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Mathematical modelling of aggregate production planning in iron and steel industry: Green supply chain management approach

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Abstract

Developing an aggregate production planning, as one of the most important manufacture tasks, can provide an efficient planning to optimize the companies' objectives such as minimizing costs and maximizing profits. Also, community's competitive pressures cause the need for considering green principles in production planning in order to balance environmental and economic performances. Hence, a multi-period, multi-product, multi-supplier, and multi-site aggregate production planning model is proposed to formulate a mathematical model of maximizing profit in green supply chain. Integer quadratic programming is used to solve the problem. Carbon dioxide emission from production and transportation modes are considered as green principle. The feasibility and validity of the formulated model was tested using data from iron and steel industry as well as a sensitivity analysis on profit function. The results demonstrate the optimal amount of productions in order to maximize profit as well as developing green supply chain. Also, sensitivity analysis shows that profit objective fell steadily due to increase in total CO_2 emissions from transportation and production processes. Consequently, some useful managerial insights were suggested regarding the consideration of green practices in aggregate production planning.

Keywords: Aggregate production planning, green supply chain management, mathematical modelling optimization

1- Introduction

The Supply Chain Management (SCM), as a management production planning from suppliers of raw materials to product end-users (Ramezani, et al., 2014) is fundamental in operational management. The SCM has prodigious effects on organizational performance through provision of competitive price, quality, and flexibility in global production markets. Highly competitive markets, governmental regulations, and community awareness have led to environmental protection concern, which in turn make the supply chain green (Ardakani et al., 2022). Hence, both practitioners and researchers in the field of industrial management try to utilize competitive advantages by emphasizing on environmental issues.

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For instance, concentrating on Carbon Dioxide (CO_2) emissions from fuel combustion as the main source of environmental pollution is of paramount importance- because- almost 80% of CO_2 - is emitted from fossil fuels -like coal and oil-which have been significantly increased in some countries since 2000 (IEA, 2018). Hence, the Green Supply Chain Management (GSCM) has turned into a key factor in environmentally-friendly issues along Supply Chain (SC) (Shabani, et al., 2014).

The basic goal of the GSCM is reducing pollution (Tseng, 2011) and making suppliers aware of the importance of considering environmental issues in their development (Ardakani et al., 2022). The GSCM design is an important part of planning activities which affects the efficiency of the SC. It consists of assigning where and how to locate assets (plants, warehouses, distribution centers) and how material flows along the supply chain which reduces the CO_2 emission (Homayouni, et al., 2021)

Since the mother plants and sectors and the transportation facilities are found accountable for CO_2 increase. For instance, industry is found to be the largest CO_2 emitter (36% or 12 billion tons of CO_2), followed by buildings, whose share has increased from 8% to 27% due to their reliance on electricity, and then the road transportation with a share of 25% in 2016. The share of road transportation is 71% larger compared to its share of 74% in 1990 (IEA, 2018) .

Accordingly, the Aggregate Production Planning (APP) is known as a prominent issue that needs to be answered in line with the GSCM. The APP is considered as a medium-term planning for the next 3-18 months. The APP determines the optimum amount of required raw materials, products, and inventories to meet the customers' needs in terms of the organizations' objectives and constraints. In addition to production planning, the APP can help in making decisions about the number of employees, their hiring, firing, or regular and overtime working times (Liu and Yang, 2021).

Iron Steel Industry (ISI) is an energy intensive industry and a main source of CO_2 emission which, for example, consumed 17% of the fossil energy and responsible for 30% of CO_2 emission in 2016 (IEA, 2018). Also, ISI emits indirect emissions which are released from the transportation sector (Yang, et al., 2019), and hence is confronted with the SC risk (Liu et al., 2017). Accordingly, the APP can be best utilized for GSCM designation.

Although the APP model can optimize profitability of organization which swings in a trade-off position between total production cost and total costs of CO_2 emissions, it has not been attended to especially with a focus on real-like experimented GSC models. In the current paper we are trying to provide an APP model which help efficient use of raw materials through pre-determining the amount of production and inventory that help to improve eco-efficiency (Entezaminia, et al., 2016). In addition, the providing model can help limiting CO_2 emissions and lead to cleaner productions by considering production systems and various modes of transportation (Mirzapour et al., 2013) which are considered as green practices. Moreover, we are going to focuses on the coordination of all SC parts in order to optimize the companies' goals and make decisions about their resource allocation (Makui, et al., 2016), supplier selection (Cárdenas, et al., 2015), scheduling, and particularly planning along the supply chain (Makui, et al., 2016). Above all, we are trying to provide an estimate of the optimal production amount in order to meet the end-users' needs while profitability is maximized and a GSM is brought about.

Hence, firstly, we provided a literature review in order to identify a research gap in the development of an APP in the GSCM design. To do so, we proposed a three-echelon network with a profit maximization objective function along with a multi-period, multi-supplier, and multi-manufacture mathematical model which was experimentally tested in the ISI context.

The second part of the paper provides a literature review of the APP and GSC studies, and different mathematical models for designing a GSC, which is followed by a problem definition in section 3. In Section 4, a mathematical model is formulated, the results of which application in the ISI context with a sensitivity analysis are provided in section 5. Section 6 presents the conclusions.

2- Literature review

The SC network design, which aims at finding the best solution for designing SC in order to reach long and short term goals and gain competitive advantages, concentrates on choosing suppliers, flowing raw materials, and producing intermediate or finished products. In addition, it keeps a look on the number, location, and capacity of plants as well as appropriate services for internal and external customers to determine SC costs (such as fixed and variable costs of production and transportation) (Homayouni, et al., 2021).

One way of designing the SC is applying the APP, which is a method of designing production schedule to effectively reach the organizations' goals by determining the optimal amount of raw materials, productions, and inventory (Ramezanian et al., 2012). To put it differently, the APP is a decision-making process for allocating resources along SC in order to maximize resource use profitability with the least expenditure costs (Mirzapour, et al., 2011). In this sense, Jamalnia et al. (2017) provided a multi-objective APP with regards to the total costs of revenue, production, human resources productivity, optimum production resources and capacity utilisations, and customer satisfactions in beverage manufacturing industry to maximize profitability. Makui et al. (2016) proposed an APP with regards to the profitability of season's cloths production. Chakrabortty et al. (2015) developed a multi-period and multi-product APP in order to minimize total costs and its accompanying risk by focusing on regular and overtime production amounts, inventory estimates, human resource levels, subcontracting and backordering rates, and other controllable variables. Furthermore, Rahmani et al. (2013) provided an APP in a refrigerator factory in Iran to minimize the total costs of establishment, production, human resources, inventory, and variable costs of uncertain production and customer demand. Yaghin et al. (2012) designed a multi period and multi product environment model of APP in a two-echelon SC to maximize the total manufacturing and retailing profit and to determine production, inventory, and human resources levels. However, the concept of trade-off between financial and environmental performances of the SC has changed. Although most of the firm design SC in order to gain more profits or decrease possible losses, different stakeholders encourage the firms to consider social and environmental indicators such as greenhouse gas emissions and their impact on society (Varsei et al. 2014). Hence, environmental considerations may be applied to design GSC (Varsei and Polyakovskiy, 2017). Rad and Nahavandi (2018) designed an integrated mathematical programming model of multi-echelon, multi-period, and multi-product closed-loop GSC to minimize economic costs and environmental emissions and to maximize customer satisfaction through determining the best suppliers. Moradinasab et al. (2018) designed a GSC in petroleum industry by developing a mixed integer linear programming to maximize the profits and minimize pollutions. Soleimani et al. (2017) designed a closed loop SC with regards to suppliers, manufacturers, distribution centers, customers, warehouse centers, return centers, and recycling centers as well as considering recycling matters of product, components and raw material. Zhao et al. (2017) presented a multi-objective model of GSC in order to minimize economic costs and risks associated with handling hazardous materials and CO_2 emissions. They provided three scenarios. Firstly, risks were minimized and CO_2 emissions were concentrated on. Then, both risk and CO_2 emissions were minimized to focus on minimizing overall costs, and finally, risk factors, CO_2 emissions, and overall costs were minimized. Tognetti et al. (2015) provided a green model in German automotive industry which focused on optimizing both CO_2 emissions and overall costs of SC with regards to the production volume and the energy mix. They demonstrated that by optimizing the energy mix, CO_2 emissions were reduced without any variable SC cost increase.

