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Sustainable Multi-Objective Optimization for the Supply Chain of Petroleum Products

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Abstract

In this paper, a framework for optimizing the oil condensate supply chain is modeled using mathematical planning to design and make strategic and tactical decisions. According to this framework, investment and operating costs for oil and gas transmission lines can be minimized to meet the pressure requirements and the transmission network. Also, we can minimize the production of pollutants in the chain-related sectors. In the case under study, all possible decisions are considered to consider the environmental aspects of the supply chain. Therefore, the structure and decisions of the supply chain are generally based on two objective functions, including reducing transmission and maintenance costs and pollution in treatment plants and distribution centers. The proposed model is 95% reliable, which is acceptable reliability, and can estimate goals with only 5% error. Using the proposed model will reduce costs by 31% and emissions by 51%. Also, there will be an 8% increase in the capacity of fields and refineries and an increase in exports by 65%. Using the results obtained from solving the model, we can determine the share of each petroleum product in the cost and each part of the chain in the production of greenhouse gases. According to the results, fuel oil has the highest and oils the lowest. In addition, refineries have the greatest impact, and storage tanks have the least impact on environmental pollution.

Keywords: Optimization, Mathematical planning, Modeling, Greenhouse gas emissions.

1 | Introduction

Today, the constant rise in oil prices and fluctuations has made oil condensate one of the most important energy sources in the world. In addition, the Middle East is a major repository of this important resource due to the presence of countries such as Iran, Saudi Arabia, and the Persian Gulf countries. With the increase in population and the economy's improvement, the demand for the use of this substance has increased in the industrial sector to expand the industrial sectors due to the increase in income. The US Energy Information Administration (EIA)[1] said in a report that energy

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Mahmoudi et al.| J. Appl. Res. Ind. Eng. 8(Spec. Issue) (2021) 1-15

consumption has doubled from 1980 to 2010 and is expected to reach approximately 4 trillion cubic meters by 2030.

For this purpose, attention to distribution and transmission systems are the two basic components of the oil condensate network. A transmission system can be thought of as a high-pressure pipeline system that transports oil and energy carriers over a long distance from the supplier to refinery centers through large diameter pipes. Crude oil is transported in large volumes through condensing stations located at strategic points of the transmission line. Distribution systems transport crude oil from the system and deliver it to the final consumer of commercial, industrial, and power plants. Distribution is done by local companies.

The existence of logical relationships between pressure drop and flow rate in the crude oil transmission line network, due to variable flow, has caused us to face different problems than other network flow problems, which usually causes the problem to be nonlinear when modeled through mathematical models programming. For example, when crude oil is placed inside a pipe, it is necessary to change the pressure inside the pipe in such a way that the crude oil flows through it. Compression booster stations provide the energy needed to maintain the pressure required along the pipe. Also, minimizing the cost of crude oil transportation by choosing the appropriate pipe diameter and taking into account the limitations of no pressure drop in the nodes and the volume of crude oil transmission flow is always one of the important challenges in the oil industry. So that more than 30% of the final price of refined crude oil is related to the cost of distribution and transfer. Therefore, given the above, in this paper, we focus on these issues, an optimization framework based on mathematical modeling to solve a nonlinear integer problem to minimize investment and operate costs for oil and gas transmission lines to meet the pressure requirements along with the transmission network. The main approach followed in this paper is to provide a multi-objective optimization framework based on mathematical planning for the supply chain of distribution and transmission of condensate network to meet customer needs by maximizing resource capacity (pressure requirements across the network). Although the ultimate goal of such networks is usually to minimize operating and investment costs, governments and international organizations have been concerned about environmental and social issues to set the rules for companies active in the field of energy and invest in sustainable development [1]. These growing concerns and pressures are forcing companies to consider sustainability in their operations throughout the supply chain. Therefore, environmental, economic, and social issues must be considered in planning, policy-making, and decision-making [2].

In addition, a development that considers the ability of future generations to meet their own needs and today's needs is called sustainable development. Therefore, meeting the demand of future generations is an important concern that should be considered in the planning and policy-making of governments and companies through sustainability. Air pollution, climate change, and global warming due to greenhouse gas emissions lead to many environmental and social issues. Air pollution, mainly caused by fossil fuels and exacerbated by climate change, damages all vital organs. In addition, it is estimated that air pollution led to three million premature deaths in 2015 [3]. As a result, public health is at risk, and if immediate action is not taken, the damage will increase in the coming years. Because fossil fuels, consisting of coal, oil, and natural gas, are the main energy source in the world. In addition to, the main source of Greenhouse Gas (GHG) emissions is the combustion of fossil fuels, with about 98% of carbon emissions coming not only from burning these sources directly, but also from the supply chain, including extraction, processing, and transportation [4].

