower than the maximum optimal rate.
16. The turnover rate of fixed assets in each period is higher than the minimum optimal rate.
17. The ratio of current assets to short-term liabilities is greater than the minimum desired value in each period.
18. The company's profit margin rate is higher than the minimum desired rate.
19. The money coverage rate in each period is higher than the minimum optimal rate.
20. The return rate of assets in each period is higher than the minimum desired rate.
21. The rate of return of shareholders' assets in each period is higher than the minimum optimal rate.
22. The turnover ratio of accounts receivable in each period is higher than the minimum desired value.

3.1. Problem formulation

Indexes:

$i = 1, \dots, I$i: Index of raw materials

K: index of final products $k = 1, \dots, K$

J: Index of suppliers $j = 1, \dots J$

L: index of customers $l = 1, \dots, L$

T: Index of time periods $t = 1, \dots T$

N: Index of financial metrics $n = 1, \dots, N$

Parameters:

d_{klt}	Customer l's demand for product k in period t	$lcap_t$	The minimum amount of production of product k in period t that is economical.
$ucap_t$	The maximum production capacity of product k in period t	b_{ik}	The amount of material i needed to produce each unit of product k
vr_i	The amount of volume required to store each unit of material i purchased	vf_k	The amount of volume needed to store each product unit k
wr	Storage capacity (by volume) of the manufacturer's receiving warehouse	wf	The storage capacity (in terms of volume) of the warehouse of the shipped goods
c_{ijt}	The purchase price of each unit of raw material i from supplier j in period t	hr_i	The cost of maintaining each unit of material i in period t
pc_{kt}	Variable production cost of each unit of product k in period t	hf_k	The cost of keeping each unit of product k in the production center in period t
ssf_{kt}	The confidence reserve of product k in period t	ssr_{it}	Safety stock of raw material i in period t
olc_{jt}	Cost of ordering one unit from supplier j in period t		

Financial flow parameters:

CFP_t	Cash rate at the end of period t	DR_t	Depreciation rate at the end of period t
tpc_{klt}	The cost of transporting each unit of product k from the production center to the customer l at the end of period t	$FATR_t$	The lower limit of the turnover rate of fixed assets at the end of period t
pr_{kt}	The selling price of each unit of product k at the end of period t	$LTDR_t$	The upper limit of the long-term debt rate at the end of period t
nhg_t	Customs duty rate at the end of period t	LTR_t	Long-term interest rate at the end of period t
CCR_t	The lower bound of the money cover rate at the end of period t	PMR_t	The lower limit of the profit margin rate at the end of period t
ex_t	Exchange rate at the end of period t	$ROAR_t$	Minimum rate of return (return) of assets at the end of period t
trp_{ijt}	The cost of transporting each unit of raw material i from supplier j to the production center during period t	$ROER_t$	The lower limit of the rate of return of shareholders' equity at the end of period t
STR_t	Short-term interest rate at the end of period t	nmv_t	Import value-added tax rate at the end of period t
TDR_t	The upper limit of the total debt rate at the end of period t	FAI_t	The amount of investment for fixed assets during the period t
tr_t	Income tax rate at the end of period t	nag_t	Customs duty rate at the end of period t
qr_t	The lower limit of the instantaneous ratio at the end of period t	DER_t	The upper limit of the debt-to-equity rate at the end of period t
rtr_t	The lower limit of the accounts receivable turnover ratio at the end of period t	bi_{it}	Transport insurance per unit of raw material i at the end of period t in dollars

Decision variables:

x_{ijt}	The amount of material i purchased from supplier j in period t	d_{nt}^{-}	The amount of downward deviation of financial index type n in period t
p_{kt}	The production amount of product k under in period t	d_{nt}^{+}	The amount of upward deviation of financial index type n in period t
S_{klt}	Quantity of product k shipped to customer l in period t	$CASH_t$	The amount of cash available at the end of period t
Ir_{it}	The final inventory level of material i in the production center in period t	DPR_t	Depreciation at the end of period t
If_{kt}	The final inventory level of product k at the production center in period t	$EBIT_t$	The amount of income before paying interest and taxes at the end of period t

