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An integrated game theoretic model and network data envelopment analysis to determine optimal export allocation to industrial units (A case study of the stone industry)

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ABSTRACT

Despite the fact that Iran is one of the main world's stone producers with more than 6000 stone-cutting centers, its share barely holds one percent of the world market. The industry, hence, awaits effective measures to increase its exports of building stone products. It is assumed in the present study that public-private partnership based on a win-win approach might not only facilitate foreign trades by different industries but also enhance export opportunities and improve production efficiency. Accordingly, efforts are made in the present study to investigate both production and supply networks in conjunction with the hitherto less heeded demand allocation. It is the objective to exploit functional criteria in each of these networks that will guarantee efficiency and functional values based on domestic and international demands. The way each player participates in its respective network and handles feedback from other players depends on the his/her conditions and the performance of the various players/components of the network they are part of. To determine these parameters, use is made in this study of the network data envelopment analysis (NDEA) with the efficiency of each industrial unit in the network considered as the weight of that unit within a game theoretic framework. More specifically, given the importance of exports and trade commodities as well as the great impacts such industrial units as R&D and sales departments have on international markets and marketing, the weights associated with each industrial unit is calculated via the network data envelopment analysis that takes into account not only the effects of all the network components but also those of the parameters affecting their efficiency. Thus, all the factors involved in the evaluation of the supply chain are initially identified based on the SCOR model and the balanced scorecard that additionally includes sustainability criteria. The model is implemented on the data extracted from a survey of 10 stone-cutting plants, the supply chain network of which is determined based on a study of their structures and the criteria considered in the relevant sub-networks. In a subsequent stage, after implementing PCA, the NDEA model is solved for each of the subnetworks in GAMS software and the efficiency of each plant is obtained using the weights obtained from the demand allocation model within a game theoretic framework. The output from the model solved in GAMS indicates that, compared to the current situation, application of the integrated model proposed in this study leads to a significant increase in the profits gained from each customer demand; the profits earned is expressed as the number of orders placed with each plant.

1. Introduction

Despite the abundant stone reserves across the state and the significant growth in stone production, the global demand for construction stones is still far above the production capacity due to its ever-increasing use in new construction projects. Indeed, one reason explaining Iran's low share of the global stone market is its booming domestic market.

Undoubtedly, the economic value of processed stone exports outweighs that of raw stone due to the included labor and technology in addition to the customer appeal finished stones might gain. Being the fourth largest producer of building stones in the world, Iran has been exporting such stones as Travertine to more than 60 countries, including Belorussia, Macedonia, Panama, China, Germany, and Austria [1]. However, Iranian raw stone export in 2006 was recorded to be 4.5 times higher in weight than that of processed stones. It may, therefore, be hypothesized that the total value of Iranian stone exports will witness a

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significant boost and that the industry will achieve a higher added value if the balance in exports is disrupted in favor of processed stones [2]. This goal can only be evidently achieved if properly supported by the government, planners, and policy makers.

Using a game theoretic model, the present study develops a cooperation scheme model comprising the two major players of private stone plants and the government to enhance their profits through elevated exports. The design of the supply chain network of the stone industrial unit with emphasis on the internal structure of each unit in this research is one of the most important measures in order to evaluate the factories. Since the purpose of this article is to develop the cooperative relationship between stone factories and the government, the importance of all sub-sectors involved in industrial units for a complete and flawless comparison of these units is necessary to be able to model based on the efficiency of each subnet and each factory. For this reason, four sub-networks of purchase, support, production and sale are considered in the issue. After implementing the principal component analysis (PCA), the network data envelopment analysis (NDEA) is initially performed to evaluate the factories surveyed in terms of their efficiency based on the criteria and standards current in international markets before the game theoretic model is employed to determine optimal scales for orders placed by foreign countries. In addition, attempts are made to develop a framework for evaluating plant efficiency based on the most significant criteria in the respective industry while also considering the various social, economic, and environmental parameters. In this study, field data from the Travertine stone plants is used for the first time to assign weights to stone plants that are duly exploited as the terms of the government profit functions and to determine the impacts of plant weight on order allocation. Finally, such other parameters as domestic and foreign sale revenues, taxes collected, costs associated with participation in domestic and international exhibitions, transportation costs, and stone block maintenance are included in the relevant functions.

The rest of the manuscript is organized as follows. Section 2 presents a literature review while Section 3 provides descriptions of the basic concepts and theories employed. The model proposed in this study is exhaustively described in Section 4 and a case study is presented in this Section. Finally, conclusions from the study are drawn and discussed in Section 5.

2. Literature review

Supply chain network design (SCND) has grown as a valuable topic in supply chain management. Significant number of studies has already been carried out. A well-optimized supply chain network can save a considerable number of resources and provide various benefits to the organization. Supply chain (SC) is a vital element of an industry which covers the network of suppliers, manufacturers, production centers, distribution centers and warehouses. Raw materials are acquired, transformed into finished product, distributed to the customers and delivered through supply chains. SC is also referred as logistics network, in which a series of procedures are interconnected, followed by the various costs and related activities [3]. This issue has been studied in the present article by considering the supply chain network of stone industrial units which has not been considered in this industry so far.

Most of the industries are forced to invest in SCs in order to acquire efficiency and efficacy in the network [4]. Supply chain network design determines the structure of a chain and affects its costs and performance. It provides a robust management solution for planning of supply chain network [5]. Modern supply chain networks (SCNs) are complex systems in which independent companies cooperate to maximize the added value of the whole SCN, while satisfying customers' needs and service level requirements [6]. As a matter of fact, modern SCNs are complex systems where multiple actors at different stages cooperate to deliver to final customers multiple products composed by different combinations of multiple items, with the highest service level [7].

After identifying and designing the supply chain network, the criteria involved in each sector should be identified. A number of related articles were studied to determine these criteria. An article in 2022, contributes a novel approach to the development of performance measurement by utilizing industrial conditions to improve the green industry as determined by various literature on various criteria, attributes, performance indicators, and models. Some of the criteria used in this article include: selection of the right supplier, delivery with environmental aspect, minimize the use of hazardous materials, minimize the use of resources, minimization and handling of hazardous waste, reuse of resources, worker training regarding green business requirements and food safety [8].

In another article, criteria such as employees work in a safe and healthy environment, multiple skills of employees, training for new employees, customer satisfaction, variety of products, simple and accurate warehousing and effective relationship with suppliers have been used for the manufacturing sector [9].

An article developed in 2022, investigated supply chain performance measurement for the manufacturing industry based on the primary and the secondary data and developed Integrated Supply Chain Performance Measurement (ISCPM) model through the supply chain performance attributes in the outlook of input-process-output considering the BSC and the SCOR model at three decision levels. The integrated model incorporates ten supply chain performance measurement attributes and thirty-six performance measurement indexes as supplier relationship management, internal supply chain management, and customer relationship management. Examples of criteria considered in this article are: supplier and buyer trust level, joint problem-solving initiative, manufacturing time/unit, no of delivery per week, goods handling volume (storage, service), preventive and scheduled maintenance, planning to payment, on time arrival, goods receiving as per specifications, raw material consumption ratio and machine utilization ratio [10].

In some cases, due to the large number of criteria, researchers have used dimension reduction methods such as principal component analysis (PCA). Principal components can be used to replace all inputs or outputs simultaneously or to replace specific groups of variables [11]. Fu et al., in their research, concluded that by combining PCA and DEA in evaluating the performance of energy projects, the results improved in comparison to those who used only the simple DEA method [12]. In a paper developed in 2020, a combination of data envelopment analysis and principal component analysis was used to evaluate the performance of 100 companies based on their 2015 financial statements [13]. In another paper, the financial performance of 46 financial institutions was calculated using a combination of two approaches: data envelopment analysis and principal component analysis [14]. In addition, in 2022, with the aim of evaluating the efficiency of stone industrial units, a combination of two methods, DEA and PCA has been used [15].