Few studies have been conducted to incorporate green design with the APP. In this regard, Asrawi et al. (2017) tried to design a GSC at technical and operational levels by proposing a mixed integer nonlinear programming model in association with multi-site, multi-product, and multi period APP not only to reduce the total costs of CO_2 emissions but also to take into account the human resources' considerations (for example the truck drivers' rights or issues). The consideration of such truck drivers with different Green Driving Indexes (GDI) and especially those of higher GDI in GSC management can help achieving these aims. In this regard, Entezaminia et al. (2016) designed a multi-objective and multi-products APP in GSC with respect to collection and recycling centers to minimize product loss and maximize the total environmental scores of products (or to show the association of green principles with the APP considerations). To do so, a sensitivity analysis of the objectives to the level of greenhouse gas emissions during the production process, transportation, or wastes productions was carried out. Modarres and Izadpanahi (2016) proposed a robust approach for designing an APP by focusing on energy savings in smelting manufacturer by considering energy planning and demand and production capacity.

Table1. Characteristics of the mathematical models based on the literature review

Author	Network	Model	Objective Function	Output	Problem definition
(Amirian et al. 2022)	CL	INLP	MO	Max profit	multi-product, multi-level, multi-source, multi-capacity, and multi-stage
(Akbarzadeh et al., 2022)	CL	INLP	MO	Min cost	multi-product green supply chain network for perishable food products
(Jamshidpour Poshtahani and Pasandideh, 2020)	OL	NLP	MO	Min cost	multi-product single-vendor single-buyer
(Yaghin, 2018)	OL	INLP	MO	Max profit	Multi production, supplier and plants
(Liu and Papageorgiou, 2018)	OL	ILP	SO	Max profit	Multi production, transportation and plant, environmental design
(Mota et al., 2018)	CL	ILP	MO	Max profit	Multi production, transportation and plant, environmental design
(Kadziński, et al., 2017)	OL	ILP	MO	Min cost	Multi transportation, environmental design
(Varsei and Polyakovskiy, 2017)	OL	ILP	MO	Min cost	Multi plant and transportation, environmental design
(Ghaithan, et al., 2017)	OL	ILP	MO	Max profit	Multi plant
(Nurjanni, et al., 2017)	CL	ILP	MO	Min cost	Environmental design
(Özceylan, et al., 2017)	CL	ILP	MO	Max profit	Environmental design
(Kisomi, et al., 2016)	CL	ILP	MO	Min cost	Multi plant and transportation
(Fahimnia, et al., 2015)	OL	INLP	MO	Min cost	Multi production, supplier and transportation, environmental design
(Validi, et al., 2015)	OL	ILP	MO	Min cost	Multi transportation and environmental design
(Amin and Zhang, 2012)	CL	ILP	MO	Max profit	Multi production, supplier and plant
(Shi et al., 2011)	CL	INLP	SO	Max profit	Multi production and environmental design
(Pishvaee et al., 2011)	CL	ILP	SO	Min cost	Multi production
The proposed model	OL	INLP	SO	Max profit	Multi production, supplier, transportation and plants, environmental design

Note: OL= open loop; CL= close loop; INLP= Integer Nonlinear Programming; ILP= Integer Linear Programming; MO=Multi Objective; SO= Single Objective

According to the literature review, planning in this field is categorized into three strategic (long-term), tactical (mid-term) and operational (short-term) sections. In strategic planning, things like establishing facilities and their capacities, choosing suppliers and business planning are planned. Tactical planning focuses on issues such as comprehensive production planning, logistics planning, distributing and recycling planning. The time period is between 3 months to one year. In operational planning, decisions are made regarding operational optimization within a week.

Most of the conducted modeling in previous studies has focused on strategic planning and less studies have been presented on providing aggregate production planning. In order to cover the research gap, the aim of the current research is to focus on modeling production and distribution planning, which are considered among medium-term plans. This model can be used well in industries such as iron and steel industry. This model reduces costs in the supply chain by considering combined production centers and combined distribution centers. In the combined distribution centers, some parts of the goods are stored and the rest of the goods are sent to the customer's centers by various modes of transportation. So, such model not only helps to control the costs but also help to control the amount of carbon dioxide emitted which help to keep the supply chain green.

Accordingly, the current mathematical model is aimed at minimizing the operational costs, energy cost, and carbon emissions. In other words, in this study, it is tried to design a multi-product and multi-site APP in GSC with respect to a developed framework based on the previous network types, characteristics, problem definitions, modelling, and outputs (see Table 1).

3- Problem definition

As shown in figure 1, the SC in ISI begins with supplying fragmentized raw materials such as ironstones (mined, or scrapped), and burning ironstone CO_2 for production purposes and finishes with delivering the products to the distribution centres. Generally, the SC in ISI starts with supplying ironstones and finishes with delivering steels to the distribution centres based on the received orders. Hence, the SC in the current paper is a forward SC, which consists of different sectors such as suppliers, plants, and distribution centres as end-users.

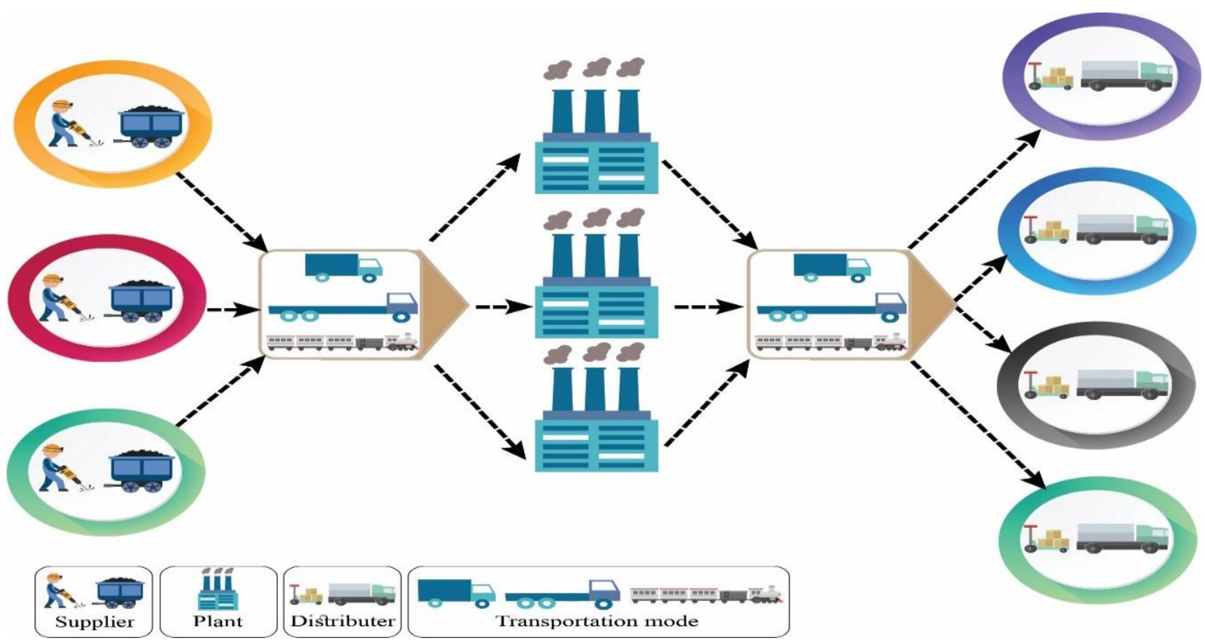


Fig 1. The SC network in iron and steel industry

In the current paper, we aimed several suppliers (indexed by s) who are accountable for supplying raw materials (indexed by p) in a time period (indexed by t) to manufacturing centres (indexed by m). The produced products, which are grouped into N product families (indexed by n), are made of the available raw materials. All the raw materials are supplied in the plants, from which the products are sent to the distribution centres as the end-users (indexed by d). Furthermore, there are G vehicle types to transport raw materials and products (indexed by g). Each production centre not only has its own production and inventory capacity but also it is able to produce regularly and overtime. Moreover, if raw materials are supplied later than the set time, a tardiness penalty cost will be regarded for the supplier company or if the plants deliver products later than the set time to the distribution centres, a tardiness penalty cost will be considered for the plants. Along the SC, CO_2 will be emitted from the production process and the transportation of raw materials and products. In order to be environmentally friendly, it is required to incorporate green components in the ISI SC to benefit from the advantages of GSC. Hence, the current problem is an integer quadratic programming which is aimed at maximizing income and minimizing overall costs of ISI operation by providing multi-products, multi-suppliers, multi-period and multi-sites APP. In this regard, the objectives of the current paper are not only maximizing plants' income with respect to the tardiness cost of delivering products to the distribution centres, but also minimizing costs of provision of raw materials and production processes such as human resources issues, storing, shortage of raw materials, and transportation. The CO_2 emissions' costs are to be considered as well. To do so, the underlying assumptions of the proposed problems are mentioned in the followings:

- The provided APP in GSC is multi-product, multi-suppliers, and multi-period.
- The number of suppliers (s) are defined.
- The number of manufacturing centre (m) is defined.
- The transportation type (g) is defined.
- The product types (n) defined.
- The number of distribution centres (d) is defined.
- Various raw materials (p) are defined.
- Aggregate demand for all product types in any specific time is assumed to be determined for the next planning time.
- The demand for each product has to be specified during each planning time: otherwise, a penalty cost is considered for the company.
- Materials should be supplied during the planning time: otherwise, a penalty cost will be considered for the supplier company
- Transportation costs and emissions rates of the trucks can be estimated.
- Carbon emissions and waste production can be estimated for production.
- Workers can be freely hired and fired period by period.
- An integer model can be formulated.