y_{jt}	1 if supplier j is given an order in period t, 0 otherwise	E_t	Total shareholders' capital at the end of the period
FA_t	Fixed assets at the end of period t	RA_t	Accounts receivable at the end of period t
IP_t	Interest paid at the end of period t	STL_t	Short-term liabilities at the end of period t
INR_t	Inventory value at the end of period t	LTL_t	Long-term liabilities at the end of period t
NTS_t	Net sales at the end of period t	TI_t	Taxable income during period t
NIS_t	New shares at the end of period t	TIP_t	Taxable operating income during period t
NE_t	New shareholders' capital during period t	CA_t	Current assets at the end of period t Accounts receivable at the end of period t
$NOPA$	Net operating income after tax at the end of period t		

3.1.1. Objective Functions

Two important objective functions have been considered for the supply chain master planning (SCMP) problem: total profit (TPRO) and total deviations of financial indicators (TDFI).

First objective function: maximization of producer's net profit. The company's net profit is equal to the difference between the net income after tax deduction and the company's loss and is calculated according to Eq. (1). It should be noted that $t + TI$ means that the income before paying the company tax is positive and is subject to income tax, and t-TI means that the income before paying the company tax is negative and is not subject to income tax. Moreover, $t + TI$ and $t - TI$ are dependent variables and cannot have the opposite value of zero simultaneously.

$$Max\ PRO = \sum_{t=1}^{T}((1 - TR_t)\, TI_t^{+} - TI_t^{-}) \tag{1}$$

The amount of income before tax deduction in each period is calculated based on Eq. (2):

$$TI_t = EBIT_t - IP_t \quad \forall\, t \tag{2}$$

The amount of interest paid in each period is obtained from Eq. (3).

$$IP_t = LTR_t . LTL_t + STR_t\, STL_t \quad \forall\, t \tag{3}$$

The amount of income before paying interest and taxes in each period is calculated based on Eq. (4).

$$EBIT_t = NTS_t - TC_t - DPR_t \quad \forall\, t \tag{4}$$

Moreover, the net sales value is calculated according to Eq. (5).

$$NTS_t = \sum_{k=1}^{K} pr_k^t \sum_{l=1}^{L} S_{klt} \quad \forall\, t \tag{5}$$

In addition, the amount of depreciation at the end of each period is obtained based on Eq. (6).

$$DPR_t = DR_t\, FA_t \quad \forall\, t \tag{6}$$

The total cost of logistics includes the total cost of purchase, production and distribution and is obtained according to Eq. (7).

$$TC_t = TCO_t + TCP_t + TCD_t \tag{7}$$

The total purchase cost includes ordering costs (olc_t), the cost of purchasing raw materials (ulc_t), cost of transporting raw materials from the supplier to the manufacturer (tlc_t), transportation insurance for raw materials (goc_t), maintaining inventory of raw materials (ag_t), and customs fees (ulc_{ijt}), which can be estimated using Eqs. (8)-(16).

$$TCO_t = olc_t + ulc_t + tlc_t + goc_t \tag{8}$$

$$olc_t = \sum_{j=1}^{J} olc_{jt}.y_{jt} \tag{9}$$

$$ulc_t = \left(\sum_{i=1} \sum_{j=1} (c_{ijt} ex_t).x_{ijt} + \sum_{i=1} hr_{it} \left(\frac{Ir_{it} + Ir_{it-1}}{2} \right) \right) \tag{10}$$

$$tlc_t = \left(\sum_{i=1}^{I} \sum_{j=1}^{J} (tr_{ijt}\ ex_t)\ x_{ijt} + \sum_{i=1}^{I} \sum_{j=1}^{J} bi_{it}\ ex_t\ x_{ijt} \right) \tag{11}$$

$$goc_t = avg_t + mav_t + hog_t \tag{12}$$

$$ag_t = \left(\sum_{i=1} \sum_{j=1} ex_t\ c_{ijt}\ x_{ijt})\ x_{ijt} + \sum_{i=1} \sum_{j=1} bi_{it}\ ex_t\ x_{ijt} + \sum_{i=1} \sum_{j=1} (tr_{ijt}\ ex_t) x_{ijt} \right) \tag{13}$$

$$hog_t = ag_t\ nhg_t \tag{14}$$

$$mav_t = (ag_t + hog_t) nmv_t \tag{15}$$

$$avg_t = (ag_t + hog_t) nag_t \tag{16}$$

The variable cost of purchasing material i from supplier j in period t is obtained from Eq. (17).