According above mentioned, main objective in this paper are as follows:

- *Proposed a framework for optimizing the oil condensate supply chain.*
- *Proposed Mathematical planning to design and planning to make strategic and tactical decisions.*

According to this framework, investment and operating costs for oil and gas transmission lines can be minimized in a way that meets the pressure requirements along the transmission network. Also, we minimize the production of pollutants in the chain-related sectors.

The rest of this paper is organized as indicated, in the Section 2, a review of historical literature from past studies is presented, in the Section 3, details of mathematical modeling are presented, in the Section 4, research results are shown. In the Section 5, presented research managerial insight implication and finally, in the fifth section, a conclusion is presented with suggestions for future research.

2 | Literature Review

In the research literature, three main network issues are used to address the various challenges in oil and gas condensate transmission networks. In condensate network design problems, the objective function may be to minimize investment costs or maximize present net worth. In network flow problems, the goal is to minimize costs and estimate customer demand. In this type of problem, the problem-solving variables are defined so that they can determine the flow of condensate in the pipe network. In network expansion issues, the goal is to schedule and plan how to invest. Decisions such as the size and location of pipelines and condensing stations must be made to achieve optimal capacity expansion [5]. For example, in a study, Borraz-Sánchez and Ríos-Mercado [6] attempted to calculate the optimal solution for condensing station operation in a transmission pipeline network with the aim of minimizing the fuel consumption of condensing stations. This network is represented by the pipeline and ridges of the condensing stations as well as the corresponding nodes located at the intersections of the ridges. In many studies, innovative approaches have been proposed to minimize condensing station costs. The ant colony optimization algorithm has been used for the first time in the study of Chebouba et al. [7], to optimize gas flow operations in this field. Chung et al. [8] proposed a multi-objective mathematical program for the transmission network problem. Investment cost, reliability, and environmental effects were the three different objective functions used in the model. They solved the problem with a Genetic Algorithm and adopted a fuzzy decision-making method to select the best network planning scenario. Hamedi et al. [9] used a hierarchical algorithm to solve the transmission network problem, which consisted of a goal function and was modeled by multi-period mixed-integer linear programming. Woldeyohannes and Abd Majid [10] developed a simulation model by incorporating pressure boost station parameters, including velocity, suction pressure, and discharge. Wu et al. [11] proposed an optimization model for natural gas main lines to balance the maximum operating profit with the maximum transfer amount. The weighted sum method combined these two objective functions, which resulted in a hybrid objective function. Borraz-Sánchez and Haugland [12] proposed a nonlinear mathematical model for the condensate transmission network to minimize fuel costs. In their research, Misra et al. [13] also considered the issue of minimizing fuel consumption in condensing stations. They used a new geometric programming approach to optimize condensing operations in pipelines. Midthun et al. [14] provided an optimal model for developing the oil and gas industry infrastructure, including production, refining, transmission, and investment decision issues. Infrastructure design and capital analysis for oil and gas decision-makers have an important role due to the imposition of large sums related to oil and gas fields, refinery equipment, transmission lines, pressure boosting stations, and other infrastructure elements. Decision-makers need to know exactly when and with what capacity to invest. The hybrid optimization model for analyzing the above topics has been well studied in the article. Finally, a complex integer linear optimization model includes both decision-making factors in defined investment and operational decisions. In their study, Farouk et al. [15] presented a mathematical model for designing and developing a natural gas transmission network to reduce operating costs and initial investment. A Mixed Integer Nonlinear Programming (MINLP) optimization model is proposed to determine the transmission network, the location of booster stations and their capacity, their installation time in a multi-period horizon, and finally, the amount of gas production in the steady-state of the network. Maadanpour Safari et al. [25] a tri-objective mathematical model proposed for the Transportation-Location-Routing problem. The model considers a three-echelon supply chain and aims to minimize total costs, maximize the minimum reliability of the traveled routes and establish a well-balanced set of routes. In order to solve the proposed model, four metaheuristic algorithms, including Multi-Objective Grey Wolf Optimizer (MOGWO), Multi-Objective Water Cycle Algorithm (MOWCA), Multi-objective Particle Swarm Optimization (MOPSO) and Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) are developed. Pourghader Chobar et al. [26] presented a novel milti-objective model for hub location problem with dynamic demand and environmental issue. The model aims to minimize the routing cost between production centers and retailers, along with emitting pollution from vehicles as less as possible. As the proposed model is bi-objective, that is minimizing costs and pollution emission, two Pareto-based solution methodologies, Namely the Non-dominated Sorting Genetic Algorithm (NSGA-II) and Non-dominated Ranking Genetic Algorithm (NRGA), are used. Lotfi et al. [27] proposed a Novel Viable a Medical Waste Chain Network Design (MWCND) by a novel two-stage robust stochastic programming that considers resiliency (flexibility and network complexity) and sustainable (energy and environment) requirements. Lotfi et al. [28] explored a Robust, Risk-aware, Resilient, and Sustainable Closed-Loop Supply Chain Network Design (3RSCLSCND) to tackle demand fluctuation like COVID-19 pandemic. For this purpose, a two-stage robust stochastic multiobjective programming model serves to express the proposed problems in formulae. Lotfi et al. [29] indicated Resilience and Sustainable Supply Chain Network Design by considering Renewable Energy (RSSCNDRE) for the first time. A two-stage new robust stochastic optimization is embedded for RSSCNDRE. The first stage locates facility location and RE and the second stage defines flow quantity between supply chain components. In reviewing articles related to the optimization of the oil condensate supply chain, based on the knowledge gained from studies, few studies have been conducted on the design and strategic planning of a sustainable supply chain that deals with the oil carrier network. For example, Hamedi et al. [16] developed a nonlinear optimization model of a single-objective, single-product, and a multi-stage mixed-integer for the natural gas supply chain, which in this study ignored natural gas components other than methane. In addition, Azadeh et al. [17] in another study, used a linear mathematical model with fuzzy parameters to optimize only methane gas flow between supply chain nodes and exclude the total cost and total emissions of greenhouse gases without considering supply chain development minimization. Attia et al. [18] proposed a multi-objective model for minimizing total cost and maximizing total revenue for tactical decision-making of oil and gas supply chains. Zarei and Amin-Naseri [19] proposed a mixed-integer linear model to minimize the development costs of increasing the capacity and location of transmission pipelines and facilities and optimizing methane flow in the NGSC network without considering sustainable development. Although the oil and gas industry considers different sectors with diverse components, most researchers have focused on transmission and distribution networks in this area. For example, Vasconcelos et al. [20] developed a linear mathematical model to identify the transport capacity of the natural gas pipeline network in Brazi. Wang et al. [21] determined the connections of pipelines and compressor stations in the oil transmission network using a complex integer linear programming model. Kabirian and Hemmati [22] developed an integrated nonlinear optimization model to formulate a strategic plan to find the best long-term development plans to determine the location, type, and installation schedule of booster stations in pipelines to minimize costs of the entire existing gas network. Andre et al. [23] developed a nonlinear capacity expansion model for oil transmission networks. Behrooz and Boozarjomehry [24] investigated a dynamic optimization model for transmission network planning in the oil and gas industry with uncertainty in future demand.

