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RESEARCH PAPER

A Bi-objective Model for Mineral Supply Chain Network Design Considering Social Responsibility and Solving by a Novel Fuzzy Multi-choice Goal Programming Method

Fatemeh Hajisoltani[1], Mehdi Seifbarghy[2] & Davar Pishva[3*]

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ABSTRACT

The main objective of this research is effective planning as well as greener production and distribution of mineral products in supply chain network. For such achievement, it employs a novel fuzzy multi-choice goal programming approach to address the conflicting nature of its objective functions and their associated uncertainty parameters. While simultaneously maximizing the profit and improving greener production and distribution, its adjustable constraint parameter ensures compliance with certain preset maximum acceptable carbon dioxide gas emission level that are released during cement production and transportation process. The main contribution of this paper can therefore be its innovative analytical approach and customizable constraint parameter. The experimentation is done through a case study in cement industry that has several factories, each with a number of production lines, and multiple distribution centers. The proposed strategy is to leave part of the transportation operation to contractor companies, so as to enable the core company to better focus on its products' quality and also create job opportunities to local people. Although leaving part of the transportation operations to contractor companies, increases the number of vehicles used by the contractor companies, the study shows that its associated decrease in the number of required factory vehicles can improve the second objective of the model. For its modeling, it uses multi-period and multi-product mixed integer linear programming and because of the uncertainty of its cost parameters, fuzzy logic has also been employed in the process. It is solved via the novel fuzzy multi-choice goal programming approach and reliability of the method has been tested through sensitivity analysis on some key parameters. Its good efficiency is also justified by comparing the obtained results with those that are from the single-objective models. Such approach should be considered by the managers since on top of profit maximization, it can help them build an eco-friendly image. Mining industries generally generate significant amount of pollutions and companies that pay attention to different dimensions of their social responsibilities can remain stable in the competitive market.

KEYWORDS: *Green supply chain; Network design; Social responsibility; Multi-choice goal programming.*

1. Introduction

Supply chain (SC) can be defined as an integrated structure that includes purchase of raw materials, production, storage, distribution, and product control. It usually consists of suppliers, production centers, distribution centers (DCs) and customers [1]. Today, supply chain management (SCM) plays a vital role in improving companies' performances and boosting their competitiveness. In fact, SCM is science and art for creating proper communication and synergy among members. The main goal of a SC manager is to provide goods and services to the desired people, in the right amount, at a specific time, and in the most effective and efficient way [2]. Appropriate

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[*] **Corresponding author:** ***Davar Pishva***
dpishva@apu.ac.jp

1. *Department of Industrial Engineering, Faculty of Engineering, Alzahra University, Tehran, Iran.*
2. *Department of Industrial Engineering, Faculty of Engineering, Alzahra University, Tehran, Iran.*
3. *Faculty of Asia Pacific Studies, Ritsumeikan Asia Pacific University, Beppu, Japan.*

SC network design is the most important decision-making strategy in SCM, which generally includes determining the locations, number and capacities of facilities as well as checking the flow of materials among them [3].

In recent years, environmental pollution, which has emerged because of human production and consumption, is one of the issues that has been repeatedly recognized as a threat to humanity by active organizations [4]. The root cause of most SC innovations in the 20th century and until the beginning of the 21st century, were only economic reasons, and the importance of addressing greenhouse effects were neglected. However, with the passage of time and the need to protect our environment, this has become essential, and activities related to green supply chain management (GSCM) have expanded. Andiç et al introduced GSCM as: "minimizing or eliminating the negative impacts of the SC on the environment" [5].

Due to the increasing public concerns on the damages that production complexes cause to the environment, it is expected that strict relevant laws will be established and communicated to companies and production complexes. One of these environmental laws, is the control of the amount of carbon dioxide emission during their production and transportation process [6]. Another study investigated dynamic nature of SC in the real world and its activities under uncertainty conditions, which are due to changes in demand, capacity, cost, etc. The authors proposed three methods when facing uncertainty along with their subsets in the model, which include the followings: “stochastic programming (recourse models, robust stochastic programming, and probabilistic models), fuzzy programming (flexible and possibilistic programming), and stochastic dynamic programming” [7]. Due to the uncertainty of the cost parameters, this article used the fuzzy approach in order to cope up with the uncertainty in the model.

In this article, SC of the mining industry, which consists of several factories, a number of production lines in each of the factories and multiple DCs, are investigated. In its model, we are looking for the optimal allocation of materials to production lines in a multi-level SC and determining the quantities of products sent from each of the factories to the DCs. Traditionally, the most important goal in a SC is to either reduce overall system costs or increase profit from product sales. Today however, one of the most essential factors in creating a sustainable industry in the world is paying attention to environmental issues and reducing the emission of polluting gases. Mining industry like cement industry has been one of the most attractive industries due to its economic prosperity and large investments are made in this industry. Nonetheless, it is considered as one of the most polluting industries due to its high carbon dioxide emissions. In this paper, our aim is to both maximize the producers’ profit as well as minimize the generated greenhouse gases in its production and transportation process. Hence, in the proposed model, we aim to simultaneously optimize the two mentioned objective functions.

In general, there are different types of cement, which are classified into different groups according to their similarity, manufacturing steps and required technology in their production lines. Types of cement that are in the same group have almost similar production steps and characteristics. Due to the diversity of production and characteristics of different cement groups and products, the existing production lines in the factories are not able to produce all of them. As such, only certain groups and types of products according to the settings of the production line are produced by default. This production process has a significant impact on the strength of cement types that are produced for different applications. Sometimes the existing production lines in factories are not able to produce all kinds of desired product groups with general changes. After preparing the production line for a certain group of products, minor adjustments will still be required to produce each type of product that belongs to these groups. Manufactured products are then sent from factories to DCs. From the point of view of social responsibility (SR) and job creation, however, it is necessary to entrust part of the transportation of produced cements to the contractors of that region. Furthermore, contractor companies produce less polluting gases than factories due to their expertise and the use of modern equipment. Nonetheless, since the contractor companies impose more costs on the factories, simultaneous optimization of these two functions is considered.

The remainder of this paper is organized as follows. The related literature is reviewed in Section 2. Section 3 describes the Mixed-Integer Linear Programming (MILP) which is used for our modeling. In Section 4, novel fuzzy multi-choice goal programming (MCGP) method, which is used to solve the model is presented along with its numerical and sensitivity analyses on some input parameters. Finally, Section 5 summarizes the obtained results and suggests directions for future research.

2. Literature Review

The term SCM for scientific and managerial purpose was initially proposed in the early 1980s by Oliver and Weber. In this definition, they mentioned the potential benefits of combining business activities such as purchasing raw materials, production, sales and distribution [8]. Until then, most of the manufacturers were the owners of their factories and they controlled the volume of production, sales offices, inventory status, customer orders and process of work progress [9].

In recent decades, with the growth of multinational companies, increasing competition at international levels, improving information technology, and increasing customer expectations, detailed planning regarding SCM has become quite important [10]. SCM is a set of methods used in order to create coordination between suppliers of raw materials, manufacturers, warehouses and retailers so as to minimize costs and meet customer expectations [11].