$$ulc_{ijt} = c_{ijt}\ ex_t \tag{17}$$

The total cost of production (TCP_t) is equal to the sum of the variable costs of production (except the costs of raw materials) and the costs of maintaining the final inventory in the factory, which is calculated according to Eq. (18).

$$TCP_t = \left(\sum_{k=1}^{K} \left(pc_{kt}.p_{kt} + hf_{kt} \left(\frac{If_{kt} + If_{kt-1}}{2} \right) \right) \right) \tag{18}$$

The cost of distribution (TCD_t) is equal to the cost of transportation, which is calculated in Eq. (19).

$$TCD_t = \sum_{k=1}^{K} \sum_{l=1}^{L} tc_{klt}.s_{klt} \tag{19}$$

Second objective function: Minimizing the deviations of financial indicators from the desired limits. Because the final performance of the supply chain is affected by financial performance, financial flow management is very important. The study of financial flows is usually focused on the analysis of financial ratios. Financial ratios are indicators that analyze the company's financial position. For the optimization of financial indicators, goal programming (GP) has been used. For this purpose, the optimal limit of each index is determined according to the existing standards, and then, according to the goal programming, an attempt has been made to minimize the deviations of the financial indicators of the company's production center from the optimal limits.

The objective function related to the minimization of the deviations of the producer's financial indicators from the optimal limits is defined in the form of Eq. (20).

$$Min\ TDFI = \sum_{t=1}^{T} (w_1.d_{1t}^{+} + w_2.d_{2t}^{-} + w_3.d_{3t}^{-} + w_4.d_{4t}^{-} + w_5.d_{5t}^{-} + w_6.d_{6t}^{-} + w_7.d_{7t}^{-} + w_8.d_{8t}^{-}) \qquad (20)$$

3.1.2. Constraints of the Model

Inventory level constraints: The constraints of adjusting the inventory level in the factory are summarized as Eqs. (21)-(27).

$$Ir_{it-1} + \sum_{j} (x_{ijt}) - Ir_{it} = \sum_{k=1}^{K} b_{ik}.p_{kt} \qquad \forall\, i,t \qquad (21)$$

$$If_{kt-1} + p_{kt} - If_{kt} = \sum_{l=1}^{L} s_{klt} \qquad \forall\, k,t \qquad (22)$$

$$s_{klt} = d_{klt} \qquad \forall\, k,t,l \qquad (23)$$

$$Ir_{it} \geq ssr_{it} \qquad \forall\, i,t \qquad (24)$$

$$If_{kt} \geq ssf_{kt} \qquad \forall\, k,t \qquad (25)$$

$$y_{jt} \leq x_{ijt} \leq y_{jt}\ M \qquad \forall\, i,t,t \qquad (26)$$

$$\sum_{j=1}^{J} y_{jt} \leq 2 \qquad \forall\, t \qquad (27)$$

Constraints (21) and (22) of the adjustment equation are the inventory of finished products and raw materials in the manufacturer's warehouses. Constraint (23_ indicates that customer demand for each product in each period must be satisfied in the same period. Constraints (24) and (25) represent the amount of safety stock of raw materials and finished products in the manufacturer's warehouses. Constraint (26) indicates that only suppliers who have been selected during that period are purchased. Constraint (27) shows that in each period maximum of 2 suppliers can be selected from the set of suppliers.