4- Model formulation

In order to formulate a model for the mentioned problem, there is a need to define the provided parameters and decision variables**.** In accordance with the type of decision variables and the necessity of not being fractional, all of the variables are considered as integer**.** Then, the objective functions and the related constraints are defined. Hence, the objective functions and the related constraints are defined separately.

Parameters	
$CP1_{pst}$	Purchase price of a unit of raw material p from supplier s in period t
$CP2_{ndt}$	Purchase price of a unit of group product n for distributor d in period t
$CDP1_{pmt}$	Penalty of each delayed time unit in supplying raw material p for manufacture m in period t
$CDP2_{ndt}$	Penalty of each delayed time unit in delivering group product n to distributor d in period t
CF_{mt}	Cost of firing each workforce in manufacture centre m in period t
CH_{mt}	Cost of hiring each workforce in manufacture centre m in period t
CLR_{mt}	Cost of hiring each workforce for regular time in manufacture centre m in period t
CLO_{mt}	Cost of hiring each workforce for overtime in manufacture centre m in period t
CI_{nmt}	Cost of storing each group products n in manufacture centre m in period t
CS_{nmt}	Cost of shortage of each group products n in manufacture centre m in period t
CEC	Cost of CO_2 emissions
CTF_g	Fixed cost of transporting by vehicle g
$CTV1_{pg}$	Variable cost of transporting raw material p by vehicle g per covered distance
$CTV2_{ng}$	Variable cost of transporting group product n by vehicle g per covered distance
UL_{nm}	The number of required human resources for producing group product n in manufacture centre m
θ_{ps}	The waste percentage in supplying raw materials p by supplier s
QWH_{pm}	The maximum allowable wastage in supplying raw materials p in manufacturer centre m (in ton)
$\rho1_{pmt}$	The percentage of raw material p which is allowed to be supplied with delay in manufacture centre m in period t
$\rho2_{ndt}$	The percentage of delivered group product n which is allowed to be delivered with delay to distributor d in period t
$TDH1_{pmt}$	The maximum amount of delay which is allowed in supplying raw materials p to manufacture centre m in period t
$TDH2_{ndt}$	The maximum allowable amount delay in delivering group product n to distributor d in period t
Q_{pn}	The percentage of raw materials p in producing each group product n
QSH_{pst}	The maximum capacity of supplying raw material p by supplier s in period t
α_{mt}	The percentage of regular overtime working in manufacture center m in period t
TR_{nm}	The required time for producing product n in manufacture center m (in a working day)
TT_{mt}	The total available regular production time in manufacture center m in period t (in a working day)
γ_{mt}	The percentage of regular overtime work in manufacture center m in period t
D_{ndt}	The amount of projected demand for group product n for distributor d in period t (in ton)
QPH_{nmt}	The maximum amount of produced group product n in manufacture center m in period t (in ton)
CWH_m	The maximum capacity of warehouse in manufacture center m
η_{nmt}	The percentage of wastage of produced product group n in manufacture center m in period t
PWH_{nt}	The maximum allowable wastage in producing group product n in period t (in ton)
$d1_{sm}$	The distance between supplier s and manufacture center m (km)
$d2_{md}$	The distance between manufacture center m and distributor d (km)

Parameters

$V1_p$	The volume of a unit of raw material p (in ton)
$V2_n$	The volume of a unit of produced group product n (in ton)
VCH_g	The maximum capacity of vehicle g
PEC_{nm}	The amount of emitted CO_2 in producing a group product unit n in manufacture centre m (mg per cubic metre)
TEC_g	The amount of emitted carbon dioxide in per covered kilometre distance by vehicle g (mg per cubic metre)
HEC	The maximum allowable emitting CO_2 for product production t and transportation in every period (mg per cubic metre)

Decision variables

ZR_{psmt}	The amount of raw material p which is supplied by supplier s for manufacture center m in period t without delay (in ton)
ZD_{psmt}	The amount of raw material p which is supplied by supplier s for manufacture centre m in period t with delay (in ton)
$TD1_{pst}$	The amount of delay for supplying raw materials p from supplier s in period t (in a working day)
$TD2_{nmt}$	The amount of delay for delivering group product n from manufacture centre m in period t (in a working day)
L_{mt}	The number of required workforce in manufacture centre m in period t
F_{mt}	The number of fired workforce in manufacture centre m in period t
H_{mt}	The number of hired workforce in manufacture centre m in period t
XR_{nmt}	The amount of produced group product n in manufacture centre m in regular time in period t (in ton)
XO_{nmt}	The amount of overtime produced group product n in manufacture centre m in period t (in ton)
I_{nmt}	The inventory amount of group product n in manufacture centre m in period t (in ton)
S_{nmt}	The amount of shortage of group product n in manufacture centre m in period t (in ton)
XV_{gsmt}	The number of vehicle g for transporting raw materials from supplier s to manufacture centre m in period t
YV_{gmdt}	The number of vehicle g for transporting group product from manufacture centre m to the distributor d in period t
YR_{nmdt}	The amount of delivered group product n from manufacture centre (m) to the distributor d in period t without delay (in ton)
YD_{nmdt}	The amount of delivered group product n from manufacture centre (m) to the distributor d in period t with delay (in ton)

4-1- Objective function

The objective function of the current study is aimed at maximizing profit in the ISI by including income and cost objectives in the formulated model. The model is composed of seven objective functions which are explained as follows:

The first function (equation 1) is maximizing Total Income of Selling (TIS) products. The function demonstrates the amount of delivering products with delay and without delay to the distribution centres. The tardiness cost of delivering products to the distributors are detracted from the TIS.

$$Max(TIS) = \sum_{t}^{T}\sum_{d}^{D}\sum_{m}^{M}\sum_{n}^{N}(YR_{nmdt} + YD_{nmdt}) \times CP2_{ndt} \tag{1}$$
$$-\sum_{t}^{T}\sum_{d}^{D}\sum_{m}^{M}\sum_{n}^{N}(YD_{nmdt} \times TD2_{nmt} \times CDP2_{ndt})$$

The second function (equation 2) is minimizing Total Cost of Purchasing (TCP) of raw materials with and without delay from the suppliers. The tardiness cost of supplying raw materials are mentioned in the TCP.

$$Min(TCP) = \sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{p}^{P}(ZR_{psmt} + ZD_{psmt}) \times CP1_{pst}$$
$$-\sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{p}^{P}(ZD_{psmt} \times TD1_{pst} \times CDP1_{pmt}) \quad (2)$$

The third function (equation 3), which is minimizing Total Cost of Manufacturing (TCM), consists of three parts. The first part demonstrates the cost of employing and firing human resources based on their numbers. The second part shows the cost of regular production based on the numbers of needed employees while the last part is related to the costs of overtime production based on the numbers of needed employees.

$$Min(TCM) = \sum_{t}^{T}\sum_{m}^{M}(F_{mt} \times CF_{mt} + H_{mt} \times CH_{mt})$$
$$+\sum_{t}^{T}\sum_{m}^{M}\sum_{n}^{N}(XR_{nmt} \times UL_{nm} \times CLR_{mt}) \quad (3)$$
$$+\sum_{t}^{T}\sum_{m}^{M}\sum_{n}^{N}(XO_{nmt} \times UL_{nm} \times CLO_{mt})$$

The fourth function (equation 4) is minimizing Total Cost of Inventory (TCI), which is about the cost of storing inventories with regards to the amount of production.

$$Min(TCI) = \sum_{t}^{T}\sum_{m}^{M}\sum_{n}^{N}(I_{nmt} \times CI_{nmt}) \quad (4)$$

The fifth function (equation 5) is minimizing Total Cost of Shortage (TCS) of raw materials, which is with regards to the amount of production.

$$Min(TCS) = \sum_{t}^{T}\sum_{m}^{M}\sum_{n}^{N}(S_{nmt} \times CS_{nmt}) \quad (5)$$