In line with the issue of combining two approaches, DEA and game theory, a Nash bargaining game data envelopment analysis (NBG-DEA) model is proposed in a paper in 2022 to measure the efficiency of dynamic multi-period network structures. This paper aims to measure the performance of decision-making units with complicated network structures [16].

Another paper in 2020, presents a technique for the strategic design and planning of SCNs in an uncertain environment, overcoming the described issues in the SCND problem by jointly addressing in an uncertain environment the decisions on the selection of partners and the allocation of the received orders among them. Candidates are first evaluated by applying a cross-efficiency fuzzy DEA, which allows ranking them in a multi objective and uncertain framework. Then, the order allocation problem is solved by applying a fuzzy bargaining game that allows modeling the behavior of each stakeholder [17].

In continuation of the topics mentioned above, this section deals with a review of the literature on the relationship between the public and private sectors (with the government and its subsidiary agencies included as players) involved in the stone industry in a game theoretic model. It is the objective to identify any likely gaps and inadequacies in the supply chain and trade arena.

Although the French mathematician Emile Berkeley is known for his original study of aspects of games in 1921, it is the Hungarian mathematician John von Neumann who is universally granted the honor of being the originator of Game Theory. In 1950, John Nash extended the theory to issues of cooperation among players and developed a new solution to the bargaining problem and subsequently one to the non-cooperative issues as well.

Game theory is a mathematical and logical approach to strategic decision-making problems and helps decision makers to improve their strategic choices by anticipating possible outcomes over the competition and collaboration horizons [18]. According to Sun et al. [19], Game Theory is nowadays used widely in such varied fields as economics, marketing, and production management, among others. In the field of industrial production management, application of the theory makes it possible for decision makers to formulate optimal strategies that help make better decisions [19].

Zhao et al. studied public-private partnership and investigated such factors as cost of manufacturing green products, economic benefits of clean production, economic penalties for failure to implement a clean system, and government subsidies for its implementation in order to choose the best strategy based on the benefits arising from integration of these factors into the relevant functions. The game theoretical results suggest a 'win-win' strategic situation as the best interaction, which indicates that the manufacturer implements the clean technology voluntarily and the government no longer needs to intervene intensely in the manufacturer's environmental unfriendly behavior [20].

Funke and Klein examined a game involving several public agencies and investigated the risks they would face when determining strategies for bio-fuel industries. The authors found that while government policies supporting relevant sectors would normally guarantee agricultural and rural development, they might be counterproductive in certain cases. The approach adopted in the game theory states that different government departments wish to find themselves in a balanced market to avoid the variability of the associated risks [21].

Sun et al. explored the evolutionary game between the government and an IT-based Ride-Hailing Platform. The authors found that both the player operating the system and the government served as actors in the evolutionary game with limited rationality and that they had to re-adjust their strategies through confrontation, dependence, and constraint. It was assumed that government regulations and performance standards of the system in question would contribute to the optimal balance of the Pareto that would not be achieved in the current situation. The authors then analyzed the parameters involved and performed simulation calculations to find that the system could be pushed towards the desired balance by reducing the cost of government supervision and increasing government support funding [22].

Wang and Tao used the game theory to study government economic subsidies on regional environmental protection. Investigating the effects of promoting government subsidy policies on environmental pollution control, the authors observed that the government had to enable and motivate companies to control pollution and protect the environment by paying subsidies to those that inevitably polluted the environment in return for any reductions they could achieve in pollution control costs [23].

The government's intervention in the competition between green and non-green supply chains was examined in Ismaili and Zandi [24]. They showed that the government played a leading role and that the profits of the supply chain members depended on the costs borne by the government. As the role of leadership was assigned to the government, the problem was formulated in a Stucklberg model in which the other chain members were considered as followers. In each chain, the order quantity as well as the retailer, producer, and supplier product prices were determined based on maximum profits and the costs borne by the government that included both fines for non-green supply chains and subsidies for green ones [24].

Madani and Rasti presented a competitive mathematical model in which the government was the leader and two green and non-green chains served as followers, with both chains including one producer and one retailer related through price policies. The authors investigated pricing policies, green strategies, and government tariffs as directly monitored by the government. Finally, government tariffs and the selling prices of both green and non-green products as well as the degree of green production were calculated as decision variables in both the centralized and decentralized models [25].

Tavanayi et al. claim that collaboration among different firms is based on the theory of cooperative games. As an example, they cited product components at Megamotors being manufactured by different companies located in different regions, which obviously increases production costs. They developed a mathematical planning model to determine production costs when companies operated independently. The model then takes into account the conditions for a cooperation scheme in which the companies operate as an integrated system. The authors finally used a case of three providers as an illustrative example that reduced their costs when they adopted a collaborative cell production system [26].

Studying a manufacturer producing a green product and delivering it to customers through a retailer, Panja and Mondal presented two game theoretic models. In the first, market demand is assumed to depend on the degree of product greenness and the retail selling price. In the second model, demand depends not only on the degree of product greenness and the retail selling price but also on the credit period offered by the retailer to customers. In order to forge a cooperative relation between the producer and the retailer, a revenue-sharing agreement is established in both models based on the game theory [27].

Ghashghaei and Mozafari conducted a study in which newspaper sales was combined with participatory advertising under uncertain demand conditions depending on retail prices. A theoretical approach to the game was adopted to determine the equilibrium value of the decisions made. In their study, three different game scenarios based on the newspaper sales model were considered. The first scenario was the Stackelberg game, in which the producer played the role of the leader in the market and the retailer followed the best decisions made by the leader. The second involved the Nash game, in which both the manufacturer and the retailer had equal market powers. A centralized scenario was considered as the third one in which the retailers and the manufacturers made the best decisions via information sharing and collaboration [28].

Gavo and Zhao reviewed an evolutionary game to coordinate the stakeholders of a Power Plant Public Project in China. Considering a few dynamic games, the authors tried to establish a relationship among the government, investors, and the public. In the first phase, a tripartite model of government, investors, and the general public was developed based on the theory of evolutionary game. The evolutionary process of the tripartite behavioral strategy was then examined using the the system dynamics model (SD). Finally, the effects of changes in the main factors on the behavioral strategies was investigated through sensitivity analysis [29].

In a recent study, Gavo and Zhao studied the behaviors of the government and investors in the new Energy Partnership Public Participation Project using the game development strategy [30]. Studying incomplete contracts in BOT highways, Song et al. used the game theory to present a bargaining-game model with complete information to analyze the process of negotiation between the government and private investors in BOT highway projects with traffic demand changes leading to early project termination. The model results are verified using the Wutong Mountain Tunnel BOT project in China [31].

Jumbe and Mkondiwa studied public-private partnerships in biofuels crops in sub-Saharan Africa with a view to striking a balance between community interests and energy harvesting. They specifically wondered in the existing policies strengthened or hindered PPT relations [32]. Zhao et al. studied corporate social responsibility (CSR) in the construction industry based on stakeholder theory [33]. Burke and Demirag reviewed the management strategies regarding risk transfer and stakeholder relations in public private partnerships in the construction of Irish roads [34]. Clerck and Demeulemeester created a tender model for public-private partnership project investors based on game theory and examined the government's impact on tender results [35]. Given the speculative behavior of investors, Gao and Bao studied the issue of strategic government selection based on the evolutionary game model [36].

Li investigated the rules of the evolutionary game as affecting investors and government regulators involved in public-private partnership projects to determine the impacts of public participation on government and investor behaviors. Guo and Lee established a three-party game model based on the evolutionary game theory and simulated the evolvement path of each participant by establishing a SD Model with relevant computer Software. They found that the government, the public, and the investors could be capable of eventually striking a balance in terms of government monitoring, owner participation, and private sector input. They reported that government played a key role in the process of strategic change such that the choice of investors and public strategy were reflections of the government's strategy and the ultimate status of public-private partnership projects depended on the cost-benefit analysis results of all the parties involved [37].