Capacity constraints: Eq. (28) shows the producer's production capacity in each period.

$$lcap_{kt} \leq p_{kt} \leq ucap_{kt} \qquad \forall\, k,t \qquad (28)$$

Eq. (29) shows the minimum acceptable order quantity from the customer that is economically viable.

$$\sum_{k=1}^{K} s_{klt} \geq ls_l \qquad \forall\, l,t \qquad (29)$$

Eqs. (30) -(31) show the space limitations of the manufacturer's receiving and sending warehouses.

$$\sum_{i=1}^{I} vr_i\,.\,Ir_{it} \leq wr \qquad \forall\, t \qquad (30)$$

$$\sum_{k=1}^{K} k\,.\,If_{kt} \leq wf \qquad \forall\, t \qquad (31)$$

Finally, the limitation of each variable is illustrated in Eqs. (32) -(33).

$$y_{jt} \in \{0,1\} \qquad \forall\, j,t \qquad (32)$$

$$x_{ijt}, p_{kt}, s_{klt}, If_{kt}, Ir_{it} \geq 0 \qquad \forall\, i, j, k, t \tag{33}$$

Cash flow constraints: The net operating income after tax deduction in each period is obtained from Eq. (34).

$$NOPAT_t = (1 - TR_t).TIP_t \qquad \forall\, t \tag{34}$$

The operating income in each period is obtained from Eq. (35).

$$TIP_t = NTS_t - TCP_t - TCD_t - olc_t - ulc_t - tlc_t \qquad \forall\, t \tag{35}$$

Eq. (36) states that total liabilities must be equal to total assets.

$$FA_t + CA_t = E_t + STL_t + LTL_t \qquad \forall\, t \tag{36}$$

This Equation shows that the sum of fixed assets (FA_t) and current assets (CA_t) should be equal to the sum of total liabilities, which includes: long-term liabilities (LTL_t), short-term liabilities (STL_t) and equity (E_t).

The amount of current assets in each period is obtained from Eq. (37).

$$CA_t = C_t + RA_t + INR_t \qquad \forall\, t \tag{37}$$

According to this Equation, current assets are: cash (C_t), receivable accounts (RA_t) and inventory (INR_t).
The amount of cash in each period is obtained from Eq. (38).

$$C_t = CFP_t + NOPAT_t + STL_t + LTL_t + NIS_t - FAI_t \qquad \forall\, t \tag{38}$$

In this regard, CFP_t is a percentage of after-tax income that is in cash. NIS_t and FAI_t represent the income from issuing new shares and the amount of investment for fixed assets, respectively.
The value of the network inventory in each period is calculated as Eq. (39).

$$INR_t = \sum_{k=1}^{K} pc_{kt}\,(If_{kt}) \qquad \forall\, t \tag{39}$$

The amount of accounts receivable in each period is obtained from Eq. (40).

$$RA_t = (1 - CFP_t)\, NOPAT_t \qquad \forall\, t \tag{40}$$

The amount of fixed assets in each period is obtained from Eq. (41).

$$FA_t = FAI_t \qquad \forall\, t \tag{41}$$

The amount of fixed assets in each period is equal to the amount of investment for fixed assets in period t.
The total share capital in each period is obtained from Eq. (42).

$$E_t = NOPAT_t + NIS_t + INR_t \qquad \forall\, t \tag{42}$$

The total share capital in each period is equal to the sum of net operating income, network inventory value and new share issue proceeds.

In the following, the financial ratios that show the economic performance of the organization at different levels are shown.

Eq. (43) shows the lower limit of the instantaneous ratio. This ratio is a more accurate indicator of a company's ability to pay its short-term debts. In this ratio, the warehouse stock is excluded from the total current assets that can be converted into cash are considered. The quick ratio is used to measure how well the company can pay short-term financial obligations without relying on inventory[2].

$$\frac{CA_t - INR_t}{STL_t} + d_3^+ - d_3^- = QR_t \qquad \forall\, t \tag{43}$$

Eq. (44) shows the upper limit of the total debt rate. This ratio is obtained by dividing the sum of debts by the sum of assets. A high debt ratio usually means that the company is forced to use more facilities to secure the required resources.

$$\frac{STL_t + LTL_t}{FA_t + CA_t} + d_1^+ - d_1^- = TDR_t \qquad \forall\, t \tag{44}$$

Eq. (45) shows the lower bound of the money coverage rate. This index shows the amount of money available to pay interest on loans and borrowings.

$$\frac{EBIT_t + DRP_t}{IP_t} + d_5^+ - d_5^- = CCR_t \qquad \forall\, t \tag{45}$$

Eq. (46) shows the lower limit of the turnover rate of fixed assets. This ratio is obtained by dividing net sales income by fixed assets. Excessive investment in fixed assets and low income from sales cause this ratio to decrease[12].