Global warming and its adverse environmental impacts have led people from different parts of the world, including researchers, academicians, doctors, and scientists to coordinate and find ways to protect the environment. Academicians and professionals proposed the concept of GSCM as a potential solution to improve environmental performance. Although the concept of GSCM was proposed in the early 1990s, significant growth of this topic in academic articles and books since 2000 indicates its increasing popularity in the last two decades [12].

GSCM is an idea to minimize harmful environmental effects and maximize productivity in all stages of the SC, including supply of resources, product production, packaging, storage, transportation, and disposal [13].

In 2007, Zhu & Dou investigated the reasons for implementing GSCM in the Chinese automobile industry [14]. From their point of view, the most important factors that put pressure on organizations to adopt GSCM are consumer pressure, lack of resources, other competitors' green solutions, the organization's environmental mission, as well as international laws and regulations. In 2011, Wang et al presented the problem of SC network design with environmental considerations. They proposed a multi-objective optimization model in order to balance the total system cost and the associated environmental effects [15].

In 2013, Özkır & Başlıgil considered the closed loop supply chain (CLSC) under conditions of uncertainty and recycling processes [16]. Their goals included increasing the desired level of transactions among the chain, customer satisfaction as well as the overall profit of the CLSC.

In recent years, researchers and planners emphasize the importance of paying attention to SR in commercial and corporate units. Since SCs play an important role in improving the business environment, it is quite important to pay attention to its SR. This should be considered during its design and planning stage, so as to move the SC towards sustainability. In 2012, Pishvaee & Razmi designed a green logistics network in fuzzy uncertainty environment to minimize the environmental impacts and the cost [17].

In 2012, Elhedhli & Merrick proposed the issue of designing the SC network by considering the costs related to carbon dioxide emissions as well as the fixed and variable costs of facility location and product production [18]. They showed the relationship between carbon dioxide emissions and vehicle weight using a concave function and employed the Lagrange method to solve the model. In 2012, Shaw et al investigated an integrated approach for selecting suitable suppliers and reducing carbon dioxide emission [19]. They used the fuzzy Analytic Hierarchy Process (AHP) to analyze the weights of various factors such as cost, quality, percentage of returned products, percentage of delivery delays, and the amount of greenhouse gas emissions.

Using the fuzzy modeling in 2013, Lin examined the factors affecting the implementation of GSCM by introducing eight criteria, including green purchasing, customer participation, product renovation and recycling, green design, stakeholder pressure, environmental performance, and economic performance [20]. In 2016, Seles et al investigated the effect of leather whip on its numerous stakeholders in the implementation of GSCM [21]. They showed that environmental pressures of final consumers, such as increase in green product demand, banning of harmful products' purchase, and formulation of relevant policies make manufacturers and suppliers turn to GSCM.

In 2015, Fahimnia et al developed a two-objective optimization model to minimize the total cost and the amount of greenhouse gases produced [22]. They suggested that moving towards GSCM will lead to a higher level of productivity, meet the needs of society and increase environmental quality at the local and global level. On top of increasing commercial profitability, it considered product quality and environmental protection. In another study, they created a model to show a tradeoff between SC costs and issues related to environmental degradation, including the amount of carbon released, energy consumption, as well as production waste during production and inventory maintenance [23].

In 2018, Liu et al presented a bi-objective model in order to minimize the total cost and maximize customer satisfaction. They considered customer satisfaction in logistics speed, product quality and product recycling rate. For small scale problem, they used the epsilon constraint method in order to obtain the exact Pareto front, and for medium and large problem they employed MOSA and NSGA-II [24].

In 2018, Sahebjamnia et al proposed a multi-objective MILP model for designing a closed-loop tire SC network [25]. In 2019, Fakhrzad & Goodarzian presented a three-objective model in order to minimize the total cost, the gas emission costs caused by transportation between centers, and maximize the reliability of demand delivery [26]. For its practical application in the real world, they considered parameters of the model as fuzzy. In 2020, Babagolzadeh et al conducted a study for combining sustainability criteria with SC concepts. By linking this approach to mathematical planning, environment, economy and social effects were considered simultaneously [27].

In 2020, Zhou et al investigated a CLSC with the two objectives of maximizing the company's profit and improving customer satisfaction in a fuzzy environment. They considered all cost components (including transportation, production, deployment, etc.), customer needs, delivery time, recovery rate, and other factors that could not be accurately estimated during design, in the form of triangular fuzzy numbers [28].

As can be seen from the above literature review, numerous approaches have been used for effective SCM. On top of those, Table 1 shows specifications and features of some additional published research that have concentrated on GSCM [29-43], which are arranged in the ascending order of their published year. It reveals the significant growth and popularity of GSCM during the last two decades as well as the different approaches that have been explored for its achievement. The originality of this work can also be easily traced from its “Analytical Approach” column.

Tab. 1. Brief outlook of some additional published articles on GSCM

Year, Authors Ref	Objectives		Analytical Approach	Model	Multi product	Multi periods	Uncertainty
	Min (costs) Or Max (revenue)	Min environmental impacts, e.g., total emissions, etc.					
2011, Paksoy et al [29]	Min	✓	Commercial packages	LP	✓	-----	-----
2012, Amin & Zhang [30]	Max	-----	Commercial packages	MILP	✓	-----	-----
2012, Mallidis et al [31]	Min	✓	Commercial packages	MILP	-----	-----	-----
2014, Sazvar et al [32]	Min	✓	Compromise programming (a posteriori method)	MINLP	-----	✓	Stochastic programming model
2015, Accorsi et al [33]	Min	✓	Commercial packages	MILP	✓	-----	-----
2015, Saffar et al [34]	Min	✓	ε-constraint method and multi objective differential evolutionary algorithm	MILP	✓	✓	Fuzzy programming model
2019, Ghahremani Nahr et al [35]	Min	✓	Individual Optimization, Sum Weight Method, LP-Metrics, Torabi-Hassini , Displaced Ideal Solution	MINLP	✓	✓	Robust optimization

2019, Yavari & Zaker [36]	Min	✓	LP-metric method	MILP	✓	✓	-----
2019, Mardan et al [37]	Min	✓	Benders decomposition algorithm	MILP	✓	✓	-----
2021, Fatemi Ghomi et al [38]	Max	✓	particle swarm optimization algorithm, ε-constraint and NSGA II	MILP	✓	✓	-----
2021, Shahedi et al [39]	Max	✓	Augmented ε-constraint method & metaheuristic grasshopper optimization algorithm	MILP	✓	✓	Fuzzy programming model
2021, Tobeh et al [40]	Min	✓	ε-constraint & NSGA II	MINLP	✓	✓	probabilistic model
2021, Khalilabad et al [41]	Min	✓	ε-constraint, Goal programming, Goal attainment, Global criteria	MINLP	-----	-----	Hybrid probabilistic chance-constrained programming
2022, Ameli et al [42]	Max	✓	LP-metric and max-min methods	MINLP	✓	✓	Scenario-based approach
2022, Karampour et al [43]	Max	✓	ε-constraint, NSGA II, Multi-Objective of Keshtel Algorithm (MOKA) and Multi-Objective of Red Deer Algorithm (MORDA)	NLP	-----	-----	-----
The Current Research	Max	✓	Novel fuzzy MCGP	MILP	✓	✓	Fuzzy programming model

Abbreviation Notes: LP = Linear Programming, NLP = Nonlinear Programming, MILP = Mixed-Integer Linear Programming, MINLP = Mixed Integer Nonlinear Programming

The focus of current research in this paper is on effective planning and greener production and distribution of SC network in mining industries. Through a case study in cement industry, it considers design of the mining industry network that includes several factories with several production lines and multiple DCs. It leaves part of its products' transportation to contractor companies so as to enable the company to better focus on its products' quality and also create job opportunity for local people. Considering the high polluting nature of the cement factories, it also sets a specific objective to minimize the amount of carbon dioxide emissions. It employs a multi-period and multi-product MILP model to both maximize the profit of the factory as well as minimize its carbon dioxide gas emissions which are released during its cement production and transportation process. The large feasible area of its novel fuzzy MCGP can be quite handy for decision makers' numerous needs. Its other advantage is that there is no need to determine the ideal solution and only defining the upper and lower bounds is sufficient.

