Sustainable Model of Port-hinterland Freight Distribution Network Considering Uncertainty: A Case Study of Iran

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Abstract:
According to the significant role of ports, port-hinterland distribution network considering various parameters, has come under the spot of attention in the recent years. This paper, considering intermodal transport, along with the possibility of constructing new inland terminals where transportation mode changes, aims to investigate the subject of port-hinterland freight distribution network. To this aim, considering the volume of exported freight being delivered as well as imported freight received, a multi-objective intermodal model has been developed for Iran's case study. In this model, it has been assumed that in addition to the existing railway and road routes in the country, new railway and road routes could be constructed as well. The first objective function involves minimizing the cost of transportation along with the cost of constructing an inland terminal. The second objective function involves minimizing CO₂ released during freight transport. The certain model of the problem has been described, first and uncertainty conditions in amounts of import demand and export supply has been taken into account. A robust modeling approach has been used. Therefore, data of goods imported or exported to/from Iran were collected and solved using robust model in GAMS software; then the results were analyzed and investigated.

Keywords: Logistic, Port, Hinterland, Inland Terminals, Transportation, Freight, Distribution, Robust
1. Introduction:
In recent years, optimizing port-to-port connection has been a key factor in transportation chain from origin to destination, and it is of paramount importance. Along with the changes happening in traditional forms of commodity exchange, various factors have become important in the design of a freight distribution network, thus, researchers try to involve them in their recent modeling. The concept of the port, which in the past was considered merely a place to transport goods from sea to land or vice versa, has developed in recent years and has led to various generations of ports, each of which has more roles than the previous generation. In the meantime, the connection between two concepts of port and hinterland has made it impossible to separate port and hinterland in the design of a freight distribution network so that the hinterland connectivity is expressed as the second most important factor driving port competitiveness, after port costs [1]. On the other hand, with the development of intermodal transport in recent years, governments have tried to increase the role of rail transport in the design of transport infrastructure; because, rail transport is proved to do less damage to the environment than road transport. In general, following the change in role and concept of port, development of intermodal transportation, along with considering environmental protection at the same time, resulted in a new perspective in the design of port-hinterland distribution network. Currently, in transportation industry environmental protection has become a vital concern in the field of sustainable development, which is considered to be an issue tied to the intermodal transportation industry; therefore, it is important to examine the connection between environment protection and sustainable development.

Intermodal transportation, in addition to rationalizing the transportation chain, and reducing energy consumption, it is more likely to make reasonable use of infrastructure. It therefore reduces environmental impact by using high maritime capacity and rail transportation. In addition, it benefits from the greater flexibility offered for road transport [2]. Also the development of integrated intermodal transport networks, coupled with the establishment of interconnected networks of inland terminals, as well as the fast increasing involvement of shipping industry actors in door-to-door services and operations, placed a greater emphasis on the importance of hinterland transport connectivity in shaping port competitiveness [3]. Given the excessive growth of maritime transport, and the connection between port and hinterland, if no improvement happens in old structures, transportation system is expected to explode as a cause of problems due to inefficiency. Therefore, changing current structures and paying special attention to environmental sustainability in new structures is a vital matter. Since train and barge are less likely to release CO$_2$ in comparison with truck and road vehicles, it can be concluded that intermodal network is capable of offering more sustainable options [4]. In the meantime, since each of these goals may conflict with the managerial goals of each of these players, the way of managing the exchange between these modes is a big challenge for transportation and logistics planners, operators and customers. In the models proposed for port-hinterland freight distribution network in this paper, the strategic view of the mentioned concerns has received less attention [5].

In this study, based on existing gaps, a strategic and multi-objective model is presented, indicating means to use rail and road transportation modes along with the rate of ports and inland terminals operation, which is determined based on the amount of import and export of
supply and demand nodes. Terminals, also known as dry port, logistic park, or distribution center, are places for goods transportation, mode change, and allocation of added value on goods. Iran has been chosen as the case study of the current study, and the provinces are considered as the nodes of supply and demand or the origin and final destination of the goods. In this model, possibilities such as constructing new rail/road routes has been considered and current network could be optimized and developed with the construction of new routes. The model determines that in which directions freight should be sent directly from port to province, and where an inland terminal shall be constructed to change transportation mode. This model's first objective function involves minimizing the cost of transportation (for both import and export) along with the cost of constructing an inland terminal, and the second one involves minimizing CO₂ released during freight transport. In this model, in order to deliver the imported goods into the country, the model first determine how much goods could be imported to each seaport, then, decides how and by which transportation mode (rail or road), based on the demand of each node (individual provinces), freights should be sent from seaports to provinces.

Regarding the matter of export goods, the model, based on the export volume of each province and transportation mode (rail or road), decides as well how to collect the goods from each province and send them to the destination ports. On the way of goods transportation (import/export) from one province to another, if there was a need to change the transportation mode, an inland terminal shall be constructed.

Since a certain model with approximation may lead to erroneous decisions, one of the most important challenges in supply chain management is the uncertainty of demand and supply (which is more closely approximated by forecasts) which is a prominent factor in precise decision-making. Demand and supply, in actual design problems of port-hinterland freight distribution network, are very dynamic and should be described as random variables. According to the literature, few authors have addressed the issue of uncertainty. A common assumption in most studies of supply chain management given random demand (supply) is that the probability distribution of demand (supply) is well known, yet its availability is rare or very difficult. Obviously, if there is no complete information about the probability distribution of demand (supply), solving the problem of "port-hinterland distribution network" requires attention to random demand (supply) in a flexible way. Using such parameters, robust optimization has proven to be a powerful method in random problems with the distribution of unknown probabilities. This method guarantees a feasible answer by finding a minimax solution, regardless of certain values of unknown variables. Based on information obtained in the current study and the literature, we found less attention and focus on the design of the port-hinterland connection network using robust optimization. As a result, in this paper, considering the uncertainty conditions for the amount of demand and supply of each province, a robust optimization approach is used to apply the uncertainty conditions to the model. Innovations done in this article are explained in brief, as follows:

i. A new model in design of port-hinterland distribution network, considering intermodal transportation network, the possibility of construction of an inland terminal when mode change happens, and the possibility of constructing new transport routes, has been proposed.
ii. Based on the literature review this is one of the first studies in the design of port-hinterland distribution system using robust for modeling.

iii. Since, robust optimization cannot be applied to equal constraints (e.g., equality is not possible in case of uncertainty); a robust optimization method is presented for equal constraints including parameters related to demand and supply.

iv. Also, this problem has been solved in a practical way for provinces in Iran as case study.

This study benefits from actual data provided by the center of statistics and ministry of roads and urban development in Iran.

2. Literature review:

Two types of qualitative and quantitative studies has been done on the subject of this research. In fact, this article focuses on qualitative issues, including how to manage infrastructure, how to deal with matters related to goods distribution between seaport and hinterland, and how to manage inland terminals. Most important qualitative studies conducted over the subject of policy-making in port-hinterland system, studies of Dooms et al. [6] in 2015, Veenstra et al. [7] in 2012, and Van den Berg & De Langen [8] in 2015 are to be named. Jason Monios [9] has focused on how to develop inland terminals, as well as their role in strategic access from seaports to hinterland; this study was done on Spanish ports. Yulia Panova and Hilmola [10] have noted the economic importance of dry ports/inland terminals and distribution centers in economic development of countries; they examined the possible means of investment leading to intended development by studying Russia. Woodburn [11] by using the UK as a case study investigates the effect of increase in rail mode share. Results show that operational efficiency improvements and reduction in the negative externalities per unit of transport activity in the hinterland.