$$\frac{NTS_t}{FA_t} + d_2^+ - d_2^- = FATR_t \qquad \forall\, t \tag{46}$$

Eq. (47) shows the lower limit of the accounts receivable turnover ratio. This is an approximate indicator that shows how many times the company's accounts receivable turn into cash balances during the year. This index is often used in connection with working capital analysis. The flow of converting accounts receivable into cash balance is one of the most important indicators of the quality of the working capital of any company and shows its ability to continue the current activities of the company[12].

$$\frac{NTS_t}{RA_t} + d_8^+ - d_8^- = RTR_t \qquad \forall\, t \tag{47}$$

Eq. (48) shows the lower limit of the profit margin rate. This indicator shows the amount of profit per unit of sale.

$$\frac{NOPAT_t}{NTS_t} + d_4^+ - d_4^- = PMR_t \qquad \forall\, t \tag{48}$$

Eq. (49) shows the lower limit of the rate of return of shareholders' assets. This index shows the amount of profit per share.

$$\frac{NOPAT_t}{E_t} + d_7^+ - d_7^- = ROER_t \qquad \forall\, t \tag{49}$$

3.2. Fuzzy Interactive Multi-Objective Solving Approach

Various methods have been presented in the theoretical foundations of the subject to solve multi-objective linear programming (MOLP) problems. Among these methods, fuzzy programming methods are widely used due to the ability to calculate the degree of satisfaction of each objective function and high flexibility. The min-max approach is the first fuzzy solution approach for MOLP problems presented by Zimmermann [36]. However, this approach sometimes gives ineffective solutions [19]. To overcome the weakness in the min-max approach, Sakawa et al. presented a fuzzy interactive approach to solve MOLP problems based on the min-max approach [31]. Moreover, Lai & Hwang presented a complementary min-max approach [18]. Torabi & Hassini have presented a new single-phase approach for solving MOLP problems, which is called the TH approach. They proved analytically that their proposed method yields efficient solutions. This approach enables the decision maker to make the final decision by choosing the appropriate solution based on the degree of satisfaction and priority of each objective function [33].

TH and SO fuzzy approaches have been used to solve the multi-objective model presented in this research. TH and SO fuzzy multi-objective approaches enable the decision maker to make the final decision by choosing the appropriate solution based on the degree of satisfaction and priority of each objective function. Moreover, these approaches are able to produce balanced and unbalanced efficient solutions according to the decision maker's preference. The steps of these two approaches are as follows:

1. Determining the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS) for each of the objective functions. To determine the Positive Ideal Solution, each objective function is solved separately, and the Negative Ideal Solution is obtained as Eqs. (50) -(51).

$$Z_h^{NIS} = Min_{k=1,2}\left(Z_h\left(x_k^{PIS}\right)\right) \qquad h = 1 \tag{50}$$

$$Z_h^{NIS} = Max_{k=1,2}\left(Z_h\left(x_k^{PIS}\right)\right) \qquad h = 2 \tag{51}$$

2. Calculation of the membership function for each of the objective functions based on Eqs. (52) -(53).

$$\mu_1(x) = \begin{cases} 1 & if \quad Z_1 < Z_1^{PIS} \\ \dfrac{Z_1 - Z_1^{NIS}}{Z_1^{PIS} - Z_1^{NIS}} & if \quad Z_1^{NIS} < Z_1 < Z_1^{PIS} \\ 0 & if \quad Z_1 < Z_1^{NIS} \end{cases} \tag{52}$$

$$\mu_2(x) = \begin{cases} 1 & if \quad Z_2 < Z_2^{PIS} \\ \dfrac{Z_2^{NIS} - Z_2}{Z_2^{NIS} - Z_2^{PIS}} & if \quad Z_2^{PIS} < Z_2 < Z_2^{NIS} \\ 0 & if \quad Z_2 < Z_2^{NIS} \end{cases} \tag{53}$$