3. Problem Statement and Modeling

This section initially states the problem and presents its associated model. It then goes to the details of the model, its parameters, settings, and underlying assumptions.

At the outset, it is worth mentioning that mining industry, especially the cement industry, is one of the basic industries. On top of its essential role in the development of economic infrastructures, it has many other application areas. Such roles have caused producers to pay special attention to the development of this industry in recent years. Despite such essential roles and the associated economic benefits, cement production pollutes air and causes environmental damage. The aim of this research is to maximize the associated economic benefits of the producers, while minimizing carbon dioxide emissions, which are released during cement productions and their transportations.

In the model, we examine production and distribution network of cement products in order to fulfill customer orders at the planning stage. The supply network consists of several factories that send finished products to different DCs.

Customers consist of individuals and organizations who purchase cement in order to advance their goals and projects. There are different types of cement products, each having different characteristics and usage in the industry and construction. The production steps of each of these cement types are different and we categorize products that have almost similar manufacturing steps as one product group. Since the production stages of each group of products are different, according to the technology and method used in each production line, each production line will be able to produce a certain group of products by default. Of course, by spending additional time and money, they can produce other groups of products as well. Nonetheless, due to their huge installation and operation costs, no factory in general has all the production lines. Through a general adjustment and moderate overhead, however, each production line can produce different products of each group, each of which via minor method adjustments. Table 2 shows the mentioned categories and various cement types in each group.

Tab. 2. A list of cement categories and their associated cement types

Number	Cement Categories	Cement Types
1	Portland Cement	Portland Cement Type 1: Ordinary Cement
2		Portland Cement Type 2: Modified Cement
3		Portland Cement Type 3: Quick Setting Cement
4		Portland Cement Type 4: Slow Setting Cement
5		Portland Cement Type 5: Anti-Sulfate Cement
6	Mixed Cement	Pozzolanic Portland Cement
7		Lime Cement
8		Laying Cement
9	Aerated Cement	Aerated Cement
10	Construction Cement	White Cement
11		Colored Cement

Several DCs are also included in the model where the products are sent after production. Each of these DCs must be able to meet the needs of customers and supply a wide range of products. Inventory of each product in the DCs is calculated based on the number of incoming products, demand, and inventory of the previous period. Although no capacity limit has been considered for the DCs, the associated cost of keeping the products is included in the model.

The production of products entails different costs and income for the producer. Maximizing the overall profit of the producer is considered as the first objective function of the problem. Considering that the production and transfer of the products to DCs cause carbon dioxide emission, which is harmful to the environment, a second objective function is also used to minimize such emissions.

One of our main strategies in this model is to leave part of the transportation operation to contractor companies. This will enable the core company to focus on its products' quality, create job opportunity for local people and as well reduce carbon dioxide emission. This is mainly because the contractor companies are specialized in the field of transportation, use modern tools and equipment, and can also simultaneously serve other customers. Although such approach may initially entail higher transportation cost to the manufacturers, its numerous long-term associated benefits and our profit maximization strategy can settle the issue.

In the process of optimization, setting a certain lower bound for transportation cost and assigning the pertinent portion of the product transportation to the contractor company, can improve social image of the company and as well generate the above-mentioned benefits. Figure (1) shows schematic diagram of production and distribution system in the presented model in which its highlighted distributed roots from the plant to DCs are examples of possible routes that should be taken by the factory's and contractor company's vehicles. The arrows from Distribution centers to Customers, show the possible paths that can be used by the delivery vehicles on a case to case basis.

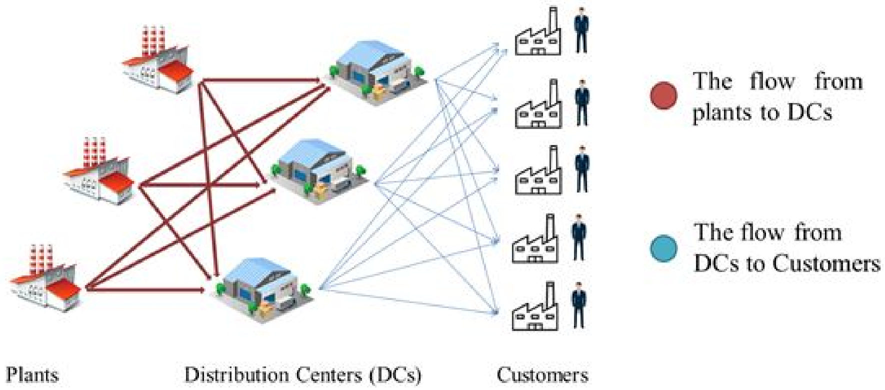

Fig. 1. Production and distribution system in the presented model

The remaining part of this section explains our assumptions, notations and proposed model.

3.1. General assumptions of the model

The proposed model is based on the following assumptions:

1. Each factory includes several production lines, and each line is equipped with technologies and production methods that can produce specific products. Through extra time, money, and general setups, desired products of this line can be produced.
2. After preparing the production line to produce a certain group of products, minor setups are still necessary to prepare the line to produce each product of that group.
3. Capacity of all vehicles used by the factory and the contractor company is considered to be the same.
4. Transportation costs and carbon dioxide emission level of the vehicles used by the contractor company are considered the same. Similar assumption is also used for the factory's vehicles.
5. The manufactured products are sent from the factory to the DCs, and the cost of transportation is based on their distance (per kilometer), the number of products to be transported, as well as the distance of the contractor company from the factory.
6. Storage of the products in each DC and their usage in future orders contain an overhead cost.

3.2. Indices, parameters, and decision variables

In this section, we define the indices, parameters, and decision variables of the model.

Index	
I	Set of products ($i \in$ I).
J	Set of product groups ($j \in$ J).
L	Set of production lines ($l \in$ L).
P	Set of factories ($p \in$ P).
L_P	Set of production lines available in the factory p.
I_j	Set of products i belongs to group j.
J_L	Group of products that are produced by default in the L line.
w	Collection of DCs ($w \in$ W).
t	Time periods. ($t \in$ T).

The following parameters are used in modeling.

P_l	Time capacity of production line l in hours.
d_{iwt}	Demand for product i in DC w during period t in kilograms.
a_{il}	The time required to produce product i in production line l in hours.
β	The minimum ratio of the amount of transportation that must be outsourced with respect to the total transportation.
V	Carrying vehicle's capacity in kilograms.
ts_{il}	Partial setup time of production line l to produce product i in hours.