Based on the review of the studies mentioned above, based on the acquired knowledge, the presentation of a combined mathematical model and simulation in the supply chain has not been done. The purpose of this study is to design a crude oil supply chain network to meet customer demand and maximize resource capacity and pipeline pressure requirements to reduce costs and capital and minimize GHG emissions. For this purpose, an optimization framework based on mathematical modeling and simulation has been designed for this supply chain. In *Table 1* literature to identification research gap categorized.

Table 1. Literature categorized.

Author	Year	Methodology					
		Heuristic	GA	AHP	WSM	Exact	Simulation
Sanchez and Rios	2009	*	*			*	
Wu et al.	2014		*				
Balcombe et al.	2017	*		*			
Zarei and Aminnaseri	2019				*	*	
Attia et al.	2019	*		*	*		
Farouk et al.	2020	*	*	*			
This research	2022				*	*	*

3 | Research Method

In this section, first, the problem in this research is introduced, then the mathematical modeling of the problem is determined by defining indices, parameters, variables, objective functions, and constraints.

3.1 | Problem Description

The supply chain proposed in this research includes strategic and tactical decisions for network design, planning, and optimization. The intended supply chain is able to select the location of potential fields, refineries, and storage tanks and determine their size. In addition, the relationship between network nodes is determined by potential pipelines along with their size. Other important decisions include the amount of oil leaving the fields, the number of final products produced in refineries, the number of final products flowing through the transmission network and their amount of sales at refinery sites, the number of crude oil exports, as well as the amount of injection, removal, and inventory. The reserve is determined in each period. In the case under study, all possible decisions are considered to take into account the environmental aspects of the supply chain. Therefore, the structure and decisions of the supply chain are generally based on two objective functions, including reducing transmission and maintenance costs and reducing pollution in treatment plants and distribution centers. *Fig. 1* shows the intended chain structure.