In 2013, Roso [12] investigated intermodal transport between seaport and dry port as a solution to reduce inland terminal congestion, as well as better access to the port and inland terminals, this study was done based on investigating short rail travels. The aim of this qualitative study is to analyze the effects of dry ports development on the sustainability of intermodal transport based on rail transport. Some studies have been conducted on the importance of dry ports. Dry ports play an important role in designing the structure of the port network. When developing transport plans at a macro-level, government agencies should carefully consider the characteristics of seaports and dry ports, the direction of development and the level of activity of the dry ports [13]. The dry port concept has gained significant attention among researchers all around the world, mainly due to its potential to improve hinterland intermodal transportation, generate economic benefits, and reduce environmental impacts [14].

Although, there already are various mathematical models proposing port-hinterland transportation network development, but few have paid direct attention to challenges addressed in this article. During research done for this paper, few models found in which they addressed this subject strategically.

So far no model considered transport infrastructure development, including routes and inland terminals. In fact, no study was found examining the transport infrastructure required for an optimal network situation along with its costs imposing from creating a port-hinterland...
network. Moreover, no study was found to consider environmental issues including the CO₂ emissions reduction, as well.

In 2016, Halim et al. [5] done the most significant strategic research in this field, presenting a strategic model for port-hinterland freight distribution as a result. In their model, they used a multi-objective optimization combination to estimate the location, as well as the network of distribution centers selected according to the different levels of service. The case study of this article was the Europe continent. The measures include port-hinterland transport cost, port-hinterland transport time, and distribution center-hinterland transport time.

There are also, many other models studied this subject at tactical level. In 2016, Lam and Gu [15] seek to minimize time, cost, and the amount of gases emitted by vehicles in their article; the first two of which are directly related to the objective functions of a bi-objective problem, and the third has been taken as the constraint of the problem. In this model, the containers could be sent from foreign ports to domestic seaports. After containers were emptied in domestic seaports, customs duties should be carried out before they would be sent to the final customers in domestic cities through the domestic transport network. Three types of vehicle (rail, barge, and truck) were considered as transportation modes in this model. Where there are railway and barge as available modes, prior to the step of delivering by truck, it is preferred to use these two at first; otherwise, truck could be used for entire route from ports to the end customer.

In 2008, Wang [16] combining the transport system, hub-and-spoke with the integrated transport system between ports and hinterlands, in his paper, presented an optimal two-level nonlinear model for the logistics system. In 2010, Mingjun and Maoying [17] proposed a two-tier planning model; in which the upper objective is the total cost of transportation in regional port group, and the lower objective is the economic profit of a single firm; this paper considers hinterland dynamics of each port in the logistics transportation system. In 2010, Iannone [18] introduced an intermodal model to develop multi-faceted freight transfer problem; this study was conducted in Italy. The model presented in this study minimizes the total logistical costs through the port-hinterland network, which is limited to balancing the terms in the nodes, and the constraints in railways capacities. Logistics costs include transportation costs (by road and rail), customs and terminal operating costs, and in-transit holding costs. In 2009, Kim and Janic [19] in their article, investigate the relationship between transportation costs and CO₂ emissions in a network. When it comes to changing different factors, the exchange of factors changes the direction of transportation. The freight network in this article present a different combination of transportation modes, in which, with changing the mode and route, this system should achieve the acceptable amount of CO₂ emission, along with reasonable time and place. In this paper, a multi-objective optimization technique has been used.

In 2008, Rahimi et al. [20] using a location-allocation model, examined the potential to integrate domestic ports in intermodal regional freight transportation system; they selected southern California as a case study. In this paper, analyzing the movement of trucks, first, potential locations for domestic ports were identified; then six domestic ports were selected using the model. In 2013, Feng et al. [21] proposed a location-allocation model to optimize the seaport-domestic port network; then, using a genetic and grade algorithm, they solved the
model. This study was conducted in Taiwan, various aspects of transportation had not been considered in this article.

In 2013, Lattila et al. [22] investigated the larger range use of rail in transportation to reduce CO₂ emissions. Railway connects distribution centers (domestic ports) to seaports. In this paper, two different configurations has been compared; in the first one, the shippers are directly connected to the seaport, while in the second one, they use dry ports. The system is evaluated using event-discrete simulation. In this system, CO₂ emission levels along with transportation costs in different configurations have been investigated. In a study conducted in Finland, the effect of constructing dry ports on reducing transportation costs has been investigated, then, it was compared with that of Sweden. Integer programming model of this study indicates that the existence of dry ports reduces costs and effects of released harmful gases [23]. In 2017, Wang et al. [24] developed a mathematical model for optimizing the dry port location, investigating the operations in dry port. In 2015, Chang et al. [25] in their article presented a template for the optimal and reasonable design of a dry port, which had been designed for a Chinese port named Dalian. In 2015, Zhang et al. [26] proposed a model for optimizing freight transportation that simultaneously considers intermodal structure, hub-centric network, and various design goals of the players. The model was validated using real data from Netherland's hinterland container shipping.

In 2018, Aregall et al. [27] reviews the importance of ports and hinterland in reducing greenhouse gases. In this regard, through studying several ports in the globe, they intended to identify ports defining measures to reduce the gas emissions; therefore, finding out to what extent they have been successful. The results of the research have shown that congestion in ports plays a key role in increasing greenhouse gas emissions associated with the ports, and the public ownership of ports, also, highlights this key role. Hu et al. [28] in 2018 investigate mathematical models for the planning of container movements in a port area, integrating the inter-terminal transport of containers with the rail freight formation and transport process. An integer linear programming model is used to formulate the container transport across operations at container terminals, the network interconnecting them, railway yards and the railway networks towards the hinterland. A tabu search algorithm is proposed to solve the problem.

In 2019, Santos and Soares [29] presented a model defining and optimizing the overall cost of port-hinterland; these costs include shipping costs, inland port costs and transit costs. In addition, in this research, transportation has been carried out in by using roads and railways. This study was conducted as a case study in the western Iberian Peninsula. The results allowed the identification of the main hinterland of different terminals based on the overall costs and the analysis of the effects of intermodal terminals in promoting a regionalization process.

Resat and Turkay [30] developed a model that includes different objective functions including total transportation cost, travel time and CO₂ emissions while optimizing the proposed network structure. Traffic congestion, time-dependent vehicle speeds and vehicle filling ratios are considered and computational results for different illustrative cases are presented with real data from the Marmara Region of Turkey. The defined non-linear model is converted into linear form and solved by using a customized implementation of the ε-constraint method.
In 2019, Liu et al. [31] presented a model based on the system dynamics to assess the emissions in the hinterland. This model has been implemented in China in order to evaluate environmental policies on emissions. Therefore, examining different policies in the form of scenarios, through displaying the hinterland transportation process, the model clearly identifies the amount of emissions. The model, also, has been able to determine the effective scenario to minimize emission, which are the rigid truck weight regulation and the construction of a grade-I railway. In 2020, Nguyen et al. [32] proposed a two-stage approach combining data mining and complex network theory to optimize the locations and service areas of dry ports in a large-scale inland transportation system. First, dry ports candidate locations were weighted based on their eigenvector centrality in the complex network of association rules mined from a large amount of international transaction data. Second, dry port locations and their service areas were optimized using the gravity-based community structure. Recently in a study by Jiang et al. [33] though ports not being involved directly in modeling, they have taken demand uncertainty into account for the development of a multimodal logistics network. According to the determined logistics demand pattern, this multi-stakeholder decision making problem has been first, formulated as a bi-level programming model. This model has been followed by its equivalent mathematical programming with equilibrium constraints (MPEC), to depict the leader-follower behaviors. In order to capture the risk aversion level of the logistics authority in uncertain demand environment, an improved adjustable robust optimization method is proposed. This method includes an individual control parameter and providing an exact expression of the maximum satisfaction probability.