3. Converting the multi-objective mathematical programming model to Eqs. (54) -(55) using SO, TH integration function:

The TH integration function is as follows:

$$Max\ \lambda(x) = y\lambda_0 + (1-y)\sum_h \theta_h \mu_h(x) \tag{54}$$

$$subject\ to:$$

$$\lambda_0 \le \mu_h(x) \qquad h = 1,2$$

$$x \in F(x), \lambda_0\ and\ y\ \in [0,1]$$

Here $\mu_h(x)$ and $\lambda_0 = min_h\{\mu_h(x)\}$ indicate the degree of satisfaction of the objective function h and are determined based on the preferences of the decision maker in such a way that $\theta_h > 0$ and $\sum_h \theta_h = 1$. The parameter y is called "compensation coefficient" which controls the minimum degree of providing the objective function. In addition, F(x) represents the justified space of the presented multi-objective model. In this method, the decision maker can change the value of parameters y and $\theta_h$according to his preferences and achieve both balanced and unbalanced solutions.

The integration function of the multi-objective model is as follows:

$$Max\ \lambda(x) = y\lambda_0 + (1-y)\sum_h \theta_h\lambda_h \quad (55)$$

$$subject\ to:$$

$$\lambda_0 + \lambda_h \leq \mu_h(x) \qquad h = 1,2$$

$$x \in F(x), \lambda_0\ and\ y\ \in [0,1]$$

In this model, $\lambda_h$is the difference between the level of satisfaction of the objective function h and the minimum level of satisfaction of the objective functions $(\lambda_h = \mu_h(x) - \lambda_0)$.

4. The resulting single-objective models should be solved based on the values of θ_h and y. If the decision maker is satisfied with the solution of the model, the solution is complete; Otherwise, the y values are changed and return to step 3.

4. Numerical Results

In this section, to show the validity of the presented model and the used solution method, a sample test problem is solved. The dimensions of the test problems are presented in Table 1. The parameters used in the test problems are randomly generated using a uniform distribution. The formulation of the problem includes a large number of parameters. Therefore, it is not possible to display all these parameters due to space limitations. As a result, some important parameters, such as parameters of financial limits for four periods, are presented in Table 2. It should be noted that each planning period (t) is considered as three months and the entire planning period (T) is one year. Table 3 shows the values of the best and best solutions of the test problem. It should be noted that the mathematical model is optimized using GAMS software with CPLEX solver. All required experiments have been performed on a five-core computer with 4 GB of memory (RAM).

Table 1. Dimensions of sample problems

	Number of products	**Number of suppliers**	**Number of customers**	**Number of time periods**
Size of the test problem	6	5	4	4

Table 2. The best and worst possible solutions for the objective functions in the sample problem

	Maximizing the first objective	**Minimizing the second objective**
First objective value	48680500000	6797846.84
Second objective value	47296000000	6738746.84

Table 3. Financial limits of parameters[7]

Financial parameter	**Value**
current ratio	2
instantaneous ratio	1.25
Accounts receivable turnover ratio	1.6
Debt to equity ratio	1.5
Money cover rate	5
Rate of return on assets	0.01
The rate of return on shareholders' equity	0.2

Among the research items conducted in the field of financial flow modeling in the supply chain, only Longinidis and Georgiadis [19] have used financial variables and parameters to model the financial flow in the supply chain, like the present study, while other researchers in this field have modeled the financial flow as one of the variable states or parameters. Longinidis and Georgiadis [19] considered financial ratios as constraints in the model and maximized the company's profit. Placing the financial ratios within limits makes achieving desirable financial indicators the first priority for the company and the company's profit goal the second priority, while the current research has used the goal programming approach to model the financial flow. Because the financial indicators each have a specific standard or goal, the goal programming approach allows these goals to be controlled simultaneously.

Moreover, the use of the goal programming approach for financial flow modeling causes balance and flexibility to be created between the two main goals of the company, i.e., maximizing the company's profit and achieving the desired limits of financial indicators. As a result, it can be concluded that the approach of Longinidis & Georgiadis [19] for financial flow modeling is in a suitable state that the company's first priority is to achieve the desired limits of financial indicators, but the approach used in the present study is due to its high flexibility, and the combination of TH and GP can be used in different goal priority situations. In order to compare the financial flow planning approach used in the research of Longinidis & Georgiadis [19] and the approach used in the present research, the problem presented in this research is mentioned under two approaches and different values of the return on investment rate which are one of the most important indicators of the organization's profitability. The results of running the models (Table 4) show that the model presented by the method of Longinidis & Georgiadis [19] is not able to find the solution (creating the solution space) for different values of the investment return rate. Therefore, it limits the organization to specific financial goals. However, the model presented in the current research method is able to find the optimal solution for different values of the return on investment rate and has high flexibility.