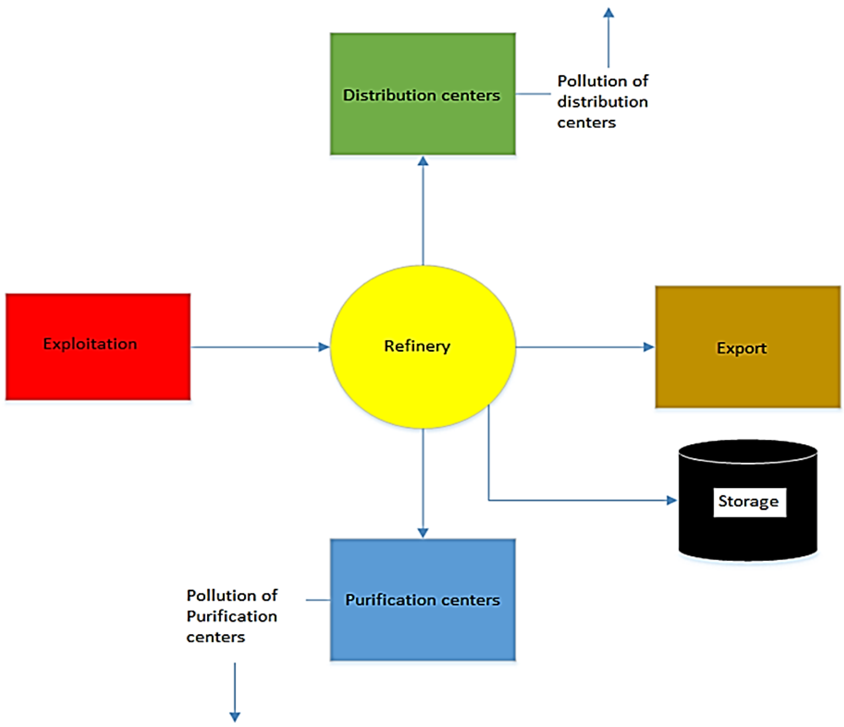

Fig. 1. The proposed supply chain framework.

In general, the objective functions considered in mathematical modeling in this paper are: transfer costs (A), inventory costs (B), the amount of environmental pollution in treatment plants (C), and the amount of environmental pollution in the distribution centers (D). To overcome the weakness of the methods when the number of objectives is more than two objectives, due to the unity of some objectives with each other such as objectives (A) and (B and C) and (D) the sum of the same objectives are considered as the final objective. This is intended to reduce the complexity of the problem and make the model a two-objective problem, so the objectives set in the modeling are as follows.

$$\mathrm{Min}(f_1) = A + B,$$
$$\mathrm{Min}(f_2) = C + D.$$

Also, there are many methods to convert a two-objective problem into a one-objective problem, such as weighted sum, epsilon constraint, and so on. After the studies, the weighted total method is superior to the epsilon method in terms of response in producing inaccurate or partial answers, so it is considered as the problem-solving method.

Sets:

I: Set of squares.

J: Set of purifiers.

P: A set of products that include petroleum products.

T: Set of time period.

H: Set of petrochemical plants.

D: Set of Distributors.

EX: Set of crude oil exporters to distributors.

S: Set of crude oil depots.

C: Set of condensate consumer.

Indices:

$i \in I$: Index related to the set of squares.

$j \in J$: Index of purifiers.

$p \in P$: Index of products.

$t \in T$: Index of time periods.

$h \in H$: Index of petrochemical plants.

$d \in D$: Index of distribution centers.

$ex \in EX$: Index of crude oil exporters to distributors.

$s \in S$: Index of oil depots.

$c \in C$: Index of condensate customers.

Parameters:

$capacity_i$: Maximum capacity of field i.

Cx_{ijt}: The cost of transporting crude oil from the field i to the refiner j in time period t.

Cyd_{jdpt}: The cost of transferring crude oil from the refiner j to the distributor d in time period t.

Cyc_{jcpt}: The cost of transferring crude oil from the refiner j to the condensate consumer in time period t.

Cyh_{jhpt}: The cost of transporting crude oil from the refiner j to the refinery h in time period t.

Cds_{dst}: The cost of transporting crude oil from distributor d to warehouse s.

Csd_{sdt}: Cost of transferring crude oil from warehouse s to distributor d.

γds_{dst}: Percentage of crude oil transferred from distributor d to warehouse s.

γsd_{sdt}: Percentage of crude oil transferred from warehouse s to distributor d.

CI_{jt}: Cost of crude oil inventory imported from the field to the refinery j at time t.

CIc_{ctp}: Cost of condensate inventory in condensate consumption center c at time t.

CId_{dtp}: Cost of crude oil inventory in distribution center d at time t.

CIh_{htp}: Cost of crude oil inventory in refinery center h at time t.

CIS_{st}: Cost of crude oil inventory in warehouse s at time t.

λ_{ip}: Percentage of product p (petroleum products) from the input gases of the field i.