The sixth function (equation 6), which is minimizing Total Cost of Transportation (TCT) includes four parts. The first part demonstrates the fixed cost of transporting raw materials from supplier to production centers with regards to the number of vehicles. The second part is the variable cost of transporting raw materials per kilometre with and without delay with regards to the number of vehicles and the distance between them. The third one is related to the fixed cost of transporting products from production centers to distribution centers with regards to the number of vehicles while the last one includes the variable cost of transporting products per kilometre with regards to distance, and number of vehicles, and the amount of production with and without delay.

$$Min(TCT) = \sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{g}^{G}(XV_{gsmt} \times CTF_{g})$$
$$+\sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{g}^{G}\sum_{p}^{P}(ZR_{psmt} + ZD_{psmt}) \times d1_{sm} \times XV_{gsmt} \times CTV1_{pg}$$
$$+\sum_{t}^{T}\sum_{d}^{D}\sum_{m}^{M}\sum_{g}^{G}(YV_{gmdt} \times CTF_{g}) \quad (6)$$
$$+\sum_{t}^{T}\sum_{d}^{D}\sum_{m}^{M}\sum_{g}^{G}\sum_{n}^{N}(YR_{nmdt} + YD_{nmdt}) \times D2_{md} \times YV_{gmdt} \times CTV2_{ng}$$

The last function (equation 7), which is minimizing Total Cost of Emission (TCE), consists of three parts. The first part shows the cost of CO_2 emissions per kilometre with regards to the raw material transportation traffic from suppliers to production centers and the distance between them. The second part is related to the cost of CO_2 emissions per kilometre with regards to material transportation traffic from producers to distributors and the distance between them. The last one demonstrates the cost of CO_2 emissions from regular and overtime production processes.

$$Min(TCE) = \sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{g}^{G}(XV_{gsmt} \times d1_{g} \times TEC_{g} \times CEC)$$
$$+\sum_{t}^{T}\sum_{m}^{M}\sum_{s}^{S}\sum_{g}^{G}(YV_{gsmt} \times d2_{md} \times TEC_{g} \times CEC)$$
$$+\sum_{n}^{N}\sum_{m}^{M}\sum_{t}^{T}(XR_{nmt} + XO_{nmt}) \times PEC_{nm} \times CEC \quad (7)$$

4-2- Constraints

The 23 constraints divided into 10 sub divisions in the proposed model are supply, production, store, distribution, balance, human resource, wastage, environmental, and decision constraints, which are expressed in details by equations 8-30.

4-2-1- Supply constraints

The constraints (8 to 10), which are related to supplying raw materials, demonstrate the maximum amount of raw materials allowed to be supplied with delay and the maximum amount of allowed time to be supplied with delay. Maximum capacity of the suppliers in supplying raw materials is also showed.

$$\sum_{s}^{S} ZD_{psmt} \times \left(1-\rho 1_{pmt}\right) \le \sum_{s}^{S} \rho 1_{pmt} \times ZR_{psmt} \quad (8)$$

$$TD1_{pst} \le TDH1_{pmt} \quad (9)$$

$$\sum_{n}^{N}\left(XR_{nmt} + XO_{nmt}\right) \times Q_{pn} = \sum_{s}^{S}\left(ZR_{psmt} + ZD_{psmt}\right) \times \left(1-\theta_{ps}\right) \quad (10)$$

4-2-2- Production constraints

The following constraints (11 to 15), which are related to the limitations of production processes, show the maximum available time for production in regular and overtime period, the maximum amount of products which can be produced in regular and overtime period and the maximum allowable delay for producing and delivering products to the distribution centers.

$$\sum_{n}^{N} XR_{nmt} \times TR_{nm} \le TT_{mt} \quad (11)$$

$$\sum_{n}^{N} XO_{nmt} \times TR_{nm} \le \gamma_{mt} \times TT_{mt} \quad (12)$$

$$XR_{nmt} + XO_{nmt} \le QPH_{nmt} \quad (13)$$

$$TD2_{nmt} \le TDH2_{ndt} \quad (14)$$

$$\sum_{m}^{M} YD_{nmdt} \times (1-\rho 2_{ndt}) \le \sum_{m}^{M} \rho 2_{ndt} \times YR_{nmdt} \quad (15)$$

4-2-3- Store constraints

The equations 16 and 17 are related to the store inventory balance and the maximum capacity of keeping inventories.

$$I_{nm(t-1)} + \left(XR_{nmt} + XO_{nmt}\right) \times \left(1-\eta_{nm}\right) = \sum_{d}^{D}\left(YR_{nmdt} + YD_{nmdt}\right) + I_{nmt} \quad (16)$$

$$\sum_{n}^{N} I_{nmt} \times V2_{n} \le CWH_{m} \quad (17)$$

4-2-4- Distribution constraints

The following constraints (18-21) are related to the distribution limitations or the maximum capacity and number of vehicles for distributing raw materials and products with or without delay.

$$\sum_{g}^{G} VCH_g \times \left(XV_{gsmt} - 1\right) \le \sum_{p}^{P} ZR_{psmt} \times V1_p < \sum_{g}^{G} VCH_g \times XV_{gsmt} \quad (18)$$

$$\sum_{g}^{G} VCH_g \times \left(XV_{gsmt} - 1\right) \le \sum_{p}^{P} ZD_{psmt} \times V1_p < \sum_{g}^{G} VCH_g \times XV_{gsmt} \quad (19)$$

$$\sum_{m}^{M} VCH_g \times \left(YV_{gmdt} - 1\right) \le \sum_{n}^{N} YR_{nmdt} \times V2_n < \sum_{g}^{G} VCH_g \times YV_{gmdt} \quad (20)$$

$$\sum_{m}^{M} VCH_g \times \left(YV_{gmdt} - 1\right) \le \sum_{n}^{N} YD_{nmdt} \times V2_n < \sum_{g}^{G} VCH_g \times YV_{gmdt} \quad (21)$$

4-2-5- Balance constraints

Balance constraints (equations 22-23) demonstrate the balances between supplying raw materials with and without delay during production at regular and overtime period. The balance between selling products with and without delay based on demands is also provided.

$$\sum_{n}^{N} \left(XR_{nmt} + XO_{nmt}\right) \times Q_{pn} = \sum_{s}^{S} \left(ZR_{psmt} + ZD_{psmt}\right) \times \left(1 - \theta_{ps}\right) \quad (22)$$

$$\sum_{m}^{M} (YR_{nmdt} + YD_{nmdt} + S_{nmt}) = D_{ndt} \quad (23)$$

4-2-6- Human resource constraints

Human resource constraints (equations 24-26) show the status of human resources (employed or fired). In other words, these constraints not only demonstrate the maximum available human resources for production at regular and overtime period but also they show how human resources can be well used in period t.

$$\sum_{n}^{N} XR_{nmt} \times UL_{nm} \le L_{mt} \quad (24)$$

$$\sum_{n}^{N} XO_{nmt} \times UL_{nm} \le \alpha_{mt} \times L_{mt} \quad (25)$$

$$L_{m(t-1)} + H_{mt} - F_{mt} = L_{mt} \quad (26)$$

4-2-7- Wastage constraints

The constraints 27 to 28 demonstrate the permissible wastages. They not only show the maximum allowable wastage for the supplied raw materials which are provided with and without delay but also they demonstrate the maximum allowable wastage produced in regular or overtime production the process.

$$\sum_{s}^{S} (ZR_{psmt} + ZD_{psmt}) \times \theta_{ps} \le QWH_{pm} \quad (27)$$

$$\left(XR_{nmt} + XO_{nmt}\right) \times \eta_{nmt} \le PWH_{nt} \quad (28)$$

4-2-8- Environmental constraints

The following constraint demonstrates the limitation of CO_2 emissions from transportation vehicles used for supplying the materials to production centers and from production centers to distributors. The limitation of CO_2 emissions in the production process is also mentioned.

$$\sum_{s}^{S}\sum_{g}^{G}(XV_{gsmt}d1_{sm}\times TEC_{g})+\sum_{d}^{D}\sum_{g}^{G}(YV_{gmdt}\times d2_{md}\times TEC_{g})$$
$$+\sum_{n}^{N}(XR_{nmt}+XO_{nmt})\times PEC_{nm}\leq HEC \tag{29}$$

4-2-9- Decision constraints

The following constraints show the positive variables used in our model formulation,

$$ZR_{psmt}, ZD_{psmt}, TD1_{pst}, TD2_{nmt}, L_{mt}, F_{mt}, H_{mt}, XR_{nmt}, XO_{nmt}, I_{nmt}$$
$$S_{nmt}, XV_{gsmt}, YV_{gmdt}, YR_{nmdt}, YD_{nmdt}\geq 0 \tag{30}$$