According to the approach taken by the mentioned article, in the present article, an attempt is made to combine the two approaches of data envelopment analysis and game theory. But in this research, it is tried to consider the network structure related to each manufacturer as a decision unit. In addition, in line with the innovations of the article, we can mention the connection of these producers to relations with the government. Because in most of the articles that have worked in this field, only the connection and cooperation of similar supply chains has been considered.

As a summary, this article, by emphasizing the internal structure of producers in the supply chain of the stone industry, and considering the purchasing sector that is related to stone mines as suppliers of this industry, as well as considering the sales sector and customer relations, has tried to examine the relationship between these units effectively.

By reviewing the articles that have done research in determining performance evaluation criteria in different sections, effective criteria in evaluating the performance of industrial units have been identified and after receiving expert opinions and adding criteria specific to the stone industry, classification of criteria to calculate unit efficiency obtained.

Moreover, most reports in the literature addressed government-industry participation in domestic quantity and quality issues, ignoring the fact that cooperation between the government and manufacturers can improve export conditions as an important component of national productivity. In addition, in these studies, all the players involved in the game theory are assigned equal weights. However, the participation of each player and the feedback received from each depend not only on their conditions but on the efficiency of the various parts of the network as well. These neglected issues have been duly addressed in the present study by applying the data envelopment analysis method while the efficiency of each industrial unit is considered as the weight of that unit in the game theory model. Moreover, given the importance of exports and export products in national economy, all the departments involved in the performance of industrial units, such as R&D and sales departments, that contribute to international sales have been considered as sub-networks of the organization in a model of the network data envelopment analysis so that the impacts of all such departments and all the criteria are included in the calculation of the weights assigned to such industrial units.

3. Modeling and research problem

Although AHP is a more convenient approach than other methods and is preferred for communications similar to the one discussed in this article, but the basis of AHP is the judgment of experts, and in this fieldwork, experts who are approved by different decision-making units were not available. On the other hand, DEA don't need to be judged by experts. Furthermore, AHP has some weaknesses, such as susceptible to rank reversal, problems of interdependence between criteria and alternatives and also limitation of inconsistencies in judgment and ranking criteria [38].

According to Dotoli's findings, DEA is to be preferred in the case of complex purchasing services with multiple conflicting criteria, since it allows comparing tenderers having considerably different and heterogeneous operating characteristics against multiple evaluating criteria only requiring the decision makers to express their judgment on each bidder and each criterion. Conversely, AHP best fits structured services having a complex hierarchy, but with a limited number of items at each level, due to the need for pairwise comparisons of alternatives [39].

The success of DEA is mainly due to its robustness and simplicity of application and to the possibility to easily cope with multiple inputs and outputs (even with different data units of measurement) and to perform homogeneous evaluations (with no need for weights ponderation and normalization of data). Another advantage of the DEA method is that, with respect to other MCDM techniques (e.g., MAUT) it does not require an assumption of a functional form relating inputs to outputs. In addition, possible sources of inefficiency can be determined, which make DEA useful for self-diagnosis and benchmarking too [40].

Therefore, it can be concluded that a most important approach used to evaluate the supply chain performance is the network data envelopment analysis that takes into account all the sectors contributing to the productivity and efficiency of industrial units. This approach combined with the game theory is employed in the present study to determine the optimal export by each of the industrial units (comprising both the public and private enterprises) investigated in an attempt to maximize the profitability of the entire supply chain. Descriptions of the theoretical foundations of the DEA approach and the game theory are provided in Section (3.1) below.

After comparing the results of CRS and VRS approaches, it was determined that the efficiency of stone factories should be calculated using the variable return to scale (VRS) model of network data envelopment analysis. The efficiency of a decision-making unit (DMU) assessed by the variable return to scale (VRS) model is higher than its efficiency in the constant return to scale (CRS) model. This is primarily because the CRS model has a straight-line efficiency frontier, whereas the VRS model has a convex line efficiency frontier [41]. In the case study used in this article, because the goal is to determine the factories that can take steps in the matter of export in line with the interests of the government and due to the high importance of exports in the economic perspective, it is clear to choose a model that can consider financial constraints, control steps and other factors that cause DMUs not to operate at their optimal size. Variable return to scale approach has been developed to overcome this problem. CRS reflects the fact that output will change by the same proportion as inputs are changed but VRS reflects that production technology may exhibit increasing, constant and decreasing returns to scale. Because there is no reason to change to a ratio between inputs and outputs, it is preferable to choose the VRS model.

In this case study, Considering the sensitivity of modeling in determining the amount of export allocation in the stone industry, it is better to use a model that is closer to the real-world conditions. For this reason, it is far from reality to consider that any amount of change in the inputs has the same effect on the amount of the outputs. So, it is better to use the VRS approach in this study.

According to the criteria and also the opinion of experts, it is much easier and more acceptable to change the selected inputs in each subnet. In the selected industry, paying more attention to inputs and resources is effective in increasing the efficiency of that industry. For this reason, the input-driven approach of data envelopment analysis has been used. In general, input-oriented model closely focuses on operational and

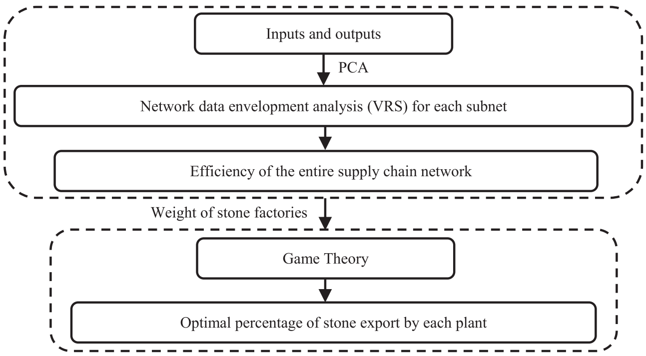

Fig. 1. Proposed structure for calculating the optimal percentage of stone exports.

Table 1
Classification of performance evaluation criteria for stone industrial units based on a combination of BSC and SCOR approaches.

Set	Criterion	Criteria considered in each step
1	Inputs of the purchase subnet	Average time to access consumables including resin Average distance between stone mines and industrial units
2	Purchase subnet outputs and producing subnet inputs	Percentage of waste per ton of product
3	Purchase subnet outputs and the share of accounting, finance, management departments in the support subnet inputs	Cost of raw materials such as stone blocks and consumables such as resins and abrasive Transportation cost of each stone block unit per kilometer
4	Accounting, finance, and management share in the support subnet inputs	Percentage of checks cashed and cash sales
5	Human resources management department under the support subnet inputs	Number of employees involved in production lines Number of formal and informal training hours and practical work
6	R&D support subnet inputs	Knowledge of global stone trade regulations Knowledge of target markets
7	Human resources management in the support subnet outputs and producing subnet inputs	Number of shifts and working hours in each stone processing unit Level of labor's work experience
8	Accounting, finance, and management support subnet outputs and producing subnet inputs	Wages per person per hour
9	Accounting, finance, and management outputs	Amount of liquidity available to a stone industrial unit as its capacity to face emerging risks
10	R&D support subnet outputs and production subnet inputs	Readiness to adopt new stone processing technologies
11	Producing subnet inputs	Maintenance costs in each period Power consumption costs in each period Stone cutting tool speed to prepare final product
12	Producing subnet outputs	Finished product storage volume at the end of each period
13	Producing subnet outputs and sales subnet inputs	Product delivery cost (cubic meter of finished product per kilometer) Retail sales to final consumers and dealers Ratio of product exports to domestic sales
14	Sales subnet outputs	Delivery time

managerial issues whereas output-oriented model is more associated with planning and strategy [41].