DC_{ctp}: Demand of consumer center c of condensate P_1 in period t

Dd_{dtp}: Demand of the distribution center d of methane P_2 in period t.

Dh_{htp}: Demand of petrochemical plant center h from ethane P_3 in period t.

$DE_{ex,t}$: Crude oil demand for export center e_x in period t.

$CIdm_{im,d,t}$: The cost of transporting crude oil from import center i_m to distribution center d in time t.

Positive Variables:

x_{ijt}: The amount of crude oil transferred from the field i to the refiner j at time t.

yd_{jdpt}: The amount of crude oil transferred from the refiner j to the distributor d at time t.

yc_{jcpt} : The amount of crude oil transferred from the refiner j to the condensate consumer at time t.

yh_{jhpt} : The amount of crude oil transferred from the refiner j to the refinery h at time t.

ds_{dst} : The amount of crude oil transferred from distributor d to warehouse s.

sd_{sdt} : The amount of crude oil transferred from warehouse s to distributor d.

II_{jt}: The amount of oil inventory imported from the field to the refinery j at time t.

Ic_{ctp}: Inventory of petroleum condensate in condensate consumption center c at time t.

Id_{dtp}: Amount of crude oil inventory in distribution center d at time t.

Ih_{htp}: The amount of crude oil inventory in refinery center h at time t.

IS_{st}: The amount of crude oil inventory in the center s at time t.

$Idm_{im,d,t}$: The amount of crude oil from the import center i_m to the distribution center d at time t.

In view of the above, the mathematical model is developed in the determined form of the problem in the following equations.

$$\begin{aligned}&\sum_{j\in J}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} yc_{jcpt}.Cyc_{jcpt} + A = \sum_{i\in I}\sum_{j\in J}\sum_{t\in T} x_{ijt}.Cx_{ijt} + \\ &\sum_{d\in D}\sum_{s\in S}\sum_{t\in T} ds_{dst}.Cds_{dst} + \sum_{j\in J}\sum_{h\in H}\sum_{p\in P}\sum_{t\in T} yh_{jhpt}.Cyh_{jhpt} + \\ &\sum_{j\in J}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T} yd_{jdpt}.Cyd_{jdpt} + \sum_{d\in D}\sum_{s\in S}\sum_{t\in T} sd_{sdt}.Csd_{sdt} + \\ &\sum_{d}\sum_{im\in IM}\sum_{t\in T} Idm_{im,d,t}.CIdm_{im,d,t}.\end{aligned} \tag{1}$$

Eq. (1) calculates the transfer costs.

$$\begin{aligned}B = &\sum_{j\in J}\sum_{t\in T} CII_{jt}.II_{jt} + \sum_{c\in C}\sum_{t\in T}\sum_{p\in P} Ic_{ctp}.CIc_{ctp} + \sum_{d\in D}\sum_{t\in T}\sum_{p\in P} Id_{dtp}.CId_{dtp} + \\ &\sum_{s\in S}\sum_{t\in T}\sum_{p\in P} Ih_{htp}.CIh_{htp} + \sum_{s\in S}\sum_{t\in T} IS_{st}.CIS_{st}.\end{aligned} \tag{2}$$

Mahmoudi et al.| J. Appl. Res. Ind. Eng. 8(Spec. Issue) (2021) 1-15

Eq. (2) calculates the inventory costs.

$$C=\sum_{j\in J}\beta_j.(\sum_{d\in D}\sum_{p\in P}\sum_{t\in T}yd_{jdpt}+\sum_{c\in C}\sum_{p\in P}\sum_{t\in T}yc_{jcpt}.Cyc_{jcpt}+\sum_{h\in H}\sum_{p\in P}\sum_{t\in T}yh_{jhpt}.Cyh_{jhpt}). \quad (3)$$

Eq. (3) calculates the amount of environmental pollution in treatment plants.

$$E=\sum_{d\in D}\beta D_d.(\sum_{t\in T}ds_{dst}.Cds_{dst}+\sum_{s\in S}\sum_{t\in T}sd_{sdt}+\sum_{im\in IM}\sum_{t\in T}Idm_{im,d,t}.CIdm_{im,d,t}). \quad (4)$$

Eq. (4) calculates the amount of environmental pollution in distribution centers.