Despite studies done so far, clearly, there was less attention to models that are able to choose how to develop intermodal transport infrastructure and the required terminals considering current network status simultaneously. In addition, there is no model providing a robust optimization approach solving a problem with uncertainty in supply and demand. Therefore, a new approach has been addressed in this article.

3. **Problem modeling:**

In this model, \( N \) represents a set of seaports \( (p \in \{1,2,\ldots,P\}) \) in addition to a set of provinces \( (i \in \{1,2,\ldots,I\}) \) defined as \( N = P \cup I \). Transport mode between nodes of \( N \) set is represented by a finite set \( (v \in \{1,2,\ldots,V\}) \), such that between two nodes of \( N \) set there can be one or several possible transport modes. In this research, on the one hand, goods imported into the country are first imported to several seaports, and then the goods can be sent from the ports to the provinces one after another. On the other hand, the goods meant to be exported from the country can also be collected from the provinces in the same manner, and then to be sent to the ports. Moreover, in case there was any need of transport mode change in provinces that are either in the way of imported or exported goods' transportation, an inland terminal should be established in that province. This model has two objective functions; the first meant to minimize the cost of establishing inland terminals and new routes, as well as the cost of goods' transportation. This is whilst, the second objective function meant to minimize the amount of \( \text{CO}_2 \) emission caused by goods transportation.

The mathematical modeling's assumptions in the problem are as follows:

- The capacity of inland terminals and seaports assumed unlimited.
- The number of transport vehicles assumed unlimited.
- The cost of establishing an inland terminal assumed on average.

3.1. **Sets:**

\( m, n \) : total set of nodes (including set of seaports and set of provinces)

\( p \) : set of seaports

\( i, j \) : customer points (Provinces)

\( v \) : transfer mode set

3.2. **Parameters:**

\( \text{dis}_{nmv} \) : distance between \( n \) and \( m \) nodes in the transport mode number \( v \)

\( f_{nmv} \) : if there exists between \( n \) and \( m \) nodes the transport mode number \( v \) it is 1, otherwise 0

\( e_i \) : cost of establishing an inland terminal number \( i \)

\( d_i \) : demand quantity of province number \( i \)

\( s_i \) : supply quantity of province number \( i \)

\( c_{ov} \) : amount of \( CO_2 \) produced by transport mode number \( v \) (g/ton/km)

\( c_v \) : amount of transfer cost by transport mode number \( v \) (USD/ton/km)

\( Ec_v \) : cost of establishing a one-way transport route with transport mode number \( v \) (USD/km)

\( f'_{nmv} \) : if there is a capability of establishing a new inland terminal between \( n \) and \( m \) nodes 1, otherwise 0

3.3. **Variables:**

\( o_p \) : amount of goods imported to the seaport number \( p \)

\( w_p \) : amount of goods exported from the seaport number \( p \)

\( x_{nmv} \) : amount of imported goods transferred from \( n \) node to \( m \) node in transport mode \( v \)

\( u_{nmv} \) : amount of exported goods transferred from \( n \) node to \( m \) node in transport mode \( v \)

\( d'_{iv} \) : amount of province number \( i \)'s demand supplied by transport mode number \( v \)

\( s'_{iv} \) : amount of province number \( i \)'s supply transferred by transport mode number \( v \)

\( y_{nmv} \) : if it could supply imported goods from \( n \) node to \( m \) node with transport mode number \( v \) (available path), it is 1, otherwise 0

\( v_{nmv} \) : if it could transfer exported goods from \( n \) node to \( m \) node with transport mode number \( v \) (available path), it is 1, otherwise 0
$z_i$: If the transport mode in the province number $i$ was changed, or if an inland terminal was established in that city 1, otherwise 0

$z_{iv}^1$: an additional variable that if the quantity of goods imported into the province number $i$ minus that of imported out of it receive a positive value in the transport mode number $v$ it is 1, otherwise it is 0

$z_{iv}^2$: an additional variable that if the value of goods imported out of province $i$ minus that of imported into it, in transport mode number $v$ was positive 1, otherwise 0

$z_{iv}^3$: an additional variable that if the amount of exported goods out of province $i$ minus that of imported into province $i$ in positive transport mode number $v$ receives a positive value 1, otherwise 0

$z_{iv}^4$: an additional variable that if the value of the exported goods to the province $i$ minus that of exported from the province $i$ receive a positive value in transport mode number $v$ is 1 otherwise 0

$r_{nmv}^1$: If from $n$ node to $m$ node, in $v$ transport mode, with the construction of a new route in order to supply imported goods, transportation could be done 1, otherwise 0

$r_{nmv}^2$: If from $n$ node to $m$ node, in $v$ transport mode, with the construction of a new route in order to transfer exported goods, transportation could be done 1, otherwise 0

$r_{nmv}^3$: If from $n$ node to $m$ node, in $v$ transport mode, with the construction of a new route (one-way route), transportation could be done 1, otherwise 0

### 3.4. Deterministic Model:

Here, the deterministic model of the problem has been described first, based on which the non-deterministic model has been presented.

\[
\min z_1 = \sum_i e_i z_i + \sum_v \sum_m \sum_n c_{iv} \text{dis}_{nmv}(x_{nv} + u_{nv}) + \sum_v \sum_m \sum_n Ec_{iv} \text{dis}_{nmv}(r_{nmv})
\]  
(1)

\[
\min z_2 = \sum_v \sum_m \sum_n c_{iv} \text{dis}_{nmv}(x_{nv} + u_{nv})
\]  
(2)

S.t

\[
o_p = \sum_v \sum_j x_{pvj} \quad \forall p
\]  
(3)

\[
\sum_v x_{nv} = \sum_v x_{ijv} + d_i \quad \forall i
\]  
(4)

\[
d_i = \sum_v d_{iv}' \quad \forall i
\]  
(5)