Before using the DEA method, since the number of decision-making units is small compared to the number of criteria and due to the limitations related to access to the data of the factories, the PCA approach was used to reduce the dimensions of the data.

This efficiency is the input as the weight of factories, the amount of positive effect on government efficiency and is related to the issue of game theory. Game theory model is examined by considering the goals of factories and government. The proposed structure of the problem is shown in Fig. 1.

3.1. DEA and network DEA

Data Envelopment Analysis is a mathematical programming model for evaluating the efficiency of decision-making units with multiple inputs and multiple outputs. It is one of the most methods widely used for selecting suppliers. It exhibits its good performance in cases where the number of decision-making units is high. Farrell defined two technical measures of efficiency and a benchmark for measuring productivity index within the framework of DEA [42]. Charnes et al. developed a model (that came later to be known as the CCR) that was capable of measuring performance with multiple inputs and outputs assuming constant return to scale [43]. The CCR model was later extended (into a new form known as the BCC model) by Banker et al. who proposed methods 'to separate technical and scale efficiencies without altering the latter conditions for the use of DEA directly on observational data' [44]. The authors introduced a new separate variable that made it possible to determine whether operations (in multiple input and multiple output situations) had been conducted in regions of increasing, constant, or decreasing returns to scale.

The original DEA model due to Charnes et al. is reproduced below in Model 1. In this model, if there are n decision making units $(DMU_j, j = 1, 2, \dots, n)$ in the problem each using M inputs $(x_{ij}, i = 1, \dots, m)$ with weights v_i and produces S outputs $(y_{rj}, r = 1, \dots, s)$ with weights u_r, then the relative efficiency of the unit DMU_o will be as follows:

$$Max \quad \sum_{r=1}^{s} u_r y_{ro} \text{Model1}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad , \quad j = 1, \dots, n$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$u_r > 0 \quad , \quad v_i > 0 \quad , \quad r = 1, \dots, s \quad , \quad i = 1, \dots, m$$

$$u_r > 0 \quad , \quad v_i > 0 \quad , \quad r = 1, \dots, s \quad , \quad i = 1, \dots, m$$

Where, $x_{io}$and y_{ro} represent the weights of input i and output r of DMU_o, respectively.

For the purposes of the present study, a number of stone factories were examined and their structures were investigated to determine their supply chain based on the performance criteria involved in each of the sub-networks. The criteria used were selected based on the SCOR model and included the sustainability criteria that were derived from both expert opinions and the Strategic Document for the Iranian Stone Industry [45]. These are classified in Table 1. Using the network data envelopment analysis approach to evaluate the plants, the network intended for these factories may be presented as in Fig. 2.

The first sub-network is related to the purchase of raw materials including stone blocks and such consumables as resin and abrasives while the second comprises the support section including human resource management, accounting, finance, management, and R&D. The third sub-network is related to the production process. Finally, the fourth sub-network involves sales and delivery to customers.

Therefore, a network VRS and CRS model is used for each section of the network. The parameters and variables used in the model are shown in Table 2.

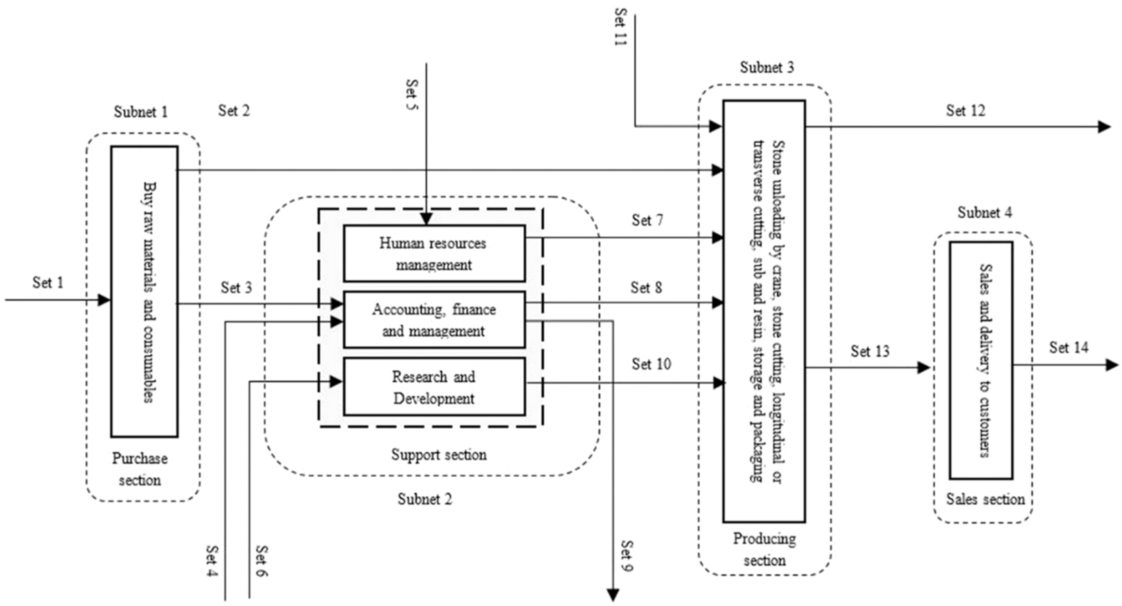

Fig. 2. Network structure of the supply chain for the stone plants investigated.

Table 2
Parameters and variables used in the network data envelopment analysis model.

x^1_{Ij}	*I-th* input of the purchasing section for unit j
$y^1_{L_1j}$	L_1-th output of the purchasing section and the input of the production section for unit j
$y^2_{L_2j}$	L_2-th output of the purchasing section and the input of the accounting, finance and management departments for unit j
$y^3_{L_3j}$	L_3-th input of accounting, finance and management section for unit j
$y^4_{L_4j}$	L_4-th input of the research and development section for unit j
$y^5_{L_5j}$	L_5-th input of the human resources management section for unit j
$z^1_{K_1j}$	K_1-th output of the human resources management section and the input of the production department for unit j
$z^2_{K_2j}$	K_2-th output of accounting, finance and management and input of production unit j
$z^3_{K_3j}$	K_3-th output of accounting, finance and management section for unit j
$z^4_{K_4j}$	K_4-th output i of the R&D section and the input of the production section for unit j
$z^5_{K_5j}$	T K_5-th input i of the production department for unit j
$p^1_{N_1j}$	Input N_1 of the production section for unit j
$p^2_{N_2j}$	Output N_2 of the production section and the input of the sales section for unit j
q^1_{Mj}	Output M of the sales section for unit j
s^1_I	Weight of criterion$x^1_{Ij} I \in \{1,2,\ldots,i\}$
$v^1_{L_1}$	Weight of criterion $y^1_{L_1j}$ $L_1 \in \{1,2,\ldots,l_1\}$
$v^2_{L_2}$	Weight of criterion$y^2_{L_2j}$ $L_2 \in \{1,2,\ldots,l_2\}$
$v^3_{L_3}$	Weight of criterion $y^3_{L_3j}$ $L_3 \in \{1,2,\ldots,l_3\}$
$v^4_{L_4}$	Weight of criterion $y^4_{L_4j}$ $L_4 \in \{1,2,\ldots,l_4\}$
$v^5_{L_5}$	Weight of criterion $y^5_{L_5j}$ $L_5 \in \{1,2,\ldots,l_5\}$
$w^1_{K_1}$	Weight of criterion $z^1_{K_1j} K_1 \in \{1,2,\ldots,k_1\}$
$w^2_{K_2}$	Weight of criterion $z^2_{K_2j} K_2 \in \{1,2,\ldots,k_2\}$
$w^3_{K_3}$	Weight of criterion $z^3_{K_3j} K_3 \in \{1,2,\ldots,k_3\}$
$w^4_{K_4}$	Weight of criterion $z^4_{K_4j} K_4 \in \{1,2,\ldots,k_4\}$
$w^5_{K_5}$	Weight of criterion $z^5_{K_5j} K_5 \in \{1,2,\ldots,k_5\}$
$h^1_{N_1}$	Weight of criterion $p^1_{N_1j} N_1 \in \{1,2,\ldots,n_1\}$
$h^2_{N_2}$	Weight of criterion $p^2_{N_2j} N_2 \in \{1,2,\ldots,n_2\}$
e^1_M	Weight of criterion $q^1_{Mj} M \in \{1,2,\ldots,m\}$