Table 4. Performance evaluation of the proposed model and the Longinidis & Georgiadis model [19]

Rate of return	Objective of the proposed model	Objective of Longinidis & Georgiadis model [35]
0.674	48147400000	48178200000
0.49	47445200000	No solution
0.65	48135300000	No solution

4.1. Sensitivity Analysis

In order to compare the TH and SO solution approaches, the two solution approaches are compared by implementing the sample problem under $\theta = (0.6, 0.4)$ and different values of y, and the results of the two solution methods are presented in Table 5. As the results show, in the sample problem, the TH method performs better than the SO method. In other words, in the TH method, as the value of y increases, the difference in the level of satisfaction of the two objective functions is smaller, and with the increase of the value, the value of the worst level of satisfaction of the objective function becomes better. However, in the SO method, with the increase in the value of y, the value of the worst satisfaction level of the objective function becomes worse.

The solution of the TH method is more balanced than the SO method, and it seems that the TH method shows more importance to the minimum satisfaction level of the objective functions than the SO method. Finally, it can be concluded that both TH and SO approaches are suitable and efficient approaches for solving MOLP problems; because they achieve effective solutions. However, in the case where the decision maker gives more importance to the minimum satisfaction level of the objective functions and, in other words, seeks to achieve more balanced solutions, the TH method is more suitable.

On the other hand, because the SO method obtains more unbalanced solutions, in the case where the decision maker pays more attention to the more important objective function, this method is more suitable.

Table 5. The results of sensitivity analysis on the value of y

y	TH approach				SO approach			
	Z_1	Z_2	$\mu(Z_1)$	$\mu(Z_2)$	Z_1	Z_2	$\mu(Z_1)$	$\mu(Z_2)$
0.1	48157100000	6935351	0.62	0.91	48156800000	6935351	0.62	0.91
0.2	48157000000	6935351	0.62	0.91	48156800000	6935351	0.62	0.91
0.3	48157000000	6935351	0.62	0.91	48156800000	6935351	0.62	0.91
0.4	48157000000	6935351	0.62	0.91	48156800000	6935351	0.62	0.91
0.5	48157000000	6935351	0.62	0.91	47316800000	6935351	0.15	0.91
0.6	48157000000	6935351	0.62	0.91	47315900000	6935351	0.14	0.91
0.7	47926900000	6935351	0.45	0.91	47316800000	6935351	0.15	0.91
0.8	48155500000	6935351	0.62	0.91	47316800000	6935351	0.15	0.91
0.9	48157100000	6981542	0.62	0.89	47316800000	6935351	0.15	0.9

4.2. Comparison of Financial and Non-Financial Models

The main feature of the proposed model in this research is the integration of financial statement analysis. Therefore, in order to investigate this type of development, the results of the proposed model are compared with a non-financial model (NFM). In the non-financial model, the second goal (minimizing deviations of financial indicators) and limitations 42-51 have been omitted. In Table 6, the tactical decisions of the problem under the financial and non-financial models are compared. Accounts receivable turnover ratio and profit margin rate are two significant profitability indicators, whose values are shown under two models in Table 7.

Table 6. Comparison of financial and non-financial model tactical decisions

	Total amount of raw materials	**Total production**	**Total distribution**	**Average level of inventory**
Financial model	8212	8392	8212	161.16
Non-financial model	8212	8392	8212	0

As shown in Table 6, the total value of the distribution in the two models is equal, and the amount of distribution under the influence of restrictions in the two models is a fixed amount (equal to customer demand). Moreover, the amount of purchase and production of the two models is also the same under the influence of the constraints of the model. However, the average level of the final inventory of products in the financial model is higher than the non-financial one. Because in the financial model, due to the fact that the inventory value is considered among current assets, and its value affects the financial flow. In Table 7, it can be seen that the profit margin rate in the two models is the same in most periods. The reason for this is the constant amount of total sales and the small difference in the net income after tax in the two models. In this issue, the total amount of sales is not affected by the financial flow and depends on the amount of customer demand.