\[
\sum_{v,n,v,i} x_{nv} - (\sum_{n,p,v,i} x_{nv} + d_{iv}') \leq Mz_{iv}^1 \quad \forall i, v
\]  
(6)
Equation (1) represents the objective of function number 1, minimizing the cost of establishing a terminal, as well as the cost of transport between nodes. Equation (2) represents the objective of function number 2, which involves minimizing the amount of CO$_2$ released during transport between nodes. The constraint equation (3) ensures that the amount of imported goods to each seaport is equal to the quantity of goods imported out of that. Equation (4) examines the balance of import flows in each province; more precisely, ensuring that the inflows of goods imported into each city are equal to the outflows of imports of that. The constraint equation (5) ensures that the total demand of each province is equal to the sum of the quantity demanded by each transportation mode. The constraint equations (6) and (7) indicate whether the transportation mode for delivering the imported goods at $i$ node has changed. The constraint equation (8) ensures that the quantity of imported goods between two specific provinces can be transferred with one transportation mode, either with an existed transportation mode or the one that would
be constructed. The constraint equation (9) indicates that if there already is a transport mode for transferring the imported goods, there is no need to construct a new route; whilst, the constraint equation (10) indicates that if there is no available transport mode, a new route would be constructed. The constraint equation (11) ensures that between two specific nodes for transferring imported goods, just one mode would be selected. The constraint equation (12) ensures that the amount of exported goods entered into each seaport is equal to the quantity of exported goods discharged from that. Equation (13) examines the balance of export flows in each province; more precisely, ensures that the export inflows of each city are equal to the export outflows of the same city. Equation (14) ensures that total supply of each province is equal to the sum of quantity supplied by each transport mode. Equations (15) and (16) indicate whether the transportation mode for collecting export commodities at \( i \)th node has changed. The constraint equation (17) ensures that the quantity of exported goods between two specific provinces can be transferred with one mode, either that is existed, or a suited mode would be constructed. Equation (18) indicates that if there already existed a transport mode for transferring the exported goods, there is no need to construct a new one; whilst, equation (19) indicates that if there was no available transport mode for transferring the exported goods, a new transport mode could be constructed on the same route. The constraint equation (20) ensures that between two nodes for the exported goods only one transport route would be selected. Equations (21) and (22) indicate that constructing a new transport mode between \( n \) and \( m \) nodes is only considerable, if it meant to be used as a transport mode for either imported or exported goods, or even both. The constraint equation (23) indicates that in each province an inland terminal can be established, when the transportation mode modification has taken place. Finally, equations (24) and (25) specify the type of decision variables.

3.5. Uncertainty:

Uncertainty can be defined as the difference between the amount of information that is required to proceed a research, and the amount of information that is actually available; and, by uncertainty, it means the uncertainty in parameters. Therefore, since the certain optimization problems are usually formulated and solved considering the data is certain, consequently, in everyday real-world problems most data suffers from uncertainty. Uncertainty can affect the optimization and justification of problems. In real-world problems, changing one of the data may violate a great number of constraints, making the results non-optimal or even impossible. So far, three main approaches of optimization, including stochastic, fuzzy, and robust optimization, have been developed to address uncertainty in optimization issues. Stochastic optimization models were first developed by Dantzig and Bill in 1995. These models provide a possible perspective to replace certainty, when it comes to unknown coefficients and parameters. Many uncertainty models take statistical distributions into account for uncertain data. So these models can be used when either the uncertainty distribution of the parameters is known and clear, or a certain distribution of parameters can be adjusted. Fuzzy logic was first invented in 1960 by a professor of computer science at the University of California, Berkeley, named Dr. Lotfizadeh. Fuzzy logic believes that ambiguity is in the nature of science. Unlike others believing approximations need to be more precise to increase productivity, Lotfizadeh believes that models should be sought to model ambiguity as a part of the system. Fuzzy logic
and its use to model uncertainty largely depends on the expert being available, and the nature of the uncertainty parameter.

In the field of robust optimization, Soyster [34] developed a pessimistic robust approach in order to deal with inaccurate linear programming problems. A robust decision is a decision that resists the uncertainty of the environment and the resulting performance fluctuates minimally. An answer to an optimization problem could be called robust answer if has feasibility and optimality robustness. Feasibility robustness means that the answer must remain feasible for all (most) possible uncertain parameters. Robust optimization also means that the value of the objective function for a robust answer must be close to its optimal value for all (most) possible cases of uncertainty parameters, or in other words, have the least deviation from its optimal value. Therefore, in order to model uncertainty in robust models, there is neither the need to know the distribution of uncertainty, nor the necessity of an expert existence; and it is enough to know the constraints of the uncertain parameter. These models are easier to use to model uncertainty compared with stochastic and fuzzy models.

3.5.1. Convex robust models:

Suppose in an optimization problem, $J_i$ is defined as a set of parameters of the technological matrix $A$ that are uncertain in the $i'th$ row. Any data with uncertainty $a_{ij}, j \in J_i$ is defined as an independent and symmetric random variable $\tilde{a}_{ij}$ that belongs to the range $[a_{ij} - \hat{a}_{ij}, a_{ij} + \hat{a}_{ij}]$ with the central value of $a_{ij}$. To model any uncertainty variable, the deviation from the nominal value is defined as follows:

$$z_{ij} = (\tilde{a}_{ij} - a_{ij}) / \hat{a}_{ij}$$  \hspace{1cm} (26)

which varies in the interval $[-1,1]$.

Robust model provided by Soyster is one of the first robust models; it is a linear model in which all uncertainty parameters are at their worst.

$$\min \sum_j c_j x_j$$  \hspace{1cm} (27)

$$\sum_j a_{ij} x_j + \sum_{j \in J_i} \tilde{a}_{ij} x_j \leq b_i \hspace{1cm} \forall i$$  \hspace{1cm} (28)

$$x_j \geq 0 \hspace{1cm} \forall j$$  \hspace{1cm} (29)

This model is very conservative and pessimistic. The value of the objective function obtained from this model is far from the amount of the nominal objective function. Ben-Tal, and Nemirovski [35] balancing stability and performance of the model presented the following robust approach:

$$\min \sum_j c_j x_j$$  \hspace{1cm} (30)
In this optimization problem, $\gamma$ is the parameter controlling the percentage of model variability. The authors of the paper proved considering uncertainty space $U$, the probability of constraint $i$ being violated at the maximum is equal to $\exp \left( -\frac{\pi^2}{2} \right)$. This model’s conservative level is less than the Soyster model, also, the objective function value of robust optimization is less than that of certain model; but this model, due to being nonlinear has computational complexity, as well. In order to counter the over-conservatism of the first model, and the complexities of the second nonlinear model, Bertsimas and Sim [36] provided a linear model with a parameter to control the level of protection.

The authors of this paper claim that it is very unlikely that all uncertainty parameters will be at their worst at the same time. The maximum number of parameters that may deviate from their nominal value in each row in this model is equal to $[\Gamma_i]$. Given $\Gamma_i$ or the "uncertainty" budget in the model as follows, the "protection level" of any constraint is defined.

$$\sum_{j=J_i} |z_{ij}| \leq \Gamma_i \quad \forall i$$ (33)

The parameter $\Gamma_i$ belongs to the interval $[0,|J_i|]$. If $\Gamma_i = 0$, the robust model would turn into certain model, and if $\Gamma_i = |J_i|$ this model would turn into the pessimistic Soyster model. $\Gamma_i$ does not have to be integer, so the number of $[\Gamma_i]$ uncertainty parameters are at their worst condition, and one $(a_{it})$ parameter changes by $(\Gamma_i - [\Gamma_i])\hat{a}_{it}$ amount. Therefore, based on this, it can be said that $\Gamma_i$ is a parameter that according to decision-maker and practical requirements balances robustness and conservatism level of the model, and makes the robust model realistic.