The performance of each of the above sections is modeled below. The mathematical model for the purchase section of sub-network 1 is expressed by Eqs. (1) to (4). Eq. (1) expresses the objective function aimed at maximizing output values in the purchasing department. Considering the CRS model in the network data envelopment analysis, Eq. (2) ensures that the amount of input to this subnet remains constant and Eq. (3) ensures that the efficiency of each decision unit does not exceed unity. Finally, Eq. (4) indicates the type of variables used in the model and the weights assigned to the inputs and outputs. If a parameter that is bolded in the model(u_0) is added to the model, the VRS approach is modeled.

$$Max \quad \sum_{L_1}\left[v^1_{L_1}y^1_{L_1k} + v^2_{L_2}y^2_{L_2k}\right] - \boldsymbol{u_0} \tag{1}$$

$$\sum_I s^1_I x^1_{Ik} = 1 \tag{2}$$

$$\sum_{L_1} v^1_{L_1}y^1_{L_1j} + \sum_{L_2} v^2_{L_2}y^2_{L_2j} - \sum_I s^1_I x^1_{Ij} - \quad \boldsymbol{u_o} \le 0 \quad , \quad j = 1,\ldots,n \tag{3}$$

$$v^1_{L_1}, v^2_{L_2}, s^1_I \ge \varepsilon \quad , L_1 \in \{1,2,\ldots,l_1\} \quad , L_2 \in \{1,2,\ldots,l_2\}, I \in \{1,2,\ldots,i\} \quad , \quad \boldsymbol{u_0 free} \tag{4}$$

The output of this mathematical model will be the efficiency of the first part of the network, that is, the purchase and consumption of raw materials, with a value equal to E_1.

The mathematical model for subnet 2 may be captured by Eq. (5) through (11). Eq. 5 is the objective function that aims to maximize the output values for the support network in all the three departments. Eq. (6) ensures that the values for the inputs in this subnet remain constant. Eq. (7) ensures that the efficiency of each decision unit in this subnet does not exceed unity while Eqs. (8) to (10) ensure that the efficiency of each part of this subnet does not exceed unity. Finally, Eq. (11) introduces the types of variables used in the model and the weights assigned to the inputs and outputs in all parts of the support network. If a parameter that is bolded in the model(u_0) is added to the model, the VRS approach is modeled.

$$Max \quad \sum_{K_1} w^1_{K_1}z^1_{K_1k} + \sum_{K_2} w^2_{K_2}z^2_{K_2k} + \sum_{K_3} w^3_{K_3}z^3_{K_3k} + \sum_{K_4} w^4_{K_4}z^4_{K_4k} - \boldsymbol{u_0} \tag{5}$$

$$\sum_{L_5} v^5_{L_5}y^5_{L_5k} + \sum_{L_2} v^2_{L_2}y^2_{L_2k} + \sum_{L_3} v^3_{L_3}y^3_{L_3k} + \sum_{L_4} v^4_{L_4}y^4_{L_4k} = 1 \tag{6}$$

$$\sum_{K_1} w_{K_1}^1 z_{K_1j}^1 + \sum_{K_2} w_{K_2}^2 z_{K_2j}^2 + \sum_{K_3} w_{K_3}^3 z_{K_3j}^3 + \sum_{K_4} w_{K_4}^4 z_{K_4j}^4 - \left[\sum_{L_5} v_{L_5}^5 y_{L_5j}^5 + \sum_{L_2} v_{L_2}^2 y_{L_2j}^2 + \sum_{L_3} v_{L_3}^3 y_{L_3j}^3 + \sum_{L_4} v_{L_4}^4 y_{L_4j}^4\right] - \boldsymbol{u_0} \le 0, \quad j = 1, \ldots, n \tag{7}$$

$$\sum_{K_1} w_{K_1}^1 z_{K_1j}^1 - \sum_{L_5} v_{L_5}^5 y_{L_5j}^5 - \boldsymbol{u_0} \le 0, j = 1, \ldots, n \tag{8}$$

$$\sum_{K_2} w_{K_2}^2 z_{K_2j}^2 + \sum_{K_3} w_{K_3}^3 z_{K_3j}^3 - \left[\sum_{L_2} v_{L_2}^2 y_{L_2j}^2 + \sum_{L_3} v_{L_3}^3 y_{L_3j}^3\right] - \boldsymbol{u_0} \le 0, j = 1, \ldots, n \tag{9}$$

$$\sum_{K_4} w_{K_4}^4 z_{K_4j}^4 - \sum_{L_4} v_{L_4}^4 y_{L_4j}^4 - \boldsymbol{u_0} \le 0, j = 1, \ldots, n \tag{10}$$

$$w_{K_1}^1, w_{K_2}^2, w_{K_3}^3, w_{K_4}^4, v_{L_2}^2, v_{L_3}^3, v_{L_4}^4, v_{L_5}^5 \ge \varepsilon, \quad K_1 \in \{1, 2, \ldots, k_1\}, \quad K_2 \in \{1, 2, \ldots, k_2\}, \quad K_3 \in \{1, 2, \ldots, k_3\}, \quad K_4 \in \{1, 2, \ldots, k_4\}, L_2 \in \{1, 2, \ldots, l_2\}, L_3 \in \{1, 2, \ldots, l_3\}, L_4 \in \{1, 2, \ldots, l_4\}, L_5 \in \{1, 2, \ldots, l_5\}, \quad \boldsymbol{u_0} \quad \textit{\textbf{free}} \tag{11}$$

As with the first subnet, the output of this mathematical model will be the performance of the second part of the network, that is, the support network.

The mathematical models for the production sub-networks (3) and the sales one (4) are captured by Eq. (12) to (15). Eq.(12) is the objective function whose aim is to maximize the output values in the production department. Considering the CRS model, Eq. (13) ensures that the values for the inputs in this subnet remain constant and Eq. (14) ensures that the efficiency of each decision unit does not exceed unity. Finally, Eq. (15) indicates the types of variables used in the model and the weights assigned to the inputs and outputs. If a parameter that is bolded in the model(u_0) is added to the model, the VRS approach is modeled.

$$Max \quad \sum_{N_1} h_{N_1}^1 p_{N_1k}^1 + \sum_{N_2} h_{N_2}^2 p_{N_2k}^2 - \boldsymbol{u_0} \tag{12}$$

$$\sum_{K_5} w_{K_5}^5 z_{K_5k}^5 + \sum_{L_1} v_{L_1}^1 y_{L_1k}^1 + \sum_{K_1} w_{K_1}^1 z_{K_1k}^1 + \sum_{K_2} w_{K_2}^2 z_{K_2k}^2 + \sum_{K_4} w_{K_4}^4 z_{K_4k}^4 = 1 \tag{13}$$

$$\sum_{N_1} h_{N_1}^1 p_{N_1j}^1 + \sum_{N_2} h_{N_2}^2 p_{N_2j}^2 - \left[\sum_{K_5} w_{K_5}^5 z_{K_5j}^5 + \sum_{L_1} v_{L_1}^1 y_{L_1j}^1 + \sum_{K_1} w_{K_1}^1 z_{K_1j}^1 + \sum_{K_2} w_{K_2}^2 z_{K_2j}^2 + \sum_{K_4} w_{K_4}^4 z_{K_4j}^4\right] - \boldsymbol{u_0} \le 0, j = 1, \ldots, n \tag{14}$$

$$w_{K_1}^1, w_{K_2}^2, w_{K_4}^4, w_{K_5}^5, h_{N_1}^1, h_{N_2}^2, v_{L_1}^1 \ge \varepsilon, \quad K_1 \in \{1, 2, \ldots, k_1\}, \quad K_2 \in \{1, 2, \ldots, k_2\}, \quad K_4 \in \{1, 2, \ldots, k_4\}, \quad K_5 \in \{1, 2, \ldots, k_5\}, N_1 \in \{1, 2, \ldots, n_1\}, \quad N_2 \in \{1, 2, \ldots, n_2\}, L_1 \in \{1, 2, \ldots, l_1\}, \quad \boldsymbol{u_0} \quad \textit{\textbf{free}} \tag{15}$$