Table 7. Comparison of profit margin rate in the financial and non-financial model

Periods	**1**	**2**	**3**	**4**
Profit margin rate of the financial model (%)	65	65	65	73
Non-financial model profit margin rate (%)	65	65	69	68

According to Table 8, the accounts receivable turnover ratio in the financial model has a better situation than in the non-financial model. This situation is due to giving importance to the amount of accounts receivable in the financial model and ignoring its amount in non-financial.

Table 8. Comparison of accounts receivable turnover ratio in financial and non-financial models

Periods	1	2	3	4
Accounts receivable turnover ratio of the financial model	4.65	3.97	4.63	3.48
Accounts receivable turnover ratio of non-financial model	5.54	3.9	3.65	3.7

Considering the financial and physical flow in a coordinated way makes the value of ratios and financial rates closer to the optimal state, and the model is closer to the real world. Examining the results of the model indicates that tactical decisions have a significant impact on the financial variables of the model. Moreover, the value of some financial parameters significantly impacts the company's profit and some tactical decisions. Therefore, simultaneous consideration of physical and financial flow in problem modeling is necessary for the effective chain management. Validation of this research includes showing the validity of the proposed model and the used solution method. The validity of the solution method (TH) used is shown by comparing it with another solution approach (SO). On the other hand, to show the proposed model's validity, the results of the proposed financial model were compared with its non-financial model, and the analysis of the results of the two models showed the superiority of the proposed model compared to the non-financial model.

5. Conclusions and Future Directions

The financial aspect of the supply chain is an important issue while simultaneously planning production and distribution [23,16]. In this research, a mathematical model for master planning (production, distribution and procurement in an integrated manner) is proposed in order to maximize the profit of the manufacturing company and minimize the deviations of the financial indicators of the manufacturing company from the optimal limits by considering the physical and financial flow simultaneously. In this regard, the decisions related to procurement, production, distribution and financial decisions (investment, debt, equity, etc.) are optimized due to the limitation of operational resources and financial limitations due to the exchange rate, duties, value-added tax, income tax and insurance.

One of the prominent features of the proposed model is the use of goal programming to handle all objective functions simultaneously. The solution method in this research is the multi-objective fuzzy SO and TH approaches, which have been widely used in solving multi-objective problems due to their ability to calculate the degree of satisfaction of several objective functions. These approaches are able to produce balanced and unbalanced efficient solutions according to the decision maker's preference.

The computational results showed the proposed model's efficiency and the high quality of performance and applicability of the proposed model. Accordingly, two financial and non-financial models were compared to show the proposed model's efficiency and high quality of performance and applicability. The results of the comparison of these two models indicated that considering the financial and physical flow in a coordinated manner, the ratio and financial rates are closer to the optimal state, and the model is closer to the real world. Examining the results of the models indicates that tactical decisions have a significant impact on the financial variables of the model. The core achievement in the numerical results is that the total value of the distribution in the two models is equal. However, the SO method obtains more unbalanced solutions when the decision maker pays more attention to the first objective function.

Finally, the value of some financial parameters significantly impacts the company's profit and some tactical decisions. Therefore, it is indispensable to consider the physical and financial flow in problem modeling for the effective chain management.

The following items can be suggested for the direction of future research.

- In today's world, disruptions can cause organizations to face great losses and lose many of their customers due to the dependence on supply chain members. Paying attention to this can cause higher chain reliability and is considered a competitive advantage for the organization in front of its competitors. Therefore, it is suggested to model the global supply chain in the condition of disruption in future research.

- Considering that in the real world, issues such as the time value of money and the inflation rate affect the cost of supply chain members. Therefore, it is suggested to present a model that pays attention to the time value of money and the inflation rate in cost calculations.
- It is difficult to predict the exact value of some parameters, such as the exchange rate (due to the fluctuations of the exchange rate and demand (due to the lack and inaccuracy of information in the medium term). Therefore, it is suggested that to make the model more realistic, the master planning model for providing a supply chain in which demand and exchange rate parameters are considered non-deterministically.

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