TS_{jl}	Overall setup time of production line *l* to produce products of group *j* in hours.
CP_{il}	Processing cost of product *i* in production line *l*.
CL_{il}	Setup cost for product *i* in production line *l*.
CH_{jl}	Setup cost for product group j in production line *l*.
CI_{iwt}	Cost of maintaining inventory of product *i* in DC *w* during time period *t*.
CTP	Each factory vehicle's shipping cost per kilometer.
CTC	Each contractor company vehicle's shipping cost per kilometer.
Dis_{pw}	Distance between factory *p* and DC *w* in kilograms.
R_{il}	Income from the sale of product *i* produced in line *l*.
EVP	Amount of carbon dioxide emissions from each vehicle of the factory in kilograms per kilometer.
EVC	Amount of carbon dioxide emissions from each contractor's vehicle in kilograms per kilometer.
EP	Amount of carbon dioxide emissions in the process of producing products in the factory in terms of weight of the products in kilograms.
M	A very large number.

Decision variables

x_{ilt}	Production amount of product *i* in production line *l* during time period *t*.
y_{ipwt}	Amount of product *i* delivered from the factory *p* to the DC *w* during time period *t*.
I_{iwt}	Inventory level of product *i* in DC *w* at the end of time period *t*.
NP_{pwt}	Number of vehicles used between factory *p* and DC *w* during time period *t*.
NC_{pwt}	Number of vehicles used by contractor companies between the factory *p* and the DC *w* during time period *t*.
z_{ilt}	It is equal to one if product *i* is produced in production line *l* during time period *t*.
u_{jlt}	It is equal to one if the setups related to the launch of the production line *l* in order to produce product group *j* are made during time period *t*.

3.3. The objective functions

The objective functions of the model are as follows:

$$\mathrm{Max}\ \mathrm{Z}_1 = \sum_{i\in I}\sum_{l\in L}\sum_{t\in T}\mathrm{x}_{ilt}\,\mathrm{R}_{il} - \sum_{i\in I}\sum_{l\in L}\sum_{t\in T}\mathrm{CP}_{il}\mathrm{x}_{ilt} - \sum_{i\in I}\sum_{l\in L}\sum_{t\in T}\mathrm{CL}_{il}\,\mathrm{z}_{ilt} - \sum_{j\in J}\sum_{l\in L}\sum_{t\in T}\mathrm{CH}_{jl}\,\mathrm{u}_{jlt} - \sum_{i\in I}\sum_{w\in W}\sum_{t\in T}\mathrm{CI}_{iwt}\,\mathrm{I}_{iwt} - \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}\mathrm{CTC}\,\mathrm{NC}_{pwt}\mathrm{Dis}_{pw} - \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}\mathrm{CTP}\,\mathrm{NP}_{pwt}\,\mathrm{Dis}_{pw} \quad (1)$$

$$\mathrm{Min}\ \mathrm{Z}_2 = \sum_{i\in \mathrm{I}}\sum_{l\in \mathrm{L}}\sum_{t\in \mathrm{T}}\mathrm{x}_{ilt}\,\mathrm{EP} + \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}(\mathrm{NP}_{pwt}\,\mathrm{EVP}\,\mathrm{Dis}_{pw} + \mathrm{NC}_{pwt}\,\mathrm{EVC}\,\mathrm{Dis}_{pw}) \quad (2)$$

The objective function (1) represents maximization of the factory's profit which is achieved by maximizing the income from the sale of products and minimizing their associated costs. The associated costs, include cost of production, setup cost of production in lines for products, the main cost of setup for product groups in the production lines, inventory cost of products in DCs during time periods, as well as their transportation cost by the core company and contractor company.

The objective function (2) represents minimization of the amount of carbon dioxide gas released during production and products' transportation by the core and contractor company.

3.4. Constraints

Constraints of the model are as follows:

$$\sum_i \mathrm{a}_{il}\mathrm{x}_{ilt} + \sum_i \mathrm{ts}_{il}\,\mathrm{z}_{ilt} + \sum_{j\in J_L}\mathrm{TS}_{jl}\,\mathrm{u}_{jlt} \le \mathrm{P}_l \qquad \forall l,t \quad (3)$$

$$\mathrm{x}_{ilt} \le \mathrm{M}\,\mathrm{z}_{ilt} \qquad \forall\, i,l,t \quad (4)$$

$$\sum_{i\in I_j}\mathrm{z}_{ilt} \le \mathrm{M}\,\mathrm{u}_{jlt} \qquad \forall\, j,l,t \quad (5)$$

$$\sum_w \mathrm{y}_{ipwt} = \sum_{l\in L_p}\mathrm{x}_{ilt} \qquad \forall i,p,t \quad (6)$$

$$\sum_i \mathrm{y}_{ipwt} \le \mathrm{V}\,(\mathrm{NC}_{pwt} + \mathrm{NP}_{pwt}) \qquad \forall p,w,t \quad (7)$$

$$\mathrm{I}_{iwt-1} + \sum_p \mathrm{y}_{ipwt} - \mathrm{d}_{iwt} - \mathrm{I}_{iwt} = 0 \qquad \forall\, i,w,t \text{ with } \mathrm{I}_{iw0} = \text{given} \tag{8}$$

$$\mathrm{NC}_{pwt} \geq \beta(\mathrm{NC}_{pwt} + \mathrm{NP}_{pwt}) \qquad \forall p,w,t \tag{9}$$

$$\begin{aligned} &\mathrm{x}_{ilt}, \mathrm{y}_{ipwt}, \mathrm{I}_{iwt} \geq 0, \\ &\mathrm{NP}_{pwt}, \mathrm{NC}_{pwt} \geq 0, \text{and integer}, \mathrm{z}_{ilt}, \mathrm{u}_{jlt} \in \{0,1\} \quad \forall\, i,j,l,w,p,t \end{aligned} \tag{10}$$

Constraint (3) gives limitation of time capacity in each line in different time periods. It indicates that the processing time on a line cannot exceed the capacity of that line in each time period. Constraint (4) indicates that if the relevant setup is not performed, no product should be produced in different lines during time periods.

Constraint (5) ensures that the set of products belonging to a given product group will be produced in that production line during different time periods if that production line is set up for that product group. Constraint (6) indicates that the total amount of product production should be equal to the total amount of goods delivered to each DC from factories during time periods.

Constraint (7) indicates the number of required vehicles and their associated capacities that are needed to move the total products of each factory to each DC. Considering the importance of daily demand fulfilment, Constraint (8) guarantees the balance of inventory flows in different DCs. The inventory of each product in each DC at the end of each period is equal to the sum of product inventories from previous period, received amounts and demands. Constraint (9) ensures that the amount of outsourced transportation relative to total required transportation is more than the minimum predefined value **β**. Constraint (10) shows the range of decision variables of the problem.

4. Solution Techniques and Numerical Analysis

The proposed model for the cement SC is a definitive model. Calculation of its objective function is not easy due to the fuzzy nature of its cost parameters. Membership functions are used to display fuzzy sets and we use the fuzzy ideal programming method to solve the problem.