The model provided by Bertsimas and Sim is as follows:

$$\text{Min} \sum_j c_jx_j$$ (34)

$$\sum_j a_{ij}x_j + \hat{\lambda}_i + \sum_{j \in J_i} \mu_{ij} \leq b_i \quad \forall i$$ (35)

$$\hat{\lambda}_i + \mu_{ij} \geq \hat{a}_{ij}x_j \quad \forall j \in J_i$$ (36)

$$\mu_{ij} \geq 0 \quad \forall j \in J_i$$ (37)

$$x_j \geq 0 \quad \forall j$$ (38)

$$\hat{\lambda}_i \geq 0 \quad \forall i$$ (39)

In above optimization problem $\mu_{ij}$ and $\hat{\lambda}_i$ are dual auxiliary variables.

Now, if the parameters on the right had uncertainty:
\begin{align}
\text{Min} & \sum_j c_j x_j \\
\sum_j a_j x_j & \leq \tilde{b}_i \quad \forall i \\
x_j & \geq 0 \quad \forall j
\end{align}

Therefore, $\tilde{b} \in [b_j - \hat{b}_j, b_j + \hat{b}_j]$ as a result of the Bertsimas and Sim model would be as follows:

\begin{align}
\text{Min} & \sum_j c_j x_j \\
\sum_j a_j x_j + \theta_j + \tau_j \Gamma_i & \leq b_j \quad \forall i \\
\theta_j & \geq \hat{b}_j \quad \forall i \\
\tau_j, \theta_j, x_j & \geq 0
\end{align}

3.5.2. Robust problem modeling:

In this research, the amount of demand and supply of each province is uncertain. As a result, each member $d_i$ and $s_i$ are defined as $[d_i - \tilde{d}_i, d_i + \tilde{d}_i]$ and $[s_i - \tilde{s}_i, s_i + \tilde{s}_i]$, respectively, and for robust problem modeling, the Bertsimas and Sim method has been used. Since robust modeling does not work accurately for equal constraints (not being possible to establish equality in case of uncertainty), therefore, for equal constraints including supply and demand parameter, based on the robust approach provided by Bretsimas and Thiele [37] to manage inventory and model presented by Hemmati Golsefidi and Akbari Jokar [38], the following method is presented, which is in fact a modeling approach based on equal constraints.

Certain model’s constraint equation \((4)\) is equal to:

\[\sum_v \sum_{n, n \neq v} x_{nv} = \sum_v \sum_{j, j \neq i} x_{ijv} + \tilde{d}_i \quad \forall i\]

In order to convert this equal constraint to an unequal one, the variable $dv^1_i$ was defined in such way that the amount of penalty for deviating from above constraint equation could be calculated. It also defines the parameters $dvc^1_i$ and $dvc^2_i$ as the amount of the penalty for each unit of deviation from equal, respectively, for when the demand of the provinces is greater than the nominal value, and when it is less than the nominal value.

Therefore, the above constraint equation should be rewritten as follows:

\begin{align}
(\sum_v \sum_{n, n \neq v} x_{nv} - (\sum_v \sum_{j, j \neq i} x_{ijv} + \tilde{d}_i))dv^1_i & \leq dv^1_i \quad \forall i \\
(\sum_v \sum_{j, j \neq i} x_{ijv} + \tilde{d}_i) - \sum_v \sum_{n, n \neq i} x_{nv} dv^2_i & \leq dv^1_i \quad \forall i
\end{align}

Now, according to Bretsimas-Sim method, it can be said:
Thus, $\Gamma_i^1$ is a parameter that determines the uncertainty budget, which is determined by the model decision-maker, and the variables $\tau_i^1$ and $\theta_i^1$ are auxiliary variables used in Bretsimas-Sim model. Parameter $d_i$ stands for demand nominal value, and parameter $\hat{d}_i$ stands for the value deviation from demand nominal value.

Certain model's constraint equation (5) is equal to:

$$\bar{d}_i = \sum_v d''_v \quad \forall i$$  \hspace{1cm} (53)

Similar to the constraint equation (4), in order to convert this equal constraint to an unequal one, the variable $d v^2_i$ was defined in such way that the amount of penalty for deviating from above constraint equation could be calculated. Parameters $d v^3_i$ and $d v^4_i$ were also defined as the amount of the penalty for each unit of deviation from equal, respectively, for when the demand of the provinces is greater than the nominal value, and when it is less than the nominal value.

Therefore, the above constraint equation should be rewritten as follows:

$$(\sum_v d''_v - \bar{d}_i)d v^3_i \leq d v^3_i \quad \forall i$$  \hspace{1cm} (54)

$$(\bar{d}_i - \sum_v d''_v)d v^4_i \leq d v^4_i \quad \forall i$$  \hspace{1cm} (55)

Now, according to Bretsimas-Sim method, it can be said:

$$(\sum_v d''_v - d_i + \theta^2_i + \tau^2_i \Gamma_i^2)d v^3_i \leq d v^2_i \quad \forall i, \Gamma_i^2 \leq |\Gamma|$$  \hspace{1cm} (56)

$$(d_i - \sum_v d''_v + \theta^2_i + \tau^2_i \Gamma_i^2)d v^4_i \leq d v^2_i \quad \forall i, \Gamma_i^2 \leq |\Gamma|$$  \hspace{1cm} (57)

$$\theta^2_i + \tau^2_i \geq \hat{d}_i \quad \forall i$$  \hspace{1cm} (58)

Thus, $\Gamma_i^2$ is a parameter that determines the uncertainty budget, which is determined by the model decision-maker, and the variables $\tau_i^2$ and $\theta_i^2$ are auxiliary variables used in Bretsimas-Sim model. Parameter $d_i$ stands for demand nominal value, and parameter $\hat{d}_i$ stands for the value deviation from demand nominal value.
The same process were repeated for constraints (13) and (14). Constraint (13) is as follows:

$$\sum_{v, j \neq i} u_{jv} + \bar{s}_i = \sum_{v, n \neq i} u_{nv} \quad \forall i$$  \hspace{1cm} (59)

In order to convert this equal constraint to an unequal one, the variable $d v_i^3$ was defined in such way that the amount of penalty for deviating from above constraint equation could be calculated. Parameters $d v c_i^5$ and $d v c_i^6$ were also defines as the amount of the penalty for each unit of deviation from equal, respectively, for when the demand of the provinces is greater than the nominal value, and when it is less than the nominal value.

Therefore, the above constraint equation should be rewritten as follows:

$$((\sum_{v, j \neq i} u_{jv} + \bar{s}_i) - \sum_{v, n \neq i} u_{nv})d v c_i^5 \leq d v_i^3 \quad \forall i$$  \hspace{1cm} (60)

$$\left(\sum_{v, n \neq i} u_{nv} - (\sum_{v, j \neq i} u_{jv} + \bar{s}_i)\right)d v c_i^6 \leq d v_i^3 \quad \forall i$$  \hspace{1cm} (61)

Now, according to Bretsimas-Sim method, it can be said:

$$((\sum_{v, j \neq i} u_{jv} + s_i) - \sum_{v, n \neq i} u_{nv} + \theta_i^3 + \tau_i^3 \Gamma_i^3)d v c_i^5 \leq d v_i^3 \quad \forall i, \Gamma_i^3 \leq |l|$$  \hspace{1cm} (62)

$$\left(\sum_{v, n \neq i} u_{nv} - (\sum_{v, j \neq i} u_{jv} + s_i) + \theta_i^3 + \tau_i^3 \Gamma_i^3\right)d v c_i^6 \leq d v_i^3 \quad \forall i, \Gamma_i^3 \leq |l|$$  \hspace{1cm} (63)

$$\theta_i^3 + \tau_i^3 \geq \bar{s}_i \quad \forall i$$  \hspace{1cm} (64)

Thus, $\Gamma_i^3$ is a parameter that determines the uncertainty budget, which is determined by the model decision-maker, and the variables $\tau_i^3$ and $\theta_i^3$ are auxiliary variables used in Bretsimas-Sim model. Parameter $s_i$ stands for supply nominal value, and parameter $\bar{s}_i$ stands for the value deviation from supply nominal value.