The sales department is modeled by Eqs. (16) to (19) below. Eq. (16) expresses the objective function that maximizes the output values in the sales department while Eq. (17) ensures that the values for inputs to this subnet remain constant and Eq. (18) ensures that the efficiency of each decision unit does not exceed unity. Finally, Eq. (19) indicates the types of variables used in the model and the weights assigned to the inputs and outputs. If a parameter that is bolded in the model(u_0) is added to the model, the VRS approach is modeled.

$$Max \quad \sum_{M} \left[e_M^1 q_{Mk}^1\right] - \boldsymbol{u_0} \tag{16}$$

$$\sum_{N_2} \left[h_{N_2}^2 p_{N_2k}^2\right] = 1 \tag{17}$$

$$\sum_{M} \left[e_M^1 q_{ij}^1\right] - \sum_{N_2} \left[h_{N_2}^2 p_{N_2j}^2\right] - \boldsymbol{u_0} \le 0, j = 1, \ldots, n \tag{18}$$

$$e_M^1, h_{N_2}^2 \ge \varepsilon, M \in \{1, 2, \ldots, m\}, \quad N_2 \in \{1, 2, \ldots, n_2\}, \quad \boldsymbol{u_0} \quad \textit{\textbf{free}} \tag{19}$$

The different methods available for calculating total network performance based on the performance of each subnet include weighted average, harmonic average, geometric average, and weighted average geometry methods [46]. Given the differences in the contributions of the different sectors to total efficiency, the present paper adopts the geometric weighted method; this is expressed by (20) below:

$$E_{total} = \sqrt[\alpha 1+\alpha 2+\alpha 3+\alpha 4]{E_1^{\alpha_1} \times E_2^{\alpha_2} \times E_3^{\alpha_3} \times E_4^{\alpha_4}} \tag{20}$$

The value for α_i represents the weight assigned to each of the sub-networks in the stone industry supply chain and is calculated based on the opinions expressed by both experts and owners of stone plants.

3.2. Game theory

The term 'game' refers to all situations in which the players' actions are interactively dependent on each other so that each player's actions reciprocally affect the decisions and strategies adopted by the other. This type of game presupposes at least two players who are in conflict over their goals and compete to maximize their profits.

Game theoretic models may be classified based on such criteria as the nature of the interactions between the players, the number of players, the number of strategies available to them, agreement or disagreement among the players, and the extent of the players' knowledge about each other. Thus, a cooperative game refers to the class of games in which the players negotiate to reach an agreement while a non-cooperative game is one there is an absence of any negotiation or no viable agreement is reached. The Nash and Stackelberg strategies are two important concepts used in many non-cooperative games. The Nash equilibrium is used when the players simultaneously choose their own unique strategies in a game. A Stackelberg balance is sought to determine the optimal strategy for each player in a leader-follower scenario in which the leader player acts before the follow-up player.

The model proposed in the present study includes two players: the government/public sector, on the one side, and stone plants, on the other. In this model, it is assumed that there exist *n* stone plants and that the profit function of each player is based on the income from domestic and foreign stone sales.

3.3. Notations used in the model

Notations used in the model D^{in}	Total domestic demand
D^{ex}	Total export demand
x_i^{in}	Percentage of domestic demand to be met by plant *i*
x_i^{ex}	Percentage of export demand to be met by plant *i*
Q_i^{in}	Domestic orders supplied by plant *i* to the domestic market per loading
Q^{in}	Total domestic orders supplied by all plants to the domestic market per shipment
Q_i^{ex}	Foreign orders supplied by plant *i* to international markets per shipment
Q^{ex}	Total international orders supplied by plants to international markets per shipment
p_{in}^i	Domestic sale price at plant *i*
p_{ex}^i	Export sale price at plant *i*
α^i	Coefficient of conversion of stone tonnage to that of m^2 of stone at plant *i*
O^i	Average purchase price of a quarry at plant *i*
A^i	Average order cost including transportation from mine to plant *i*
$1-\mu^i$	Percentage of costs covered by the government for plant *i* to participate in domestic exhibitions
$1-\sigma^i$	Percentage of costs covered by the government for plant *i* to participate in international exhibitions
C_{in}	Average cost of participation in domestic exhibitions
C_{ex}	Average cost of participation in international exhibitions
γ_i	Percentage of exports by plant *i* returned to the origin
t^i	Liquidity available to plant i during the study period
Z^i	Percentage of profits earned by the government from the cash of plant *i* saved in banks
p_{tax}^{in}	Percentage of domestic sales tax
p_{tax}^{ex}	Percentage of export tax
ρ^i	Coefficient of conversion of stone square meters to number of pallets at plant *i*
U_i^{in}	Domestic production capacity of plant *i*
U_i^{ex}	International production capacity of plant *i*
C_p^i	Value of each pallet at plant *i*
C_N	Labor cost for cutting and resin application of 1 m^2 of stone
j_t^i	Percentage of export tax rebate for plant *i*
C_R	Average cost of resin application per 1 m^2 of stone
C_A	Average cost of abrasives per 1 m^2 of stone
C_S	Average cost of diamond cutting segment consumed for 1 m^2 of stone
C_D	Average cost of stone cutter disc depreciation per 1 m^2 of stone
C_{Bill}^i	Average cost of water and power consumption over the study period for plant *i*
h_i^{in}	Cost of inspection per 1 m^2 of stone for a one-time load receipt for the total domestic orders placed for plant *i*
h_i^{ex}	Cost of inspection for 1 m^2 of stone for a one-time load receipt for the total international orders placed for plant *i*
Z_c	Percentage of customs tariffs on stone exports
C_{per-km}^{in}	Average cost of transportation to domestic markets for 1 m^2 of stone per kilometer
C_{per-km}^{ex}	Average cost of transportation to international markets for 1 m^2 of stone per kilometer
π_i^C	Profit function for plant *i*
π_g	Government profit function

The profit function for each stone plant is expressed by π_i^C as in Relations (21) to (34). This function takes account of the revenues from product sales, quarry purchase cost, ordering cost, and other chain costs to obtain the balance to be reported as the net profit.

$$\pi_c^i = \left[D^{ex} * x_i^{ex} * p_{ex}^i + D^{in} * x_i^{in} * p_{in}^i\right] \tag{21}$$

$$+ j_t^i * \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex}\right] \tag{22}$$

$$- \left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * O^i\right] \tag{23}$$

$$- \left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] \tag{24}$$

$$- \left[\frac{D^{in} * x_i^{in}}{Q_i^{in}}\right] * C_{per-km}^{in} \tag{25}$$

$$- \left[\frac{D^{ex} * x_i^{ex}}{Q_i^{ex}}\right] * C_{per-km}^{ex} \tag{26}$$

$$- \left[\mu^i * C_{in} + \sigma^i * C_{ex}\right] \tag{27}$$

$$- \left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right) * C_N \tag{28}$$

$$- \left[\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right) * \left(C_R + C_A + C_S + C_D\right)\right] \tag{29}$$

$$- C_{Bill}^i \tag{30}$$

$$- \left[C_p^i * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] \tag{31}$$

$$- \left[Z_c * \left(D^{ex} * x_i^{ex} * p_{ex}^i\right)\right] \tag{32}$$

$$- \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex} + D^{in} * x_i^{in} * p_{in}^i * p_{tax}^{in}\right] \tag{33}$$

$$- \left(Q_i^{in} * h_i^{in} + Q_i^{ex} * h_i^{ex}\right) \tag{34}$$

Relation (21) in the profit function captures the income from both the domestic and international sales. In this Relation, the total domestic sales by each plant is multiplied by the unit price of domestic product and the total international sales is multiplied by the unit price of international product. Relation (22), which is considered to represent the revenues for each plant, is also related to the tax discounts on international sales granted by the government to each plant. Descriptions of the Relations expressing the expenses of each plant are presented below.