Due to the same unity of the objective functions (1, 2) and (3 and 4), the resulting objective functions are equal to:

For the amount of cost reduction: $Min(F1)=A+B.$

To reduce the amount of environmental pollution: $Min(F2)=C+D+E.$

Also, the sum of the objective functions is calculated by weighted sum method as $F=0.5*F2+0.5*F2.$

Constraints:

$$\sum_{j\in J}x_{ijt}\le capacity_i,\quad \forall i\in I,t\in T. \quad (5)$$

Eq. (5) ensures that the maximum amount sent from the field to the purifiers is taken into account.

$$II_{jt}=II_{jt-1}+\sum_{i\in I}x_{ijt}-\sum_{i\in I}\sum_{p2\in P}yd_{jdpt}-\sum_{c\in C}\sum_{p1\in P}yc_{jdpt}-\sum_{h\in H}\sum_{p3\in P}yh_{jhpt},\quad \forall i\in I,t\in T. \quad (6)$$

Eq. (6) indicates the amount of crude oil inventory coming in from the refiners.

$$Ic_{ctp}=Ic_{c,t-1,p}+\sum_{i\in I}x_{ijt}-\sum_{j\in J}yc_{jdpt}-DC_{ctp},\quad \forall c\in C,t\in T,p1\in P. \quad (7)$$

Eq. (7) considers the amount of oil condensate inventory in condensate consumption centers.

$$\sum_{d\in D}yd_{jdpt}\le\sum_{i\in I}\lambda_{ip}.x_{ijt},\quad \forall j\in J,t\in T,p2\in P. \quad (8)$$

Eq. (8) ensures that the amount of crude oil sent from the refiner j to other distributors does not exceed the maximum refined product input.

$$\sum_{c\in C}yc_{jcpt}\le\sum_{i\in I}\lambda_{ip}.x_{ijt},\quad \forall j\in J,t\in T,p1\in P. \quad (9)$$

Eq. (9) ensures that the amount of condensate sent from the purifier j to other distributors should not exceed the maximum refined product input.

$$\sum_{c\in C}yc_{jcpt}\le\sum_{i\in I}\lambda_{ip}.x_{ijt},\quad \forall j\in J,t\in T,p3\in P. \quad (10)$$

Eq. (10) ensures that the amount of crude oil sent from the refiner j to other distributors does not exceed the maximum refined product input.

$$Id_{dtp}=Ic_{d,t-1,p}+\sum_{im\in IM}idm_{im,d,t}-\sum_{ex\in EX}DE_{ex,t}-\sum_{s\in S}\gamma ds_{st}.ds_{dst}+\sum_{s\in S}\gamma sd_{st}sd_{sdt}$$
$$+\sum_{j\in J}yd_{jdpt}-Dd_{dtp},\quad \forall d\in D,t\in T,p2\in P. \quad (11)$$

Eq. (11) calculates the amount of crude oil in distribution centers.

$$Ih_{htp} = Ih_{h,t-1,p} + \sum_{j \in J} yh_{jhpt} - Dh_{htp}, \quad \forall d \in D, t \in T, p2 \in P. \tag{12}$$

Eq. (12) calculates the amount of crude oil inventory in petrochemical plants.

4 | Research Findings

The mathematical model presented in Section 3-2 is solved using GAMS software and the BARON tool. The research results show 95% confidence in the calculations, which is an acceptable value and can satisfy the decision-maker. This amount of confidence is based on the results of the software output and the current situation, which shows that only 5% of the goals cannot be met. *Table 2* presents the results obtained from the multi-objective model. According to *Table 2*, with decreasing costs, total profit increases. Also, greenhouse gas emissions are reduced due to the selection of less sensitive areas.

Table 2. Results of objectives based on the proposed model.

Total Objective	Sub-Objectives	Change Percentage	Sum of Changes
Costs	Transport costs	15% reduction	31% reduction
	Inventory costs	16% reduction	
Greenhouse gas emissions	The amount of pollution in purifier centers	25% reduction	51% reduction
	The amount of pollution in distribution centers	26% reduction	

In addition, *Table 3* shows the results for different decision values such as field and refinery capacity and export volumes. According to the results, the total capacity of fields and refineries will increase by 18% according to the proposed model, which will provide an opportunity to produce petroleum products. Also, the amount of exports increases by about 65%, which in the context of sanctions against Iran, due to more currency, the value of the national currency increases. Therefore, the development of old oil fields and refineries is offset by an increase in exports.

Table 3. Percentage of changes in various decisions based on the proposed model.

Decision	Change percentage
Capacity of fields and refineries	18% increase
exports	65% increase

In addition, the contribution of each of the intended petroleum products (such as diesel, LPG, fuel oil, gasoline, and oil) to greenhouse gas emissions is shown in *Table 4*. The lowest and highest share of the cost of petroleum products is related to oils and fuel oil, respectively. It should be noted that the consumption of gasoline and diesel due to the existence of some private and public cars do not have the necessary standards, which due to the quota of gasoline and its single price, the government compensates part of the costs by people purchase.

Table 4. The share of each petroleum product in costs.