Constraint (14) is as follows:

$$\bar{s}_i = \sum_{v} s'_v \quad \forall i$$  \hspace{1cm} (65)

In order to convert this equal constraint to an unequal one, the variable $d v_i^4$ was defined in such way that the amount of penalty for deviating from above constraint equation could be calculated. Parameters $d v c_i^7$ and $d v c_i^8$ were also defines as the amount of the penalty for each unit of deviation from equal, respectively, for when the supply of the provinces is greater than the nominal value, and when it is less than the nominal value.

Therefore, the above constraint equation should be rewritten as follows:

$$\left(\sum_{v} s'_v - \bar{s}_i\right)d v c_i^7 \leq d v_i^4 \quad \forall i$$  \hspace{1cm} (66)
Now, according to Bretsimas-Sim method, it can be said:

\[
(\sum_{v} s'_{iv} - s_{i} + \theta_{i}^{4} + \tau_{i}^{4} \Gamma_{i}^{4}) dv_{i}^{7} \leq dv_{i}^{4} \quad \forall i, \Gamma_{i}^{4} \leq ||\]

(68)

\[
(\sum_{v} s'_{iv} - s_{i} + \theta_{i}^{4} + \tau_{i}^{4} \Gamma_{i}^{4}) dv_{i}^{8} \leq dv_{i}^{4} \quad \forall i, \Gamma_{i}^{4} \leq ||\]

(69)

\[
\theta_{i}^{4} + \tau_{i}^{4} \geq \hat{s}_{i} \quad \forall i
\]

(70)

Thus, \( \Gamma_{i}^{4} \) is a parameter that determines the uncertainty budget, which is determined by the model decision-maker, and the variables \( \tau_{i}^{4} \) and \( \theta_{i}^{4} \) are auxiliary variables used in Bretsimas-Sim model. Parameter \( s_{i} \) stands for supply nominal value, and parameter \( \hat{s}_{i} \) stands for the value deviation from supply nominal value.

Now, considering uncertainty, the certain model in previous section is as follows:

\[
\min z_{1} = \sum_{i} e_{i} z_{i} + \sum_{v} \sum_{m} \sum_{n} c_{i} \cdot dis_{nv} (x_{nv} + u_{nv}) + \sum_{v} \sum_{m} \sum_{n} Ec_{i} \cdot dis_{nv} (r_{nv}) + \sum_{j=1}^{4} \sum_{i} dv_{i}^{j}
\]

s.t

(3)

\[
(\sum_{v, n, i} x_{nv} - (\sum_{v, j, i} x_{ij} + d_{i}) + \theta_{i}^{1} + \tau_{i}^{1} \Gamma_{i}^{1}) dv_{i}^{1} \leq dv_{i}^{1} \quad \forall i, \Gamma_{i}^{1} \leq ||
\]

(50)

\[
((\sum_{v, j, i} x_{ij} + d_{i}) - \sum_{v, n, i} x_{nv} + \theta_{i}^{2} + \tau_{i}^{2} \Gamma_{i}^{2}) dv_{i}^{2} \leq dv_{i}^{2} \quad \forall i, \Gamma_{i}^{2} \leq ||
\]

(51)

\[
\theta_{i}^{1} + \tau_{i}^{1} \geq \hat{d}_{i} \quad \forall i
\]

(52)

\[
(\sum_{v} d'_{iv} - d_{i} + \theta_{i}^{2} + \tau_{i}^{2} \Gamma_{i}^{2}) dv_{i}^{3} \leq dv_{i}^{3} \quad \forall i, \Gamma_{i}^{2} \leq ||
\]

(56)

\[
(d_{i} - \sum_{v} d'_{iv} + \theta_{i}^{2} + \tau_{i}^{2} \Gamma_{i}^{2}) dv_{i}^{4} \leq dv_{i}^{4} \quad \forall i, \Gamma_{i}^{2} \leq ||
\]

(57)

\[
\theta_{i}^{2} + \tau_{i}^{2} \geq \hat{d}_{i} \quad \forall i
\]

(58)

(6) - (12)
\[
((\sum_{v,j} u_{jv} + s_i) - \sum_{v,j} u_{jv} + \theta_i^3 + \tau_i^3 \sum_{j} \Gamma_i^j) dv_i^5 \leq dv_i^3 \quad \forall i, \Gamma_i^3 \leq [1] \tag{62}
\]

\[
(\sum_{v,n} u_{nv} - (\sum_{v} u_{jv} + s_i) + \theta_i^3 + \tau_i^3 \sum_{n} \Gamma_i^n) dv_i^6 \leq dv_i^3 \quad \forall i, \Gamma_i^3 \leq [1] \tag{63}
\]

\[
\theta_i^3 + \tau_i^3 \geq \hat{s}_i \quad \forall i \tag{64}
\]

\[
(\sum_{v} s_{iv} - s_i + \theta_i^4 + \tau_i^4 \sum_{v} \Gamma_i^v) dv_i^7 \leq dv_i^4 \quad \forall i, \Gamma_i^4 \leq [1] \tag{68}
\]

\[
(s_i - \sum_{v} s_{iv} + \theta_i^4 + \tau_i^4 \sum_{v} \Gamma_i^v) dv_i^8 \leq dv_i^4 \quad \forall i, \Gamma_i^4 \leq [1] \tag{69}
\]

\[
\theta_i^4 + \tau_i^4 \geq \hat{s}_i \quad \forall i \tag{70}
\]

(15)-(23)

\[
o_p, x_{nmv}, d_w, w_p, u_{nmv}, s_{iv}, dv_i^1, dv_i^2, dv_i^3, dv_i^4, \theta_i^1, \theta_i^2, \theta_i^3, \tau_i^2, \tau_i^3, \tau_i^4 \geq 0 \quad \forall p, n, m, v, i \tag{73}
\]

(25)

4. Problem Solving:

In this method, epsilon constraint method (\(\varepsilon\)-constraint method) has been used to prove the model multi-objective potential with non-aligned objectives. The epsilon constraint method is one of the well-known approaches to multi-objective problems; solving all these problems through conveying all the objectives except one at each stage. In this method through the method of constraint \(\varepsilon\), the Pareto Boundary is created.

Consider the following multi-objective model:

\[
\min( f_1(x), f_2(x), ..., f_n(x) )
\]

St:

\[x \in S\]

Where \(x\) is decision variables' vector, \(f_1(x), f_2(x), ..., f_n(x)\) are the objective functions and \(S\) is the feasible area.

The steps of the Epsilon constraint method are as follows:

1. Consider one of the objective functions as the main objective function.
2. Solve the objectives each time with one of the functions, trying to obtain the optimal value for each objective function.
3. Divide the interval between the two optimal values of the sub-objective functions into a predefined number and form a table of values for \(\varepsilon_2 \ldots \varepsilon_n\).
4. Each time solve the problem with the main objective function with each value of \( \varepsilon_2 \) ... \( \varepsilon_n \).