4.1. Novel fuzzy MCGP for solving fuzzy multi-objective linear programming problems

In multi-objective decision-making (MODM) problems, the decision-maker tries to find solutions for a problem with multiple objective functions based on the existing constraints, which inherently conflict with each other. In fact, it is almost impossible to find a solution that simultaneously optimizes all the objective functions. For solving such problems, two methods of interval programming and fuzzy programming have been widely used in the past. The theory of fuzzy sets has become quite attractive for solving MODM problems, since the presentation of its study was introduced by Zadeh in 1965 [44]. This issue has led to the development of Fuzzy Multi-Objective Linear Programming (FMOLP), which allows the decision-makers to set their desired levels for fuzzy objectives. Many methods for solving fuzzy multi-objective linear programming problems have been presented, such as Zimmermann's Max Mean methods in 1978 and Guu et al's two-phase method in 1999 [45-46]. These methods in general cannot give efficient answers. One of the methods for solving multi-objective planning problems is ideal planning, which transforms the problem into a single-objective problem. In the ideal planning method, an ideal value is set for each of the goals and the aim is to minimize their deviations in the objective functions. The main idea of multi-objective ideal planning is to determine levels for each of the objectives, in such a way that their optimized value cannot be outside these ranges.

This article uses a new method which was proposed by Chung et al in 2018 [47]. This approach reduces complexity of the solution process since it does not require ideal and non-ideal solutions. It should be noted that it is not easy for the decision-maker to define the exact values of the upper and lower limits. In this approach it is sufficient for the decision-maker to set a maximum acceptable value for the upper limit, and it uses zero for the lower limit. Appendix A shows the general mathematical form of the problem for better understanding of the usage of fuzzy multi-objective linear programming method in MODM problems.

4.2. Solving the model using the novel fuzzy MCGP

The following shows elements of the model as in Eqs. (11)-(18) according to our proposed algorithm,

$$\text{Min } \mathrm{d}_1^- + \mathrm{e}_1^- + \mathrm{d}_1^+ + \mathrm{e}_1^+ \tag{11}$$

$$\sum_{i\in I}\sum_{l\in L}\sum_{t\in T} \mathrm{x}_{ilt}\,\mathrm{R}_{il} - \sum_{i\in I}\sum_{l\in L}\sum_{t\in T} \mathrm{CP}_{il}\mathrm{x}_{ilt} - \sum_{i\in I}\sum_{l\in L}\sum_{t\in T} \mathrm{CL}_{il}\,\mathrm{z}_{ilt} - \sum_{j\in J}\sum_{l\in L}\sum_{t\in T} \mathrm{CH}_{jl}\,\mathrm{u}_{jlt} - \tag{12}$$

$$\sum_{i\in I}\sum_{w\in W}\sum_{t\in T}\mathrm{CI}_{iwt}\ \mathrm{I}_{iwt} - \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}\mathrm{CTC}\ \mathrm{NC}_{pwt}\mathrm{Dis}_{pw} - \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}\mathrm{CTP}\ \mathrm{NP}_{pwt}\ \mathrm{Dis}_{pw} + \mathrm{d}_1^- = \emptyset_1$$

$$\emptyset_1 + \mathrm{e}_1^- = \mathrm{g}_{1,max} \tag{13}$$

$$\sum_{i\in \mathrm{I}}\sum_{l\in \mathrm{L}}\sum_{t\in \mathrm{T}}\mathrm{x}_{ilt}\ \mathrm{EP} + \sum_{w\in W}\sum_{p\in P}\sum_{t\in T}(\mathrm{NP}_{pwt}\ \mathrm{EVP}\ \mathrm{Dis}_{pw} + \mathrm{NC}_{pwt}\ \mathrm{EVC}\ \mathrm{Dis}_{pw}) - \mathrm{d}_1^+ = \vartheta_1 \tag{14}$$

$$\vartheta_1 - \mathrm{e}_1^+ = \mathrm{f}_{1,min} \tag{15}$$

$$\mathrm{g}_{1,min} \leq \emptyset_1 \leq \mathrm{g}_{1,max} \tag{16}$$

$$\mathrm{f}_{1,min} \leq \vartheta_1 \leq \mathrm{f}_{1,max} \tag{17}$$

$$\mathrm{d}_k^-, \mathrm{e}_k^-, \mathrm{d}_s^+, \mathrm{e}_s^+ \geq 0, \quad k=1,2,\ldots,K\ ,\ s=1,2,\ldots,S \qquad \mathrm{x} \in \mathrm{F}\ , (\mathrm{F}\text{ is a feasible set}) \tag{18}$$

It is worth mentioning that the constraints of the main model, i.e., Constraints (3) to (10), are also added to the abovementioned set of constraints

4. 3. Input data of the problem

Table 3 shows a list of data that are used for solving the problem.

Tab. 3. A list of data that are used for solving the problem

Index	Data Type	Their Values
1	Number of products	11
2	Number of product groups	4
3	Number of production lines	6
4	Number of factories.	3
	Number of DCs.	3
	Number of time periods	4
5	Production lines in factory *p*	Factory 1 includes lines 1 and 2 Factory 2 includes lines 3 and 4 Factory 3 includes lines 5 and 6
6	Products *i* that belongs to group *j*	Group 1 includes products 1 to 5 Group 2 includes products 6 to 8 Group 3 includes product 9 Group 4 includes products 10 and 11
7	The group of products that can be produced in the *L* line by default	Line 1, for product group 1 and 2 Line 2, for product group 2, 3 and 4 Line 3, for product group 3 and 4 Line 4, for product group 1, 3 and 4 Line 5, for product group 2 and 4 Line 6, for product group 1, 2 and 3
8	Time capacity of production line *l*	24
9	Demand for product *i* in DC *w* in time period *t*.	Uniform [10000,20000]
10	The time taken to produce product *i* in production line *l*	Uniform [0.00002, 0.0003]
11	Partial setup time on production line *l* to produce product *i*.	Uniform [0.1, 0.3]
12	Overall setup time in production line *l* for production of product group *j*	Uniform [0.7, 2]
13	Processing cost of product *i* in production line *l*	Uniform [0.1, 0.9]
14	Setup cost for product *i* in production line *l*	Uniform [10, 30]
15	Setup cost for product group *j* in production line *l*	Uniform [200, 1000]
16	The cost of inventory holding of product *i* in DC *w* during time period *t*.	Uniform [0.00002, 0.0003]
17	The distance between factory *p* and DC *w* in km.	Uniform [40, 100]
18	Revenue from the sale of each kilogram of product *i* produced in line *l*	Uniform [0.8, 1.2]

19	The minimum ratio of the amount of transportation that must be outsourced with respect to the total transportation.	0.5
20	Vehicle capacity in kg.	18000
21	Transportation cost per kilometer of each vehicle used by the core company	120
22	Transportation cost per kilometer of each vehicle used by the contractor company	170
23	The amount of carbon dioxide gas emission from each vehicle of the core company in kg/km.	0.948
24	The amount of carbon dioxide emissions from each contractor's vehicle in kg/km.	0.758
25	The amount of carbon dioxide gas emitted in the process of producing products in the factory in terms of the weight of the manufactured products in kg.	0.9

4.4. Source of the input data and logic behind some underlying assumptions

Most of the data shown on Table 3 is based on the actual field data of our case study and the following criteria are used to estimate the remaining ones. In 2003. Mahasena et al. reported that the amount of carbon dioxide gas released per kilogram of produced cement is equal to 0.9 kg [48]. Furthermore, based on the report prepared by the European Federation for Transport and Environment AISBL, the average amount of carbon dioxide gas that are generated by each truck for transporting one ton of cargo is equal to 52.7 grams per kilometer. Thus, our estimated value of 0.948 kg for each vehicle of the company is based on this value. According to the experience of the contractor company and their use of up-to-date and modern equipment, their amount of carbon dioxide emission is around 20% lower, thus equivalent to 0.758. The initial inventory at the planning stage is considered zero. This is because we have considered the cost of maintaining the inventory that remains at the end of the last period quite large.