Petroleum Product	Share Rate
Diesel	5.74%
LPG	4.90%
Fuel oil	60.33%
Gasoline	25.82%
Oil	3.19%

Also, *Table 5* shows the amount of greenhouse gas emissions generated by refineries, fields, transmission facilities (pipelines), and storage tanks. According to the results, most of the greenhouse gas emissions

Mahmoudi et al.| J. Appl. Res. Ind. Eng. 8(Spec. Issue) (2021) 1-15

are from refineries. Therefore, according to the results, storage tanks and transportation facilities do not have a negative effect on greenhouse gas emissions.

Table 5. The share of each GHG producers.

Center	Share
Refinery	38.88%
fields	26.52%
Transport center	34.61%
Storage center	0

4.1 | Sensitivety Analysis

In this secion, the effect of changing key parameter like as maximum capacity of centers on decisions of proposed model is examined. This changing of parameter were identified in constulating with petroleum experts. As shown in *Table 6*, changing maximum capacity have the remarkable effect on Fuel oil and Gasoline. *Fig. 2* shows the rate of change of the parameter for different values on each product.

Table 6. Changing maximum capacity on product quantity.

Parameter	Product				
	Disel	LPG	Fuel oil	Gasoline	Oil
10000	1000	1000	3000	4000	1000
20000	2000	1000	3000	13000	1000
30000	2500	2500	10000	15000	0
40000	5000	2500	10000	20000	2500
50000	1000	1000	15000	30000	3000
60000	2500	1000	15000	40000	1500

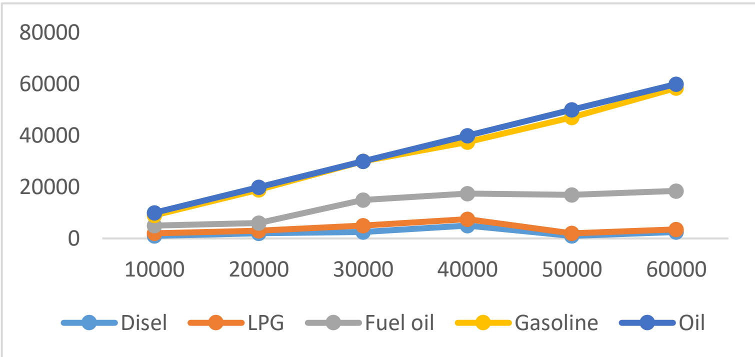

Fig 2. Changing maximum capacity on each product quantity.

Also, it is important to mention that change the key parameter on all objective function was examined. For this purpose, value objective function for each centers (refinery, fields, transport center and storage center) calculated. According to the objective functions results the effect of maximum capacity parameter was ignored. In *Fig. 3* to *5* show changing maximum capacity parameter effect on Transfer costs, inventory costs and environmental pollution respectivelety.

Mahmoudi et al.| J. Appl. Res. Ind. Eng. 8(Spec. Issue) (2021) 1-15

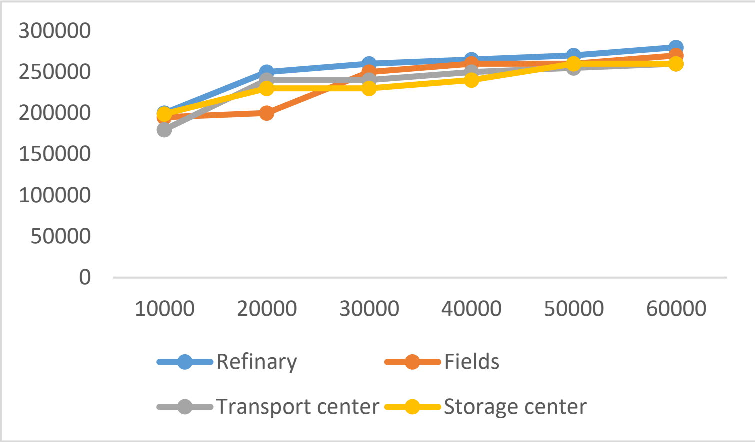

Fig 3. Changing maximum capacity on transfer costs.

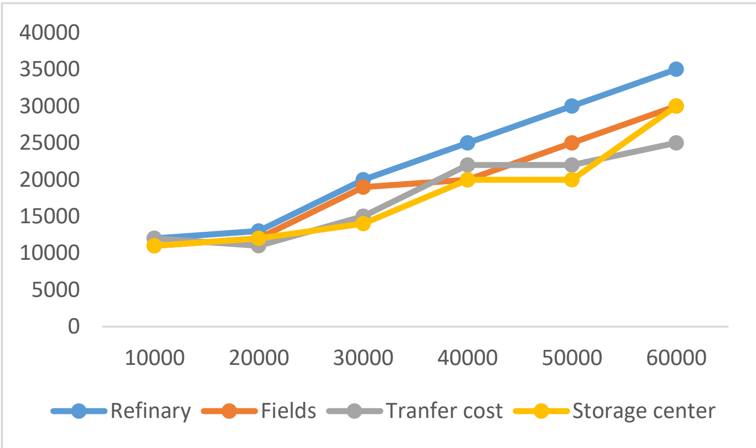

Fig 4. Changing maximum capacity on inventory costs.