Relation (23) captures the price of a stone block purchased from stone quarries; this obviously has to be converted into square meter of stone because this raw material is commonly purchased in blocks but sold in square meter units. Relation (24) expresses the cost of transporting stone blocks from mines to the plant while Relation (25) expresses the cost of transporting the finished stone product to domestic markets. Relation (26) captures the cost of transporting finished stone products to international markets; this is calculated so as to cover only the costs up to the customs because transportation costs beyond the customs office and the transportation costs will be borne by international customers rather than the stone plant.

Relation (27) determines the cost of participation in or representation at domestic and international exhibitions from which the subsidies paid by the government will be deducted. These subsidies are captured by the discount coefficients μ and σ in the model. Relation (28) calculates the production labor cost based on the quantity of finished product processed. Relation (29) calculates the cost of consumables such as resins, abrasives, and diamond cutting segments. Relation (30) determines the utility costs while Relation (31) expresses packing costs for export sales. This, of course, solely pertains to the portion of export products as finished products supplied to domestic markets typically lack any packaging. Hence, for the products supplied to domestic markets, only the cost of palletizing per square meter is calculated in this Relation. Relation (32) calculates export tax levied by the customs office for international sales and Relation (33) captures the general taxes and VATs calculated based on the total volume of sales by each plant.

Table 3
Data on stone industrial units for use in the DEA model.

	Criteria	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Plant 9	Plant 10
Set 1	Average time to access consumables such as resin	2	3	3	2	1	1	7	3	2	3
	Average distance between stone mines and plant	300	120	350	170	320	450	380	180	330	150
Set 2	Percentage of waste per ton	35%	30%	25%	30%	30%	35%	20%	30%	30%	30%
Set 3	Cost of raw materials such as stone blocks and consumables such as resin and morsel	20000000	17000000	22000000	25000000	18500000	21000000	24000000	15000000	20000000	19500000
	Cost of transporting each unit of stone block per kilometer	250	220	230	250	180	300	320	250	250	280
Set 4	Percentage of checks cashed and cash payments	100%	80%	70%	100%	100%	90%	85%	90%	100%	70%
Set 5	Number of employees in the production department	23	17	20	15	22	25	23	22	27	15
	Number of formal and informal training hours and practical work	18	12	9	20	25	15	20	20	30	20
Set 6	Awareness of world trade rules for stone exports	Very familiar	Moderately familiar	Moderately familiar	Extremely familiar	Very familiar	Moderately familiar	Extremely familiar	Moderately familiar	Very familiar	Slightly familiar
	Knowledge of target markets	Very familiar	Very familiar	Very familiar	Very familiar	Moderately familiar	Moderately familiar	Moderately familiar	Slightly familiar	Moderately familiar	Very familiar
Set 7	Plant's number of shifts and working hours per shift	12	15	12	12	12	17	16	12	12	12
	Skills and work experience of labor (year)	15	7	5	11	15	10	11	7	10	14
Set 8	Labor cost per person per hour	8000	8500	10000	8000	12000	10000	95000	7500	8000	8000
Set 9	Liquidity available to the plant (million)	200	0	50	100	150	0	0	100	250	200
Set 10	Readiness to employ new emerging techniques (month)	6	3	5	6	6	12	6	3	3	2
Set 11	Maintenance and repair costs in each period (million)	7	5	10	6	11	8	8	9	11	10
	Monthly power consumption (Rials)	6000000	5500000	6000000	10000000	8000000	7500000	9500000	5000000	6800000	7000000
	Cutting machine speed to prepare final product (square meters per day)	300	500	250	400	250	250	480	380	550	250
Set 12	Volume of stone products stored at the end of each month (square meters)	1500	1000	2000	2100	1500	2500	2000	1100	2300	2000
Set 13	Cost of transporting and delivering products to clients (m^2/km)	30	35	30	50	43	30	30	40	42	33
	Direct sales to clients and dealers (m^2)	5000	5500	6500	8000	5000	6800	6800	5600	6000	6000
	Ratio of products exported	90%	30%	50%	80%	50%	40%	80%	30%	50%	40%
Set 14	Time required to meet customer demand (days)	3	0	1	0	0	3	2	1	1	2

Table 4
Descriptive statistics and the correlation matrix of input and output variables.

		Set 1		Set 2	Set 3		Set 4	Set 5		Set 6	
		1	2	3	4	5	6	7	8	9	10
Observation		10	10	10	10	10	10	10	10	10	10
Mean		2.7	275	0.295	20200000	253	0.885	20.9	18.9	3.6	3.4
Standard Deviation		1.702939	111.8779	0.04378	3020302	40.01389	0.120301	4.094712	6.026792	0.966092	0.699206
Minimum		1	120	0.2	15000000	180	0.7	15	9	2	2
Maximum		7	450	0.35	25000000	320	1	27	30	5	4
Set 1	**1**	1.000									
	2	0.188	1.000								
Set 2	**3**	-0.343	-0.616	1.000							
Set 3	**4**	0.384	0.682	-0.912	1.000						
	5	0.501	0.656	-0.895	0.889	1.000					
Set 4	**6**	-0.330	-0.600	0.998	-0.901	-0.896	1.000				
Set 5	**7**	0.177	0.862	-0.729	0.634	0.703	-0.709	1.000			
	8	0.050	0.335	-0.495	0.432	0.425	-0.456	0.585	1.000		
Set 6	**9**	-0.144	-0.434	0.862	-0.663	-0.763	0.893	-0.568	-0.275	1.000	
	10	-0.309	-0.649	0.949	-0.804	-0.864	0.939	-0.826	-0.593	0.816	1.000
Set 7	**11**	0.384	0.512	-0.337	0.371	0.537	-0.341	0.394	-0.106	-0.268	-0.358
	12	-0.227	-0.033	0.152	-0.067	-0.116	0.167	-0.092	0.386	0.231	0.172
Set 8	**13**	0.875	0.398	-0.238	0.366	0.430	-0.206	0.273	0.150	0.071	-0.253
Set 9	**14**	-0.253	0.055	-0.281	0.199	0.154	-0.272	0.296	0.717	-0.277	-0.267
Set 10	**15**	-0.390	-0.069	0.745	-0.549	-0.563	0.749	-0.369	-0.495	0.719	0.677
Set 11	**16**	-0.317	-0.275	0.749	-0.726	-0.719	0.751	-0.376	-0.100	0.587	0.637
	17	0.368	0.605	-0.817	0.933	0.806	-0.793	0.539	0.556	-0.502	-0.749
	18	0.498	0.295	-0.692	0.620	0.648	-0.666	0.580	0.551	-0.437	-0.684
Set 12	**19**	0.185	0.769	-0.749	0.877	0.827	-0.746	0.661	0.475	-0.600	-0.690
Set 13	**20**	-0.099	0.098	-0.586	0.537	0.361	-0.556	0.314	0.685	-0.359	-0.602
	21	0.358	0.588	-0.907	0.960	0.902	-0.901	0.584	0.396	-0.710	-0.834
	22	-0.295	-0.606	0.998	-0.895	-0.888	0.998	-0.732	-0.494	0.883	0.951
Set 14	**23**	-0.281	-0.538	0.987	-0.882	-0.827	0.982	-0.678	-0.509	0.845	0.934

Finally, Relation (34) pertains to inspection costs for both domestic and international orders.