4-3- Quadratic programming formulation

The formulated model in integer quadratic programming aims at maximizing profit (see equation 31). In addition to the regular costs in modelling an APP, other kinds of costs such as tardiness penalties in supplying raw materials and delivering products, have been considered in the model. The cost of CO_2 emissions to provide a GSC has also been mentioned in the model. As all parts of the objective function are within a same scale, it is possible to aggregate them into one objective function as follows in the formulated model:

$$MAX\ \ Z=TIS-TCP-TCM-TCI-TCS-TCT-TCE \tag{31}$$

5- Experimental results

The APP in ISI was determined in order to maximize profits with green approach along SC in a six-month period. There were three group products, three manufacturing cities (indexed as *m*), four distributing centers (indexed as *s*) which were spread geographically, and two kinds of raw materials which were supplied by *p*. The proposed model was coded by the GAMS optimization software. The results provided opportunity to choose optimal supplier, manufacturer, distributor, and kind of transportation in each period. As table 2 shows the optimal amount of supplying raw materials, raw materials could be supplied with and without delay. The first column depicts the kind of raw materials, the second column is suppliers, and the third column is the manufacturing sites. The fourth and fifth columns are the optimal amount of raw materials which are provided with and without delay in the specified periods. In other words, the amount of raw material (*p*), which was supplied by supplier (*S*) for production center (*m*) in specified period (*t*), with delay (ZD_{psmt}) or without delay (ZR_{psmt}) is shown. For instance, the first row of table 2 shows the optimal amount of raw material kind 1 which should be supplied by supplier 1, for production center 3, in period 2 and 3 without delay ($ZR_{1.1.3.2}.ZR_{1.1.3.3}$) are 900 and 1050 tons and with delay ($ZD_{1.1.3.2}.ZD_{1.1.3.3}$) are 0 and 0 ton. Hence, raw material 1 was not allowed to be supplied by supplier 1 for manufacturer site 3.

Supplying raw materials without delay is zero in some periods, which is because of prevention of supply surplus that not only increases the cost of supplying raw materials but also increases CO_2 emissions during transportation of raw materials to the manufacturers. As most of the periods had zero estimates, suppliers are not allowed to deliver products with delay. Delays in supply not only will cost penalty for suppliers but also will increase the production costs for the manufacturers and decrease their profits.

Table 2. The optimal amount of supplying raw material (P) with delay *(ZD_{psmt})* and without delay *(Zr_{psmt})*

Raw Materials (P)	Supplier (S)	Manufacturer (M)	ZR_{psmt}						ZD_{psmt}					
			Period (t)						Period (t)					
			1	2	3	4	5	6	1	2	3	4	5	6
1	1	1	0	800	0	0	1200	700	0	50	0	0	60	0
1	1	2	600	0	650	1100	0	500	0	45	0	0	0	0
1	1	3	0	900	1050	0	0	600	0	0	0	0	70	0
1	2	1	0	650	0	0	500	0	0	0	0	0	0	80
1	2	2	750	0	0	600	0	850	0	0	0	0	75	0
1	2	3	1300	0	1100	0	0	900	0	0	100	0	0	0
1	3	1	0	0	0	1200	0	600	0	0	0	0	0	0
1	3	2	0	0	0	1150	1100	0	120	0	0	0	0	0
1	3	3	0	600	1300	0	0	0	0	0	75	0	0	100
2	1	1	400	0	0	300	0	0	0	0	0	0	0	0
2	1	2	0	0	500	0	0	600	0	0	90	0	0	0
2	1	3	0	0	0	500	0	300	0	75	0	0	0	110
2	2	1	500	0	0	900	0	800	0	0	0	120	0	0
2	2	2	0	0	800	0	1150	0	90	0	0	0	130	0
2	2	3	0	700	1000	0	1200	0	0	0	0	60	0	75
2	3	1	850	0	1450	0	0	1200	0	0	50	0	0	0
2	3	2	0	0	1150	0	1350	0	0	0	0	110	0	65
2	3	3	1750	0	0	1600	0	0	0	0	50	0	0	0

As table 3 depicts the optimal number of vehicle (g) of different types for transporting raw materials from different suppliers (s) to different manufacturing centers (m) in period (t) are presented. In accordance with the kind of transportation systems and suppliers and manufacturers and the distance between them, the optimal number of vehicles are different in periods, which not only decrease transportation costs but also affect CO_2 emissions. For instance, transportations 1, 2 and 3 from supplier 1 to manufacturer 2 for period 1, are 0, 1 and 4, showing that the transportation type 3 is best for period 1.

Table 3. The optimal number of vehicle for transporting raw materials

Transportation type (g)	Supplier (s)	Manufacturer (m)	XV_{gsmt}					
			Period (t)					
			1	2	3	4	5	6
1	1	1	2	4	0	1	3	0
1	1	2	0	0	4	0	2	1
1	1	3	3	1	3	0	2	0
1	2	1	0	3	0	4	2	7
1	2	2	1	0	3	0	5	4
1	2	3	0	5	0	3	0	1
1	3	1	1	0	2	0	3	0
1	3	2	0	0	2	3	0	1
1	3	3	6	0	1	5	0	2
2	1	1	3	0	3	0	7	0
2	1	2	1	0	1	2	4	0
2	1	3	0	1	3	2	0	1
2	2	1	1	0	1	4	2	0
2	2	2	0	1	0	2	3	1
2	2	3	0	1	1	4	0	2
2	3	1	1	0	4	0	3	1
2	3	2	1	0	2	3	1	1
2	3	3	1	2	4	1	2	0
3	1	1	2	1	0	3	1	0
3	1	2	4	0	1	3	0	1
3	1	3	2	3	0	2	0	1
3	2	1	0	2	1	2	0	3
3	2	2	0	7	0	4	1	6
3	2	3	4	2	0	3	0	1
3	3	1	1	7	4	2	0	0
3	3	2	1	1	6	4	0	2
3	3	3	1	1	3	2	4	0

In addition, the optimal amount of delay for supplying raw materials from different suppliers ($TD1_{pst}$) was computed. As shown in table 4, the first column is the kind of raw material, the second column is the supplier, and the third column is the amount of delay for 6 periods. For instance, supplying raw materials kind 1 from supplier 1 was not allowed with delay in any of the periods. Furthermore, the optimal delay time for supplying raw materials of kind 2 from supplier 2 for periods 3 and 4 ($TD1_{2.2.3}$ and $TD1_{2.2.4}$) are 1 and 3 days. As can be seen, the delay is not acceptable in most of the periods, (for example, especially raw materials kind 1 from supplier 1 is 0 for all periods). The results confirmed that decreasing delay is effective not only for increasing profits but also for being green.

Table 4. The amount of delay for supplying raw materials (p) ($TD1_{pst}$)

Raw Material (P)	Supplier (S)	$(TD1_{pst})$ period (t)					
		1	2	3	4	5	6
1	1	0	0	0	0	0	0
1	2	0	4	0	2	0	0
1	3	0	3	0	0	2	0
2	1	0	0	0	0	2	0
2	2	0	0	1	3	0	0
2	3	0	0	0	0	3	3

The regular and overtime period were devoted to each manufacturer in order to produce different group products. As can be seen in table 5, the first column shows the kind of group products, the second column displays manufacturers, the third column is the amount of products in different periods in regular time, and the last column is the amount of products in different overtime periods. In other words, the optimal amount of produced group product (n) in manufacture center (m) in regular and overtime period (t) are depicted. For example, the production of optimum amount of product 1 in manufacture center 1 was not allowed in periods 1 and 2 in regular and overtime periods although its production in period 3 and 4 in regular ($XR_{1.1.3}.XR_{1.1.4}$) and overtime periods ($XO_{1.1.3}.XO_{1.1.4}$) were 140, 250, 35, and 0 tons, respectively. Table 5, which compares the optimum amount of the product in regular and overtime periods, demonstrates that production in overtime is much less than production in regular time, confirming that, overtime production should be decreased because of its high cost of production.