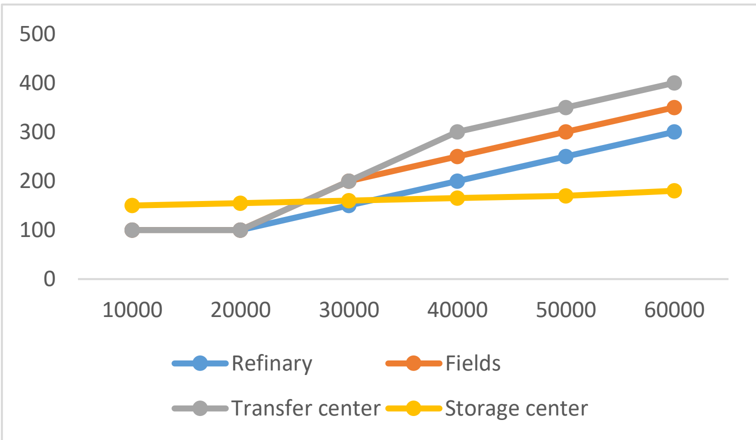

Fig 5. Changing maximum capacity on environmental pollution.

4.2 | Validation

Validation step shows how the model can reflect the behavior of real system. Model validity is acmplished through many methods that compare two series outputs [30]. In this paper, Absolute Relative Error (ARE) method ($\frac{|Mathematical\ model\ output - Simulation\ model\ output|}{Simulation\ model\ output}$) was used to accept the mathematical model. When, between mathematical model output and simulation model, ARE is lower than 0.05 it means that the mathematical model can predict behavior real system. Because, simulation model is alternative for real system Abolghasemian et al. [31]. For this purpose, a simulation model that can predict behavior real system built using ARENA. Validation results show in *Table 7*.

Table 7. Validation.

Conditions	objectives		
	Transfer costs	Inventory costs	Pollution
Mathematical model	25550	35562	500
Simulation model	26658	36587	523
ARE	0.04	0.02	0.04

The ARE value for each comparison is lower than 0.05. Therefore, mathematical model can predict well the real system behavior.

5 | Managerial Insight Implication

Integrated planning for natural gas components can prevent them from being wasted. At the time of the sanctions in Iran, large quantities of condensate product were discarded, as exports of this product had declined, as well as planning had been separately carried out for the products of supply chain and the capacity of its processing plants and storage facilities was not as high as its production. According to the study results, condensate product is the most valuable component of natural gas and should be utilized in a well planned manner.

6 | Conclusion

Given the knowledge gained from the study of the subject, few studies can design and strategically plan a sustainable supply chain that deals with the network of oil carriers. In this study, the main goal is to design a crude oil supply chain network to meet the needs in line with resource capacity, reduce costs and investment and minimize GHG emissions. For this purpose, an optimization framework based on mathematical modeling has been introduced for this supply chain. The proposed supply chain is used to design, plan and optimize the oil condensate network in strategic and tactical dimensions. For the transfer of condensate components, a pipeline connection is considered. In addition to the cases mentioned in the study, due to the knowledge gained from studying the experiences of others who pay less attention to economic factors and environmental aspects in the supply chain, environmental aspects are also considered in this study. Therefore, the structure and decisions of the supply chain include the simultaneous consideration of minimizing the total costs and investment of the supply chain and minimizing the total emission of greenhouse gases. Main results of the paper are as follows:

I. The proposed model is able to estimate the objectives with 95% confidence, which is acceptable reliability with 5% error.
II. There is a 31% reduction in costs and 51% reduction in greenhouse gas emissions.
III. To establishment of optimal results and their analysis, the capacity of fields and refineries will increase by 8% and the export rate will increase by 65%.

Using the results obtained from solving the model, we can determine the share of each of the intended petroleum products. According to the results, fuel oil has the highest and oils the lowest. In addition, it can be calculated separately for each greenhouse gas sector. According to the results, refineries have the most, and storage tanks impact environmental pollution. Finally, based on the results, we believe that this research will provide a valuable contribution and help to managers active in the field of energy.

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Mahmoudi et al.| J. Appl. Res. Ind. Eng. 8(Spec. Issue) (2021) 1-15

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