5. Report the Pareto answers found.

Given the above steps, the mathematical model is as follows:

\[
\min f_1(x) \\
f_2(x) \leq \varepsilon_2 \\
. \\
. \\
. \\
f_n(x) \leq \varepsilon_n
\]

Returning to the problem under study, considering the objective function \( z_1 \) (minimizing the total cost of the system) as the main objective function, and the objective function \( z_2 \) (minimizing \( \text{CO}_2 \) pollutant) as constraint, the equation turn into equation (74).

\[
\sum_{v} \sum_{m} \sum_{n} c_{i_1} \text{dis}_{nmv} (x_{num} + u_{num}) + \sum_{i=1}^{4} \sum_{j} d_{ij} \leq \varepsilon_2
\]  

(74)

To solve the model, real data on the amount of imports and exports from 31 provinces of Iran that are imported into or out of the country through three seaports (Imam Khomeini, Shahid Rajaee and Shahid Beheshti seaports) has been used. It should be noted that there are only two modes of road and rail transport on the transport route. The \( p \) set (\( p \in \{p_1, p_2, p_3\} \)), consist southern seaports of Iran, to name respectively, Imam Khomeini Seaport, Shahid Rajaee Seaport and Shahid Beheshti Seaport; and the set \( i,j \in \{1,2,\ldots,31\} \) comprises the provinces of Iran, shown in Table A1 in the Appendix. The set \( n,m \in \{1,2,\ldots,31,p_1,p_2,p_3\} \) comprises nodes that exchange goods with each other; the exchange is done through the transportation modes \( v \in \{1,2\} \), which are road and rail transportation modes, respectively. The parameters \( d_i \) and \( s_i \), which are the demand and supply quantities of the provinces, can be found in Tables A2 and A3 in the Appendix. The parameters of the transfer cost and \( \text{CO}_2 \) emission rates are listed in Table A4. Moreover, the value of \( d_i \) shown in Table A5 is equal to the amount of deviation from the nominal value of demand in \( i^{th} \) province, and the value of \( s_i \) shown in table A6 is equal to the amount of deviation from the nominal value of supply in \( i^{th} \) province; these are both, about 10 percent of the nominal value. The penalty for deviation from the equal constraints previously described is shown in Table A7 in the Appendix. In addition, \( \Gamma_i^1 = \Gamma_i^2 = \Gamma_i^3 = \Gamma_i^4 = 1 \) is considered to be the most pessimistic state, and each province is in the most pessimistic state of uncertainty.

According to the description provided, uncertainty model, is solved in GAMS software for a problem with the mentioned parameters; therefore, the following values obtained. It should be noted that to form the Pareto Layer the number of iterations taken into account is 20. The results
of the basic model solution are shown in Table A8 in the Appendix. According to the results, the better the condition of the first objective function is, the worse the second objective function would be. The results of the model variables for first and 20th iterations are shown in Figures 1 and 2, respectively. As introduced earlier, \( p1, p2 \) and \( p3 \) represent Imam Khomeini, Shahid Rajaei and Shahid Beheshti ports, respectively. In first iteration, these three mentioned ports manage the transfers of 29178, 9372 and 959 thousand tons of imported goods, and 110880, 17028 and 4092 thousand tons of exported goods, respectively; in provinces number 28,26,25,17,16,11,4 inland terminals shall be established. In 20th iteration, \( p1, p2, \) and \( p3 \) ports manage the transfers of 32285, 6265, and 959 thousand tons of imported goods, and 111804, 7788 and 12408 thousand tons of exported goods, respectively; in 20th iteration no terminals would be established.

Since the first objective function is to minimize costs and the second objective function is to minimize pollutants, in the first iteration, which is the second best objective function and the first worst objective function, the model tries to reduce CO\(_2\) as much as possible using rail routes. As a result, since there are no rail routes in many provinces and road routes have to be used, there would be a shift in transportation modes; therefore, an inland terminal has to be established that boost the first objective function. In the contrary, as the number of iterations increases, the cost optimization model prefers to use road routes in order to prevent establishing more inland terminals, yet, on the other hand still produces more CO\(_2\). The deviation penalty from the constraints has been added to both objective functions, (if it was added just to the first objective function, due to minimizing the second objective function, the model in the first iterations could not answer the provinces need of supply/demand. Therefore, the results of the model would be useless) because if deviation from the constraints was equal, both functions would experience penalty and increase at the same time. The results of above model also provide the amounts of goods transported in each of the available and constructed routes (Figures 1 and 2).

As stated before, in the first iteration (Figure 1), the model prioritizing the second objective function decreasing CO\(_2\) emissions, attempts to use less rail routes. Therefore, considering the fact that there is no possibility of constructing new rail routes in some provinces, and there is no other way but to use road routes, 7 inland terminals shall be established, as a result. Along with increase in the number of iterations, model seeks to minimize the first objective function. The model prefer to use more road routes to reduce the costs, and to construct less routes and inland terminals. In 20th iteration (Figure 2) no terminals were established, while only four routes were used for import and export. In this case, road routes have been used for import and export are 27 and 31, respectively. Number of inland terminals established, number of rail and road routes used, as well as number of new rail and road routes constructed in each iteration are shown in Table 1.

5. **Managerial Insight:**

Solving the problem with different parameters, important points have been obtained that should be considered in defining the parameters.

- Parameters \( \Gamma_1^1, \Gamma_1^2, \Gamma_1^3, \Gamma_1^4 \leq |1| \) could be allocated in \([-1,1]\) interval. If the value is 0, the model would turn into certain state with nominal value of demand and supply; if it
is 1, the model considers the most pessimistic state of robust, and if it is -1, the model considers the most optimistic state of robust. (The model is currently solved with the values $\Gamma^1_i, \Gamma^2_i, \Gamma^3_i, \Gamma^4_i = 1$.

- Since in this solved model, the amount of penalty ($dvc_i^{1-8}$) for deviating from all constraints was considered at 100,000, the model attempted to send/receive the same amount of goods demand/supply. But:

In constraints (50) and (51), if the value of $dvc_i^1$ is much higher than $dvc_i^2$, and in constraints (56) and (57), if the value of $dvc_i^3$ is much higher than $dvc_i^4$, it is more likely that the model would consider the minimum demand (less than nominal value) for each province, and delivery would be done according to this minimum demand. Therefore, each province may suffer from deficit. This is whilst, if these two costs were considered equal, the model itself would decide on the deficit or surplus. In the third case, if in constraints (50) and (51), the value of $dvc_i^2$ is much higher than $dvc_i^1$, and in constraints (56) and (57), if the value of $dvc_i^4$ is much higher than $dvc_i^3$, it is more likely that the model would consider the maximum demand (more than nominal value) for each province, and delivery would be done according to this maximum demand. Therefore, each province may suffer from surplus.

In constraints (62) and (63), if the value of $dvc_i^5$ is much higher than $dvc_i^6$, and in constraints (68) and (69), if the value of $dvc_i^7$ is much higher than $dvc_i^8$, it is more likely that the model would consider the minimum supply (less than nominal value) for each province, and receipt would be done according to this minimum supply. Therefore, each province may suffer from deficit. This is whilst, if these two costs were considered equal, the model itself would decide on the deficit or surplus. In the third case, if in constraints (62) and (63), the value of $dvc_i^6$ is much higher than $dvc_i^5$, and in constraints (56) and (57), if the value of $dvc_i^8$ is much higher than $dvc_i^7$, it is more likely that the model would consider the maximum supply (more than nominal value) for each province, and receipt would be done according to this maximum supply. Therefore, each province may suffer from surplus.