Table 5. The optimal amount of produced group product in manufacture center in regular and overtime periods

product (n)	Manufacturer (m)	XR_{nmt} Period (t)						XO_{nmt} Period (t)					
		1	2	3	4	5	6	1	2	3	4	5	6
1	1	0	0	140	250	0	340	0	0	35	0	0	45
1	2	90	0	0	220	175	0	0	0	0	40	0	85
1	3	0	0	0	195	0	420	0	110	0	0	90	0
2	1	0	0	170	0	295	0	0	0	0	70	0	65
2	2	0	0	230	0	0	140	75	0	45	0	0	0
2	3	0	85	0	0	340	0	40	0	65	0	75	0
3	1	0	0	325	0	270	0	0	0	0	55	0	40
3	2	0	0	310	0	0	429	0	0	25	0	70	0
3	3	0	245	0	0	270	350	0	40	0	105	0	35

Moreover, the optimum amount of products and the optimum amount of delay (in days) in producing group products (n) in manufacture center (m) in period (t) are presented in table 6. For instance, the optimum amount of product 1 in manufacture center 1 during optimum periods 3 and 4 ($TD2_{1.1.3}$ and $TD2_{1.1.4}$) were 25 and 0 days. As mentioned before, the high expense of delivering late products is either in its minimum level in most of the periods or is 0 in some others.

Table 6. The optimal amount of delay in producing product

Product (n)	Manufacturer (m)	$TD2_{nmt}$ period (t)					
		1	2	3	4	5	6
1	1	0	0	25	0	70	0
1	2	60	0	0	20	0	145
1	3	0	120	0	0	90	0
2	1	0	0	50	0	0	180
2	2	0	0	35	0	120	0
2	3	0	0	50	170	0	0
3	1	25	0	0	90	0	90
3	2	0	50	0	120	0	45
3	3	60	0	0	60	0	120

In table 7, the optimum amount of inventories and shortages of group product (n) in manufacture center (m) in period (t) is illustrated. The first column refers to the kind of group products, the second column refers to manufacturers, the third is related to optimum amount of inventories in each manufacturer during these periods, and the last column is allowable amount of shortages of group products during the periods. For instance, the optimal amount of inventory of product kind 2 in manufacturer center 1 in periods 4 and 5 ($I_{2.1.4}$ *and* $I_{2.1.5}$) are 120 and 150 tons while product shortages were not allowed ($S_{2.1.4}.S_{2.1.5}$) and hence they were equal to 0 (in ton). Excess inventory will result in imposing costs on the manufacturers because of the increase of costs of raw materials, and production, or storing processes. Besides, transporting excessive products can increase emissions along the SC. Also, shortage of products has a negative effect on the profit function when the products are not delivered to the customers on time. Hence, the optimum amount of inventory and shortage of products in most of the periods are 0.

Table 7. The optimal amount of inventory and shortage of products

Product (n)	Manufacturer (m)	I_{nmt} period (t)						s_{nmt} period (t)					
		1	2	3	4	5	6	1	2	3	4	5	6
1	1	40	0	110	0	0	120	0	110	0	170	134	0
1	2	45	0	120	0	0	50	0	136	0	162	157	0
1	3	0	75	0	0	0	60	0	127	0	188	161	0
2	1	0	0	0	120	150	0	106	0	0	0	0	60
2	2	0	0	95	0	145	0	123	0	0	0	0	79
2	3	0	0	90	0	90	0	101	0	0	0	0	63
3	1	0	0	0	80	0	75	0	0	328	0	0	0
3	2	50	0	0	120	0	125	0	0	296	0	0	0
3	3	0	0	0	60	0	45	0	0	316	0	0	0

In order to have optimum amounts of products, it would be necessary to estimate the optimum number of human resources like necessary workforce (L_{mt}), fired workforce (F_{mt}), and employed ones (H_{mt}) in different periods (t) and different manufacturing centers (m) (see table 8). Evidently, the first column is manufacturer, the second column is optimum number of human resources, the third column is optimum number of human resources which should be fired and the last one demonstrates the optimum number of human resources that should be employed. For instance, table 8 shows that manufacturing center 1 in period 3 needed 195 numbers of workforce ($L_{1.3}$), so it had to fire ($F_{1.3}$) 20 human resources at that time and to employ ($H_{1.3}$) no one. Firing and hiring human resources increase costs, with its negative effects on profitability.

Table 8. The optimal number of required, fired, and employed human resources

Manufacturer (m)	Required human resources (l_{mt})						Fired human resources (f_{mt})						Employed human resources (h_{mt})					
	Period (t)						Period (t)						Period (t)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1	170	160	195	195	210	220	0	0	20	0	20	0	190	0	0	10	20	0
2	160	180	230	210	180	180	40	0	0	40	0	30	0	0	110	120	0	0
3	160	180	180	210	210	190	0	0	0	0	40	0	0	0	0	80	0	100

Tables 9 and 10 depict the interaction between manufacturers and distributors as well as the way of transporting products. Products could be delivered with or without delay. In accordance with table 9, the first column shows the kind of group products, the second column refers to manufacturer, the third one shows distributors, the fourth one is about the optimum amount of delivering products without delay, and the last one is related to the optimum amount of products which can be delivered with delay.

Table 9. The amount of group products delivered from manufacture centers to the distributors with and without delay

Product (n)	Manufacturer (m)	distributor (d)	YR_{nmdt}						YD_{nmdt}					
			period (t)						Period (t)					
			1	2	3	4	5	6	1	2	3	4	5	6
1	1	1	930	0	730	710	600	600	175	0	630	500	270	450
1	1	2	920	930	870	1000	1000	1200	300	540	250	990	990	1100
1	1	3	350	300	500	400	400	300	400	350	400	200	200	300
1	1	4	850	760	760	780	980	960	450	450	600	600	545	540
1	2	1	1100	1000	780	850	850	890	0	900	425	360	360	700
1	2	2	1000	580	610	550	400	400	700	350	145	145	250	250
1	2	3	780	950	980	980	1150	1100	400	750	750	1000	1000	0
1	2	4	600	1000	925	930	750	780	150	400	200	200	345	345
1	3	1	900	820	800	650	730	680	390	410	400	360	150	270
1	3	2	1150	900	580	620	780	780	600	600	270	340	500	500
1	3	3	1000	280	430	1150	1200	900	900	0	350	350	425	400
1	3	4	300	400	680	680	420	370	230	230	100	100	150	100
2	1	1	540	680	700	290	380	400	300	125	125	75	75	200
2	1	2	280	460	450	390	500	860	340	0	200	200	180	180
2	1	3	630	0	860	500	670	800	145	0	0	230	230	400
2	1	4	450	450	320	320	520	660	230	450	0	320	0	660
2	2	1	550	500	630	628	245	245	320	300	280	290	245	0
2	2	2	470	628	560	520	450	450	100	146	255	255	0	450
2	2	3	700	520	450	450	250	500	0	75	90	120	120	300
2	2	4	500	950	950	890	550	1000	0	125	125	90	90	0
2	3	1	850	1100	950	900	1100	1200	300	400	95	90	110	120
2	3	2	590	590	800	950	950	1100	0	450	450	600	600	500
2	3	3	400	450	253	253	680	650	320	320	320	0	230	230
2	3	4	863	863	460	450	850	900	200	0	200	150	150	90
3	1	1	560	700	700	650	640	600	200	450	0	350	350	300
3	1	2	280	460	500	390	500	860	0	320	350	0	200	200
3	1	3	630	800	860	500	670	800	350	600	0	400	450	450
3	1	4	450	450	350	320	520	660	0	245	125	150	150	0
3	2	1	550	500	560	900	500	245	0	300	300	120	120	245
3	2	2	300	628	300	520	540	450	0	200	200	150	120	90
3	2	3	700	520	980	980	250	450	0	150	150	0	110	80
3	2	4	990	248	463	360	450	500	0	360	0	320	350	300
3	3	1	1000	248	950	323	350	600	175	175	150	150	95	90
3	3	2	700	360	563	380	458	540	400	0	250	250	300	300
3	3	3	124	360	563	470	458	250	150	0	125	125	90	90
3	3	4	300	124	248	450	600	470	200	0	175	175	320	320

To put it differently, the optimal amount of delivering products which were produced in manufacturing centers to the distributors in specified periods without delay (YR_{nmdt}) and with delay (YD_{nmdt}) are provided. As an example, product 1 which was manufactured in manufacturing center 1 and delivered to distributor 2 in periods 2 and 3 without delay ($YR_{1.1.2.2}.YR_{1.1.2.3}$) and with delay ($YD_{1.1.2.2}.YD_{1.1.2.3}$) were 930, 870, 540 and 250 (in tons), respectively.

Finally, the optimal number of vehicle (g) for transporting group products from manufacture center (m) to distributor (d) in period (t) is shown in table 10. For instance, the number of transportation of kind 1 from manufacture center 1 to distribution center 3 for weeks 1, 2, 3 ($YV_{1.1.3.1}.YV_{1.1.3.2}.YV_{1.1.3.3}$) were 5, 1 and 4, respectively. As can be seen, the number of different types of transportations for different periods from different manufacturer to distributor centers are different.