4.5. Generated results using single objective model approach

Using the above-mentioned parameter values, we initially calculated optimal values of the first and second objective functions in single objective models so as to know their ideal values. The optimal value of the first objective function is 629,043.073 and that of the second objective function is 1,778,331.142. Table 4 shows the pertinent number of vehicles that are used by the contractor company and the factory in the process.

Tab. 4. Number of vehicles used by the factory and contractor in the single objective solution mode

Pertinent Objective	Contractor/Factory	Intended Period	Number
single objective solution for the first objective function	Number of factory vehicles	First round	15
		Second round	13
		Third round	13
		Fourth round	13
	Number of contractor vehicles	First round	15
		Second round	15
		Third round	14
		Fourth round	13
single objective solution for the second objective function	Number of factory vehicles	First round	0
		Second round	0
		Third round	0
		Fourth round	0
	Number of contractor vehicles	First round	29
		Second round	28
		Third round	29
		Fourth round	25

The role of the first objective is to increase the overall profit of the factory and we expect that after solving the single objective, the number of vehicles used by the contractor company will be minimized due to their higher cost. However, due to the existence of Constraint 9 (ratio of the outsourced transportation to that of total transportation should be above a lower bound), a zero value cannot be generated. After solving the equations related to the second objective function, the total number of vehicles used by the factory in all periods is equal to zero, due to our objective of minimizing the carbon dioxide emission. As can be seen in Table 4, the number of vehicles used by the factory or the contractor company in different time periods has little fluctuation. This can be quite desirable from the management point of view, since it prevents needs for specific adjustments, hiring of workers, purchase or use of other vehicles thus facilitating future plans.

4.6. Results of the model using the novel fuzzy MCGP method

Considering that in multi-objective functions, there is no way to obtain absolute optimal value for each objective of the function, drawing a Pareto front is one strategy. On the other hand, weights can also be assigned to each objective function based on the decision maker's priorities, so as to obtain near optimal values for the specific high priority objective.

Table 5 shows obtained results of the model via our novel fuzzy MCGP method under different scenarios. The upper and lower bounds should be determined by the decision maker, which is within twenty percent of the optimal values that were obtained from the single objective for scenario 1 and other scenarios are considered randomly. By placing the values of the decision variables of the novel fuzzy MCGP method in the main model, the objective functions of the main model are also calculated. As it is known and expected, both values of the main objective functions of the model in all scenarios, are less optimal compared with those of the single objective approach. Their conflicting nature makes it impossible to obtain ideal optimized values when solved simultaneously thru a bi-objective model.

Table 5 shows the effect of different scenarios on the value of the objective functions of the main model. Due to the appropriate assignment of upper and lower limits, the lowest deviation of the novel fuzzy MCGP objective function has occurred in scenario 1. Figure (2) shows the values of the objective functions of the model for different scenarios. Since the first objective function is maximization and the second objective function is minimization, scenario 1 performs better than scenarios 4, 5 and 6. In this example, between scenarios 1 and 3, which represent the Pareto front, scenario 1 is considered as the basic scenario since it has a less ideal planning objective function. Assignment of the right limits and consideration of the basic scenario depends on the policies of the factory regarding which factor has more value and importance. Percentage deviation of the obtained values from the novel fuzzy MCGP method in scenario 1, and those of the single objective functions are as follows:

Percentage deviation of the first objective $$\frac{628735.133 - 629043.073}{629043.073} * 100 = -0.00048$$

Percentage deviation of the second objective $$\frac{1779232.738 - 1778331.142}{1778331.142} * 100 = -0.00050$$

The above-indicated deviation shows good efficiency for the proposed model.

Tab. 5. Values of objective functions in different scenarios

Scenario	$f_{1,min}$	$f_{1,max}$	$g_{1,min}$	$g_{1,max}$	Objective Function of the Multi-choice	Objective Function 1	Objective Function 2
1	1422665	2133997	503235	754852	482684.605	628735.133	1779232.738
2	10	2133997	10^4	754852	1897672.890	626395.706	1779216.596
3	1422665	10^{11}	503235	10^{11}	10^{11}	625286.021	1779207.148
4	0	10^{11}	0	10^{11}	10^{11}	628016.685	1779232.738
5	10	10^{11}	10^4	10^{11}	10^{11}	625041.091	1779244.110
6	10^3	10^9	10^3	10^9	1001150000	628422.743	1779256.460

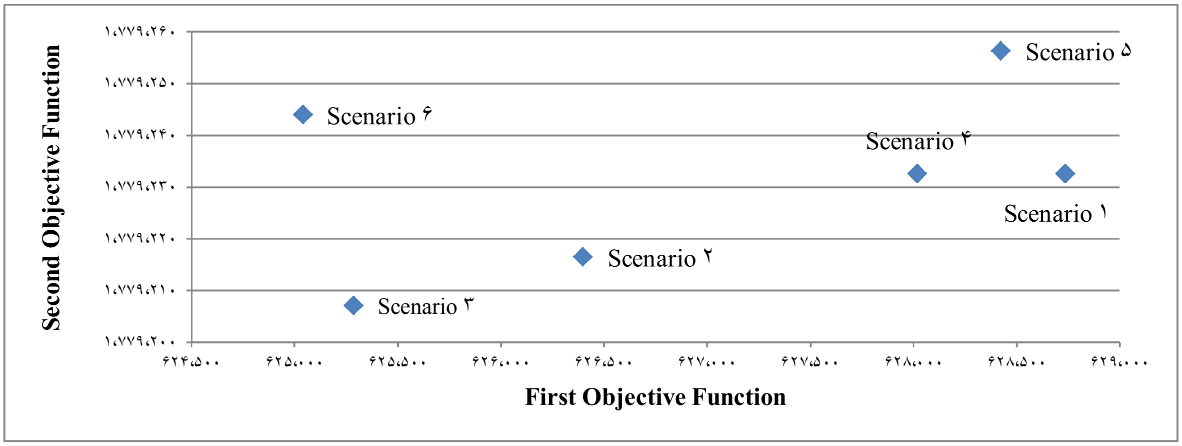

Fig. 2. Values of the objective function under different scenarios

4.7. Sensitivity analysis

In order to investigate the impact of our inputs on the objective functions and decision variables, we carried out sensitivity on the input parameters. One of the essential parameters of the model is the minimum amount of the transportation that should be outsourced. We considered different values for the parameter **β** and calculated the total number of vehicles that should be used by the contractor company and the factory. Obtained numerical results and their associated diagram are shown in Table 6 and Figures (3-4) respectively.