6. Conclusion:
Being a large part of logistics cost is related to hinterland, studying on design of port-hinterland freight distribution network has come under the researchers' spot of attention. Moreover, strategic studies, with objective to determine means to design and use transportation infrastructures, have received little attention. Various parameters such as geographical distribution of hinterland regions' supply/demand, existing infrastructure (roads, railways and inland terminals), ports that are gateway to distribution of export/import, different costs that each of these factors impose, and finally, environmental sustainability issue, which is of great importance to researchers in today's world, play immense roles in designing an optimal freight distribution network.
Given the importance of uncertainty concepts in the supply chain, with various applications in the real world, this article presented a model of port-hinterland freight distribution network problem, including a robust optimization based on the best possible information obtained in recent studies. In this article, the design of a port-hinterland distribution network, including intermodal transportation, establishment of inland terminal where mode change happens, and the possibility of constructing new routes in each mode of transportation, have been investigated. Iran is considered as the case study of this research, and its provinces are considered as nodes of supply/demand or origin/final destination of goods. A certain and a robust multi-objective and intermodal model (for uncertainty conditions) have been developed, in order to deliver imported goods to provinces and receive export goods from them. The model assumes that in order to transport goods, existing rail/road routes can be used, and new rail/road routes could be constructed as well. Therefore, in the first objective function, model seeks to minimize transportation costs (both for transfer of imported/exported goods), construction of new inland terminals and routes; while, the second objective function seeks to minimize the CO$_2$ released during freight transportation. Being real-life problems are uncertain, demand for imported goods and supply of exported goods in each province have been considered uncertain, and robust optimization method has been used to deal with this uncertainty. After modeling, the actual data of goods imported to/exported from Iran were collected and solved for an uncertain model in GAMS software; then, results have been analyzed.

This research is recommended as future research by considering capacity constraints on routes or developing an innovative algorithm or certain solution to solve large-scale problems. Geopolitical Iran is at a crossroads and has been influenced by various international corridors, such as Silk Road. Considering the effect of imported/exported transit goods from these routes on the determination of routes or points of construction inland terminals can be suggested as future studies’ subject. This research can be extended to all areas benefit from port for goods distribution. Many countries in open-waters neighborhood, have strategic concerns for distribution of goods and achievement of optimal conditions. Adding the desired conditions and constraints, this model can be developed.

References:


(2004).


**Figure and Table Captions:**

Figure 1- Results of first iteration

Figure 2- Results of 20th iteration

Table1- Number of new rail and road routes constructed in each iteration

**Figures and Tables:**
Figure 1 - Results of first iteration
Figure 2- Results of 20th iteration
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<th>Number of road routes (newly constructed)</th>
<th>Number of rail routes (available)</th>
<th>Number of rail routes (newly constructed)</th>
<th>Number of inland terminals established</th>
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Appendix:

Table A1- Set of provinces of the country

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<td>West Azerbaycan</td>
<td>Ardabil</td>
<td>Isfahan</td>
<td>Alborz</td>
<td>Ilam</td>
<td>Boushehr</td>
<td>Tehran</td>
<td>Chaharmahal &amp; Bakhtiari</td>
<td>South &amp; Khorasan</td>
<td>Razi &amp; Khorasan</td>
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<td>Province name</td>
<td>North Khurasan</td>
<td>Khuzestan</td>
<td>Zanjjan</td>
<td>Semnan</td>
<td>Sistan &amp; Baluchestan</td>
<td>Fars</td>
<td>Qazvin</td>
<td>Qom</td>
<td>Kurdistan</td>
<td>Kerman</td>
<td>Kerman Sahah</td>
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<td></td>
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<tr>
<td>Province name</td>
<td>Kohgiluyeh &amp; Boyer - Ahmaad</td>
<td>Golestan</td>
<td>Guilan</td>
<td>Lores tan</td>
<td>Mazandaran</td>
<td>Markazi</td>
<td>Hormozgan</td>
<td>Hamedan</td>
<td>Yazd</td>
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Table A2 - $d_i$ value (Thousand Tones)

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Table A3 - $s_i$ value (Thousand Tones)

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### Table A4 - Model cost parameters

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<th>Unit</th>
<th>Amount</th>
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<tr>
<td>$c_1$: amount of transport costs by rail transport mode</td>
<td>dollar/ton/km</td>
<td>0.024$</td>
</tr>
<tr>
<td>$c_2$: amount of transport costs by rail transport mode</td>
<td>dollar/ton/km</td>
<td>0.021$</td>
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<tr>
<td>$c_{o_1}$: amount of CO$_2$ produced by road transport mode</td>
<td>gr/ton/km</td>
<td>62</td>
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<tr>
<td>$c_{o_2}$: amount of CO$_2$ produced by rail transport mode</td>
<td>gr/ton/km</td>
<td>22</td>
</tr>
<tr>
<td>$E_{c_1}$: cost of establishing each kilometer of one-way transport route</td>
<td>dollar/km</td>
<td>5.63 million $</td>
</tr>
<tr>
<td>$E_{c_2}$: cost of establishing each kilometer of one-way transport route</td>
<td>dollar/km</td>
<td>1.88 million $</td>
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<tr>
<td>$e_i$: cost of establishing $i$th inland terminal</td>
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<td>15600000 $</td>
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### Table A5 - $\hat{d}_i$, amount of deviation from demand nominal value of province $i$'th (Thousand Tones)

(about 10% of nominal value is defined)

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<tbody>
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### Table A6 - $\hat{s}_i$, amount of deviation from supply nominal value of province $i$'th (Thousand Tones)

(about 10% of nominal value is defined)

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<tr>
<td>$\hat{s}_i$</td>
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### Table A7 - Values of penalty deviation parameter from equal constraints

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<td>100000</td>
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<td>18</td>
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<td>22</td>
</tr>
<tr>
<td>$d_{vc_1}^{1-8}$</td>
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<td>10000</td>
<td>100000</td>
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<td>29</td>
<td>30</td>
<td>31</td>
<td></td>
<td></td>
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<tr>
<td>$d_{vc_1}^{1-8}$</td>
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<td>10000</td>
<td>100000</td>
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Table A8- The objective functions varieties in 1 to 20th iteration

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Biographies:

Mohammad Mohammadpour Omran was born in 1971 in Iran. He is an Assistant Professor of Industrial Engineering at Iran University of Science and Technology. He received his Ph.D. from Iran University of Science and Technology. His researches are concentrated on operation research, logistics, information systems and system analysis and quality control.

Rouzbeh Ghousi is an Assistant Professor of Industrial Engineering at Iran University of Science and Technology. He received his Ph.D. from Iran University of Science and Technology in 2013. His researches are concentrated on safety and healthcare engineering, human reliability, sustainable supply chain management, data science.

Ahmad Taherkhani Kadkhodaei was born in 1990 in Iran. He received his BS degree in industrial engineering and MS degree in socio-economic systems engineering from Sharif University of Technology. He went to Iran University of Science and Technology as a Ph.D. candidate in industrial engineering from 2015. His researches are concentrated on logistics, especially port-related logistics.