Table 10. The optimal number of vehicle for transporting group products

Kind of transportation (g)	Manufacturer (m)	Distributor (d)	YV_{gmdt} Period (t)					
			1	2	3	4	5	6
1	1	1	2	0	1	1	2	1
1	1	2	0	0	6	0	1	3
1	1	3	5	1	4	4	2	1
1	1	4	3	2	2	3	0	2
1	2	1	1	3	3	4	4	10
1	2	2	2	1	3	4	2	3
1	2	3	0	2	1	3	4	2
1	2	4	0	3	2	2	1	3
1	3	1	0	2	1	4	2	4
1	3	2	1	0	6	4	1	3
1	3	3	3	1	2	7	4	1
1	3	4	1	5	0	0	4	2
2	1	1	3	1	4	3	4	8
2	1	2	2	0	3	2	4	5
2	1	3	0	2	2	3	0	4
2	1	4	2	1	0	4	2	5
2	2	1	2	3	1	5	0	1
2	2	2	1	2	0	1	7	5
2	2	3	1	0	5	2	4	0
2	2	4	0	2	6	4	2	3
2	3	1	1	1	2	1	5	3
2	3	2	1	4	2	3	3	1
2	3	3	1	0	2	6	1	3
2	3	4	0	1	1	2	4	2
3	1	1	0	2	0	3	4	0
3	1	2	0	0	4	0	4	6
3	1	3	2	0	7	2	4	3
3	1	4	4	0	2	1	4	2
3	2	1	4	1	3	2	2	3
3	2	2	2	0	1	7	3	7
3	2	3	1	3	1	2	0	4
3	2	4	3	0	4	1	0	2
3	3	1	1	0	2	1	3	4
3	3	2	1	0	5	3	1	4
3	3	3	2	1	0	4	2	3
3	3	4	1	6	0	1	5	4

5-1- Sensitivity analysis

A range of sensitivity analyses was conducted on different parameters of the proposed model (see figures 2 to 8) to validate it and to explore its potential trade-off solutions. The results of profit function coefficients with $CP2_{ndt}.CEC.TEC_g.PEC_{nm}.\ \theta_{ps}$ and η_{nmt} are presented as well. In accordance with figures 2 to 4, a sensitivity analysis assessed the extent to which the CO_2 emission levels affect the TCE and how they are associated with transportation and production with respect to the SC profit.

The objective function of TCE (figure 2) was decreased (approximately 490000 Rials) while it dramatically was increased due to the increasing cost of CO_2 emissions. Because the manufacturers are allowed to have a certain amount of CO_2 emission. The government penalize the manufacturers for the excessive amount of emissions. So, the excessive amount of emission will increase the cost of emissions. The results help the managers to have control on the amount of emissions in order to minimize their costs as well as to be green along the supply chain.

The effect of CO_2 emissions related to the transportation mode and production process on the profit function are analyzed (see figures 3-4). As can be seen, the profit objective is fell steadily due to increase in total CO_2 emissions from transportation and production processes. When the amount of production increases, emission levels, transportation from suppliers to production and distribution centers will increase, too. Such increases result in increasing in total cost of emissions which consequently decrease the profit. The figures show that the cost of transportation emissions slope is steeper than the production processes (with a 16% of optimum amount), indicating that the transportation system is more effective on the profit function (with an optimum percentages of 14% CO_2 emissions in transportation). Hence, the transportation modes play critical rule in controlling cost and profit as well as the amount of emissions. It is suggested to the managers to invest on the transportation systems in order to be able to control the costs.

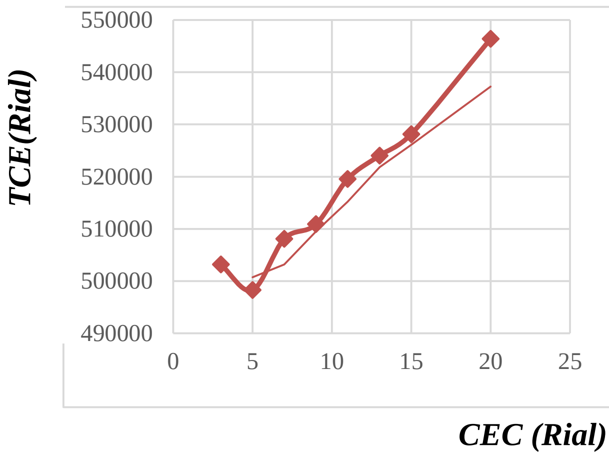


Fig 2. Effect of CO_2 emissions on total cost of emission function

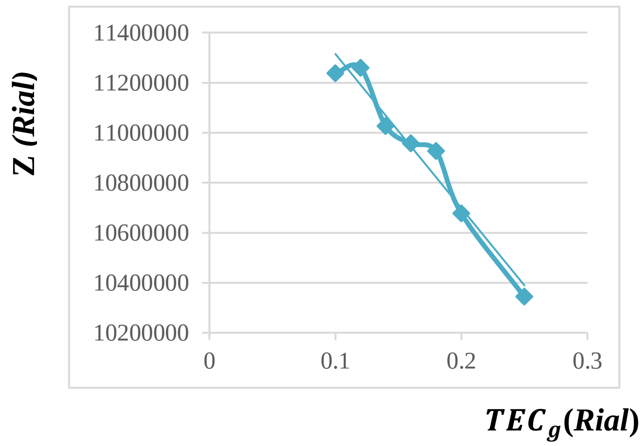


Fig 3. Effect of CO_2 emissions from vehicle g on objective function

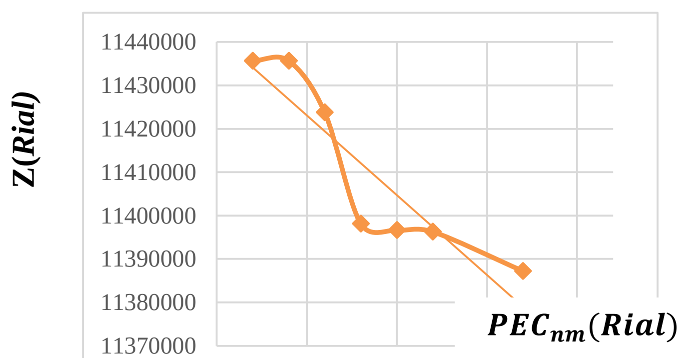


Fig 4. Effect of CO2 emissions from producing process on objective function

Figure 5 demonstrates the effect of changing purchase price of distributors' group products on the objective function, which changes the profit objective function through total selling products income. The result shows that at the beginning, the increases of the purchasing prices will increase the profit but the profit function will steadily decrease after a point in objective function. The function shows the elasticity of the products' prices in the market. From a point that the users are not ready to pay more for purchasing the products so the profit function will start to steadily decrease. The results help the managers to know the elasticity of their products' prices. So, they will be able to set prices for the products in a way that increase the profit.

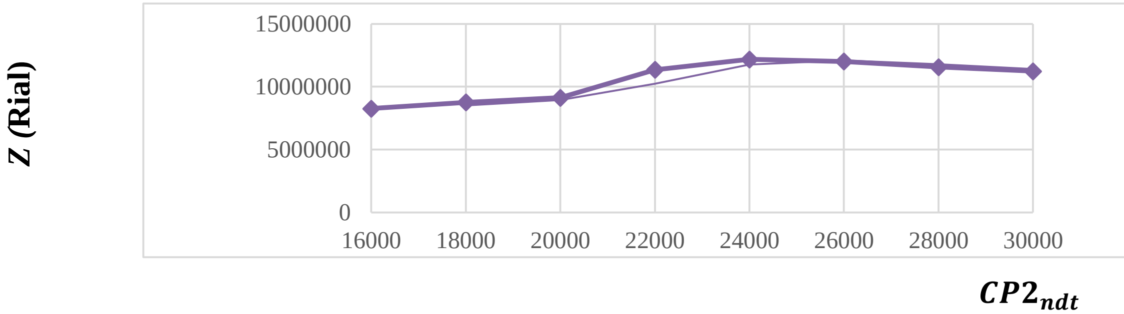


Fig 5. Effect of selling price on objective function

Furthermore, figure 6 demonstrates the effect of the wastage of raw materials on the profit function. The result shows that the profit function decreased through the increase of wastage of raw materials. In other words, the more amount of wastages, the more raw-materials are needed to keep a balance between raw materials and production processes. Hence, it will enhance the cost of supplying raw materials which may decrease the profit. The optimum percentage of wastage of raw materials was 8%. Also, the profit function fell in response to the increase in the wastage of product (with an optimum percentage of 6 %.in figure 7). The effect of change in some parameters ($\rho1_{pmt}.\eta_{nmt}, \theta_{ps}.Q_{pn}$) on the profit function is demonstrated in figure 8, revealing that the optimum percentage of supplying raw materials (Q_{pn}) is 4%, with a dramatic fall . In other words, excessive amount of raw materials decreased profits, displaying the necessity of resource efficiency and raw materials efficiency for increase of profits. Although the percentage of wastage