As can be seen in Table 6, increasing the value of **β** adversely affects objective values in the novel multi-choice approach. As the value of **β** increases, the percentage of the product transportation that must be outsourced also increases, thus increasing the number of the contractor's company vehicle and decreasing the number of the factory's vehicles. Since the transportation cost of the contractor company is higher than that of the factory, the first objective function, which is the producer's profit, decreases due to the imposition of more costs on the SC. On the other hand, due to the expertise of the contractor company in transportation and their use of up-to-date equipment, the second objective function, which is the amount of gas emitted from transportation, is reduced.

As also evident from Figure (3), increase of **β** results in the increase of contractor company vehicles and decrease of the factory vehicles. Figure (4) graphically displays the values of the objective function in terms of different values of **β**.

Tab. 6. Number of vehicles of the contractor company and the factory, as well as the values of the objective functions in terms of different values of β

Scenario	Different values of β	Total vehicles of the factory	Total vehicles of the contractor company	Objective Function of the Multi-Choice	Objective Function 1	Objective Function 2
1	0	94	17	357028.182	754852.000	1779693.182
2	0.25	78	33	400511.285	711215.881	1779540.166
3	0.5	54	57	482684.605	628735.133	1779232.738
4	0.75	24	95	579855.957	531187.543	1778856.500
5	1	0	111	660984.742	449743.366	1778541.108

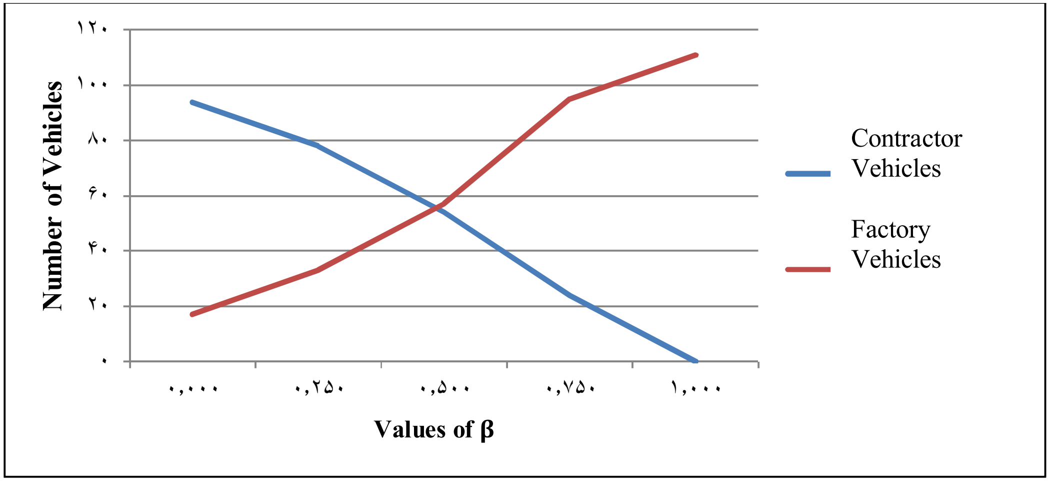

Fig. 3. Graphical view of the number of vehicles of the contractor company and the factory according to different values of β

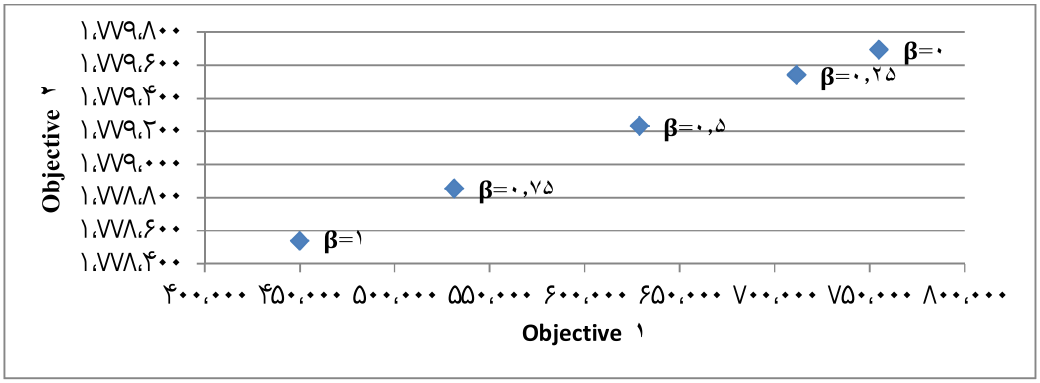

Fig. 4. Graphical view of the objective function's values according to different values of β

Table 7 shows the impact of the capacity of the contractor's vehicles on the values of the objective functions as well as on the number of required vehicles for their transportation in all periods. As mentioned earlier, the average amount of carbon dioxide emission by each ordinary truck for transporting one ton of cargo is equal to 52.7 grams per kilometer and with 20% efficiency of the contractor company truck, this will reduce to 42.16 grams (52.7*0.8) per kilometer. Hence, a fully loaded 14-ton contractor company truck will produce 0.590 kg (14*52.7*0.8/1000) carbon dioxide emission per kilometer.

Tab. 7. Impact of the capacity of the contractor's vehicles on the required number of vehicles and objective functions

Vehicle Capacity of Contractor	EVC	Number of vehicles used by factory	Number of vehicles used by contractor	Objective Function of the Multi-choice	Objective Function 1	Objective Function 2
14000	0.590	61	64	619623.722	491861.828	1779298.550
16000	0.674	57	61	549940.079	561539.253	1779292.332
18000	0.758	54	57	482684.605	628735.133	1779232.738
20000	0.843	48	56	419826.187	691460.077	1779099.264
22000	0.927	38	59	366842.930	744301.257	1778957.187

As can be seen from Figure (5), by using high-capacity contractor's vehicle, the number of required vehicles of the factory decreases drastically. The decreasing trend of the number of vehicles used by the contractor company is due to their high capacity. Thus, the focus of the model is on the use of the contractor company's capacity and decrease in their number of required vehicles. As can be seen on Table 7, increase in the capacity of the contractor's vehicles, decreases their required number, something which leads to the improvement of our first objective function (cost reduction). Due to the decrease in the number of vehicles, the second objective function of main models, which is the amount of carbon dioxide emission, has also been decreased. As such, the use of high-capacity vehicles can have a great impact on the optimization of the SC, something which needs to be considered by policy makers and managers of this field.

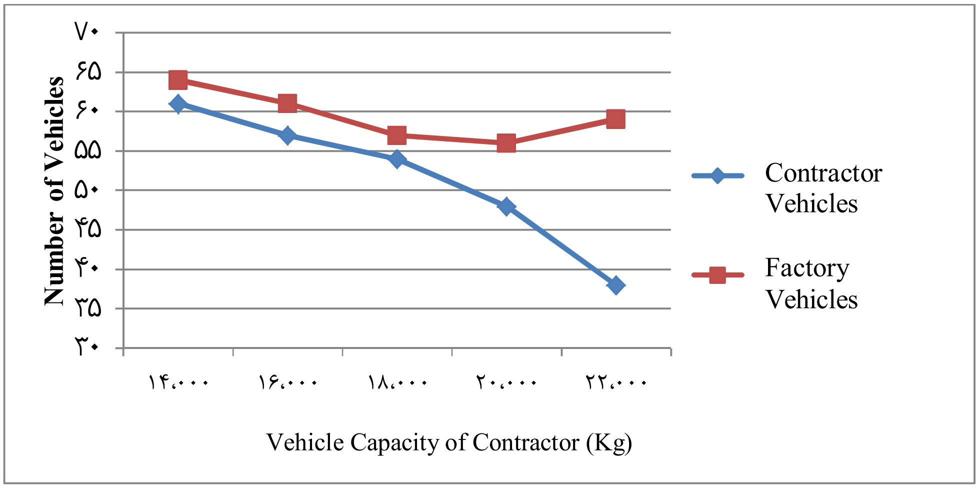

Fig. 5. Impact of the capacity of contractor's vehicles on the required number of vehicles

Table 8 deals with sensitivity and impact of production lines' capacity, on the objective functions and the number of required vehicles. As can be seen, changes in the capacity of the production lines has the greatest impact on objective function 1. Since decrease in the production lines' capacity significantly reduces the value of the objective function 1, reduction of the production lines' capacity should be avoided.