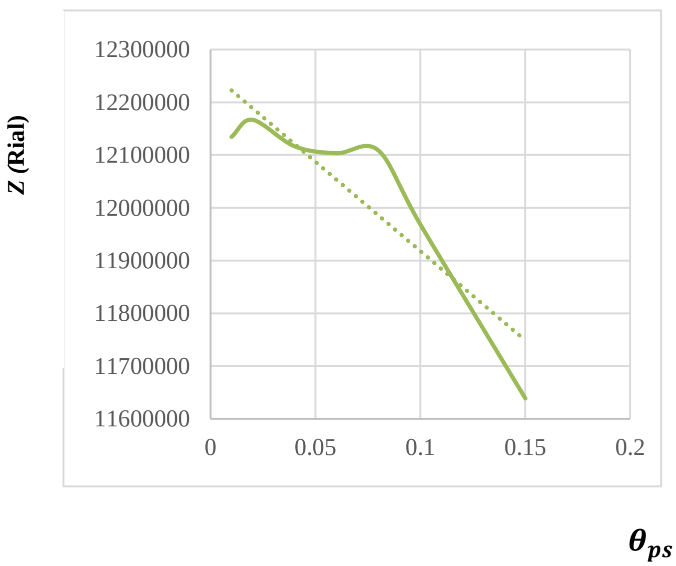


Fig 6. Effect of percentage of wastage of raw material on objective function

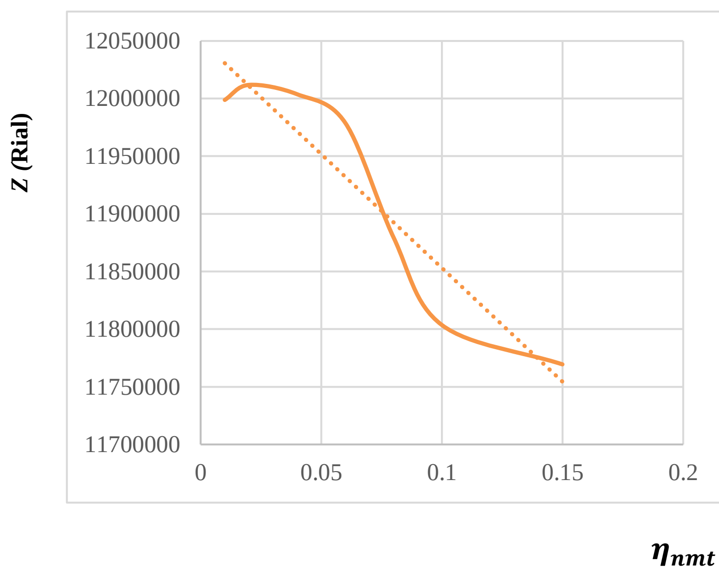
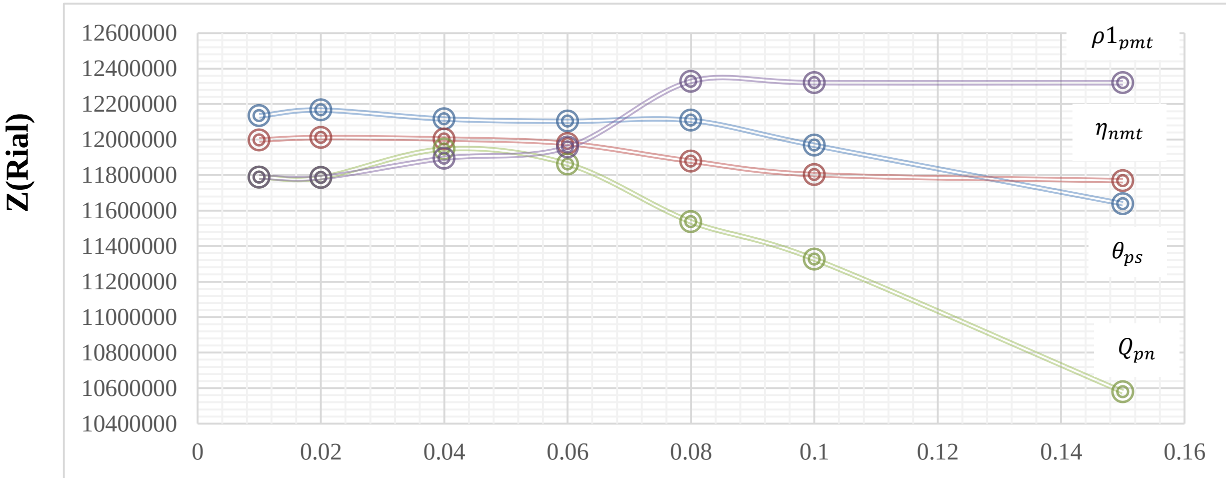


Fig 7. Effect of percentage of wastage of producing product on objective function

in raw materials (θ_{ps}) seems to be under control, the profit function seems to dramatically fall if it proceeds 6% . The amounts of wastage in products (η_{nmt}) caused mitigation of profits. But, it was not salient because the wastage of production was reproducible. Supplying raw materials with delay ($\rho1_{pmt}$) increases in profits because a tardiness penalty would be considered for suppliers. However, if it increases more than 8%, it can decrease profits because it can make longer the production late and delivering processes, and hence may result in a tardiness penalty for suppliers.



θ_{ps}	Z	η_{nmt}	Z	Q_{pn}	Z	$\rho 1_{pmt}$	Z
0.01	12134658	0.01	11998637	0.01	11789328	0.01	11789328
0.02	12167028	0.02	12011658	0.02	11786325	0.02	11786325
0.04	12116804	0.04	12003548	0.04	11947621	0.04	11895301
0.06	12103647	0.06	11978627	0.06	11863271	0.06	11957461
0.08	12108876	0.08	11879321	0.08	11536982	0.08	12328759
0.1	11968459	0.1	11803479	0.1	11326870	0.1	12321038
0.15	11638746	0.15	11769320	0.15	10579328	0.15	12320489

Fig 8. The effect of change of $\rho 1_{pmt}.\eta_{nmt}.\theta_{ps}.Q_{pn}$ on profit function

6- Conclusion

In this paper, a multi-period, multi- product APP with GSCM approach was developed to maximize profit in ISI SC. To do so, the objective functions not only maximize total income of selling products, but also minimize total cost of emissions, purchasing raw materials, manufacturing, inventory, and shortage of raw materials and transportations.

The formulated model not only considered the CO_2 emission from production processes but also considered different transportation modes to reduce their CO_2 emissions. Moreover, wastage of materials and production managements are taken into account in order to minimize the cost of supplying raw materials and to reduce the amount of production. In order to make the model more flexible, on one hand, we considered delay in supplying raw materials, and production and delivering processes and tried to minimize it in order to increase profit. On the other hand, overtime productions are considered to be minimized to gain more profit. As all the conflicting objective functions (i.e., minimizing total costs and maximizing total income) were in the same scale, they were collected and aggregated to one objective function that is maximizing profit with regards to the green principle, and a quadratic solution was generated to solve the problem by an optimum solution in GAMS software.

The results demonstrated an optimum amount of supplying raw materials with respect to delays, producing product in regular and overtime periods, delivering products to distributors' centers with and without delay, number of vehicles, the amount of shortage and inventory, and the number of required human resources for different periods. Furthermore, a sensitivity analysis was done for different parameters like CO_2 emissions from production and transportation processes and their wastage productions, selling prices, supplying raw materials with delay, and optimum percentage of supplying raw materials and how they affect the profit function.

The results of the analyses would help the managers not only to maximize the profits, but also to consider green principles like minimizing CO_2 emissions in SC. On the other hand, the interaction of profit, cost, and green principle can be considered at the same time.

The model demonstrates that the manager can focus on the transportation modes which help controlling the CO_2 emissions which consequently decrease the emission costs and increase profits. Also, the results showed that the managers should concentrate on the efficient use of raw materials which influence the profit function and have green consequences. Furthermore, decreasing product wastage will have profitable and green results. In addition, the optimum number of the employees should be considered which have remarkable effect on the profit function.

Furthermore, it is recommended that more studies consider green principles in APP. Above all, as some factors are not certain in reality, it is necessary to work on robust, fuzzy, or stochastic optimizations to obtain more realistic models.

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