Tab. 8. Impact of the capacity of production lines on the required number of vehicles and objective functions

Production line capacity	Number of vehicles used by factory	Number of vehicles used by contractor	Objective Function of the Multi-choice	Objective Function 1	Objective Function 2
21	53	59	824896.607	286569.139	1779278.746
22	52	59	642648.977	468761.419	1779223.396
23	54	57	552451.285	558985.513	1779249.798
24	54	57	482684.605	628735.133	1779232.738

5. Conclusion and Future Research Ideas

Advent of environmental law has significantly increased social responsibility (SR) awareness as well as greener production and distribution of supply chain (SC) network. Thus, consideration of environmental impacts and their better managements have become quite important in different industries and businesses. Green supply chain management (GSCM) is one of the innovative approaches that considers this issue.

This research presented a new bi-objective, multi-product, multi-period (MILP) model for mineral SC network thru a case study of cement factories. The two goals of maximizing the factory's net profit (i.e., maximizing the factory's income and minimizing associated costs, including partial and main start-up costs, product production costs, inventory maintenance costs, and transportation costs) and minimizing the amount of carbon dioxide gas emission during the process of production and transportation of the products were considered.

It employed a novel fuzzy multi-choice goal programming (MCGP) approach to address the conflicting nature of its objective functions and their associated uncertainty parameters. Its results showed that it is possible to effectively maximize the profit and minimize carbon dioxide emission while ensuring compliance with a certain preset maximum acceptable carbon dioxide gas emission level. Reliability of the method was tested via sensitivity analysis on some key parameters and its good efficiency was also justified by comparing the obtained results with those that are from the single-objective models. Thus, achieving its aim of better planning as well as greener production and distribution of SC network, something which should be considered by the managers since on top of profit maximization it can help them build an eco-friendly image.

It considered SR and environmental issues by leaving part of product transportation to the contractor company. Such approach can help the company reduce carbon dioxide emission since the contractor company is specialized in the field of transportation and uses modern tools and equipment. It can also benefit the local people in form of job creation. On top of these, it can also help the company to focus on its main goal, which is the production of quality products.

Effects of its $\boldsymbol{\beta}$ parameter on the number of vehicles showed that its increase reduces the number of required factory vehicles thus improving the second objective function (minimizing the greenhouse gas emissions). Though such increase, also increases the required number of contractor's vehicles, the study showed that by increasing the capacity of the contractor's vehicles, both objective functions improve, something which again should be considered by managers. However, since reducing the capacity of the production lines adversely affected the profit maximization objective function, it should be avoided. Such results can provide management insight for decision makers in different fields to control the emission of polluting gases with different measures.

Considering the new and attractive nature of the field, this study employed some restrictive assumptions so as to obtain feasible results in a timely fashion. Further studies along this field can extend such limitation from various perspectives, a few of which are as follows:

- Since most constructions are usually done in summer and spring, cement demands can be considered seasonally.
- By considering several transportation contractors, a competitive environment can be created among them to further improve product transportation process.
- Considering capacity limitation of DCs is another aspect of model innovation.
- Future research might also consider the application of metaheuristic methods for solving large scale instances of the problems and compare its obtained results with those of previous findings.
- Considering business nature of the factories, they can also be pursued to pay attention to environmental issues via incentive policies. For example, a subsidy level can be considered for their efforts of reducing carbon dioxide emission in their operation process.

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Appendix A

The general mathematical form of the multi-objective linear programming method is as follows:

$$\begin{aligned} &\text{Max } z=[z_k(x)]^T \quad && k=1,2,\dots,K \\ &\text{Min } w=[w_s(x)]^T \quad && s=1,2,\dots,S \\ &\text{St.} && \\ & && X \in F \text{ (F, is the set of feasible regions)} \end{aligned} \tag{A1}$$

Where the functions of the first category are maximization type and the second category are minimization type. Based on the first model of Chung et al., through the solution of the linear programming model, a subset of Pareto solutions for the multi-objective problem can be produced. Equation (A2) shows the objective function.

$$\text{Min } \sum_{k=1}^{K}\left(\alpha_k d_k^- + \xi_k e_k^-\right) + \sum_{s=1}^{S}\left(\beta_s d_s^+ + \delta_s e_s^+\right) \tag{A2}$$

Expressions (A3) to (A9) show other limitations and scope of decision variables.

$$z_k(x) + d_k^- = \emptyset_k \qquad k=1,2,\dots,K \tag{A3}$$

$$\emptyset_k + e_k^- = g_{k,max} \qquad k=1,2,\dots,K \tag{A4}$$

$$w_s(x) - d_s^+ = \vartheta_s \qquad s=1,2,\dots,S \tag{A5}$$

$$\vartheta_s - e_s^+ = f_{s,min} \qquad s=1,2,\dots,S \tag{A6}$$

$$g_{k,min} \le \emptyset_k \le g_{k,max} \qquad k=1,2,\dots,K \tag{A7}$$

$$f_{s,min} \le \vartheta_s \le f_{s,max} \qquad s=1,2,\dots,S \tag{A8}$$

$$\begin{array}{ll} d_k^-, e_k^-, d_s^+, e_s^+ \ge 0, & k=1,2,\dots,K \;\;, s=1,2,\dots,S \\ x \in F \text{ , (F is a feasible set)} & \end{array} \tag{A9}$$

According to the above expressions, d_k^- and d_s^+ are non-negative variables and represent the amount of deviations related to the relationships $z_k(x) - \emptyset_k$ and $w_s(x) - \vartheta_s$ in expressions (A3) and (A5). e_k^- and e_s^+ are the values of deviations added to $\emptyset_k - g_{k,max}$ and $\vartheta_s - g_{s,min}$ in expressions (A4) and (A6). $\emptyset_k$ and ϑ_s are also continuous variables, the limits of which are determined based on equations (A7) and (A8). $g_{k,max}$ and $g_{k,min}$ as well as $f_{s,max}$ and $f_{s,min}$ show the upper and lower limits. α_k and β_s, which take positive values, are weights for d_k^- and d_s^+. δ_s and ξ_k, which take positive values, are weights for e_k^- and e_s^+. Expression (A9) also shows the limits of decision variables.

Chung et al proved that if $(x, z_k(x))$ are the optimal values of this model, then x will be an acceptable solution for multi-objective fuzzy programming [47].

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