Based on the assumptions made, we will have:

$$Q^{in} = \sum_{i=1}^{n} Q_i^{in} \tag{35}$$

$$Q^{ex} = \sum_{i=1}^{n} Q_i^{ex} \tag{36}$$

$$Q_i^{ex} = x_i^{ex} * Q^{ex} \tag{37}$$

$$Q_i^{in} = x_i^{in} * Q^{in} \tag{38}$$

$$\sum_{i=1}^{n} x_i^{in} = 1 \tag{39}$$

$$\sum_{i=1}^{n} x_i^{ex} = 1 \tag{40}$$

Substituting Relations (35) to (40) in (21) to (34) yields Model 2 as follows:

$$\pi_c^i = \left[D^{ex} * x_i^{ex} * p_{ex}^i + D^{in} * x_i^{in} * p_{in}^i\right] + j_t^i * \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex}\right] - \left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * O^i\right] - \left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] - \left[\frac{D^{in} * x_i^{in}}{x_i^{in} * Q^{in}}\right] * C_{per-km}^{in} + \left[\frac{D^{ex} * x_i^{ex}}{x_i^{ex} * Q^{ex}}\right] * C_{per-km}^{ex} - \left[\mu^i * C_{in} + \sigma^i * C_{ex}\right] - (D^{in} * x_i^{in} + D^{ex} * x_i^{ex}) * C_N - \left[(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}) * (C_R + C_A + C_S + C_D)\right] - C_{Bill}^i - \left[C_p^i * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] - \left[Z_c * (D^{ex} * x_i^{ex} * p_{ex}^i)\right] - \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex} + D^{in} * x_i^{in} * p_{in}^i * p_{tax}^{in}\right] - (x_i^{in} * Q^{in} * h_i^{in} + x_i^{ex} * Q^{ex} * h_i^{ex})\text{Model2}$$

This profit function is formulated for each plant and the functions thus obtained are added up. The resulting expression is considered as the profit function for all the stone plants as in Model 3:

$$\pi_C = \sum_{i=1}^{n} \pi_c^i = \sum_{i=1}^{n}\left[D^{ex} * x_i^{ex} * p_{ex}^i + D^{in} * x_i^{in} * p_{in}^i\right] + \sum_{i=1}^{n} j_t^i * \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex}\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * O^i\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] - \sum_{i=1}^{n}\left[\frac{D^{in} * x_i^{in}}{x_i^{in} * Q^{in}}\right] * C_{per-km}^{in} + \sum_{i=1}^{n}\left[\frac{D^{ex} * x_i^{ex}}{x_i^{ex} * Q^{ex}}\right] * C_{per-km}^{ex} - \sum_{i=1}^{n}\left[\mu^i * C_{in} + \sigma^i * C_{ex}\right] - \sum_{i=1}^{n}(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}) * C_N - \sum_{i=1}^{n}\left[(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}) * (C_R + C_A + C_S + C_D)\right] - \sum_{i=1}^{n} C_{Bill}^i - \sum_{i=1}^{n}\left[C_p^i * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] - \sum_{i=1}^{n}\left[Z_c * (D^{ex} * x_i^{ex} * p_{ex}^i)\right] - \sum_{i=1}^{n}\left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex} + D^{in} * x_i^{in} * p_{in}^i * p_{tax}^{in}\right] - \sum_{i=1}^{n}(x_i^{in} * Q^{in} * h_i^{in} + x_i^{ex} * Q^{ex} * h_i^{ex})\text{Model3}$$

The government's profit function includes a percentage of export revenues earned by each stone plant and a percentage of the foreign currency earned from the related transaction; these two are expressed by Relations (41) and (42) below. Relation (43) expresses the weight gained by a plant due to its export success; it includes the revenues from exports. Relation (44) captures the taxes levied on both domestic sales and exports. Government levies are then deducted from its total pays that also include the subsidies paid on participation in exhibitions and the tax breaks granted to plants, as expressed by Relations (45) and (46), respectively. This profit function is written as follows:

Set 7		Set 8	Set 9	Set 10	Set 11			Set 12	Set 13			Set 14
11	12	13	14	15	16	17	18	19	20	21	22	23
10	10	10	10	10	10	10	10	10	10	10	10	10
13.2	10.5	17500	105	5.2	8.5	7130000	361	1800	36.3	6120	0.54	1.3
1.988858	3.472111	27266.18	92.64628	2.859681	2.068279	1653985	117.4214	501.1099	7.071853	930.7106	0.217051	1.159502
12	5	7500	0	2	5	5000000	250	1000	30	5000	0.3	0
17	15	95000	250	12	11	10000000	550	2500	50	8000	0.9	3

1.000												
-0.211	1.000											
0.531	0.029	1.000										
-0.585	0.474	-0.324	1.000									
0.137	0.183	-0.066	-0.506	1.000								
-0.501	0.198	-0.193	0.092	0.481	1.000							
0.389	0.120	0.458	0.165	-0.444	-0.645	1.000						
0.337	-0.303	0.373	0.177	-0.690	-0.651	0.583	1.000					
0.381	-0.026	0.244	0.269	-0.336	-0.435	0.817	0.450	1.000				
-0.168	-0.006	-0.132	0.429	-0.563	-0.428	0.635	0.573	0.404	1.000			
0.403	-0.235	0.285	0.114	-0.567	-0.755	0.899	0.653	0.860	0.609	1.000		
-0.334	0.151	-0.187	-0.293	0.741	0.750	-0.797	-0.679	-0.743	-0.590	-0.897	1.000	
-0.271	0.182	-0.164	-0.288	0.777	0.747	-0.804	-0.711	-0.696	-0.680	-0.892	0.987	1.000

$$\pi_g = \sum_{i=1}^{n} \left(Z^i * t^i\right) \quad (41)$$

$$+ \sum_{i=1}^{n} (\gamma_i * p_{ex}^i * D^{ex} * x_i^{ex}) \quad (42)$$

$$+ \sum_{i=1}^{n} w_i * (D^{ex} * x_i^{ex} * p_{ex}^i) \quad (43)$$

$$+ \sum_{i=1}^{n} \left[D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex} + D^{in} * x_i^{in} * p_{in}^i * p_{tax}^{in}\right] \quad (44)$$

$$- \sum_{i=1}^{n} [(1 - \mu^i) * C_{in} + (1 - \sigma^i) * C_{ex}] \quad (45)$$

$$- \sum_{i=1}^{n} j_t^i * [D^{ex} * x_i^{ex} * p_{ex}^i * p_{tax}^{ex}] \quad (46)$$

Summation of these two functions yields the total network profit function expressed by π_t (It may be noted that the cost of participation in exhibitions is fixed once two equal phrases are added that can be omitted because it will have no effect on maximizing the total profit function).

Table 5
Amount of variance preserved by the selected principal components.

O. Sa.	I. Sa.	O. Pr.	I. Pr.	O. RD	I. RD	O. Fi.	I. Fi.	O. Hu.	I. Hu.	O. Pu.	I. Pu.	
1	3	4	8	1	2	2	3	2	2	3	2	Number of Criteria
1	1	1	1	1	1	1	1	1	1	1	1	Number of PCAs
1	0.999944973	0.884484318	0.999799949	1	0.65934436	0.996044878	1	0.764216834	0.75303128	1	0.999768365	Covered Variance

Table 6
Selected principal components.

DMUS	I. Pu.	O. Pu.	I. Hu.	O. Hu.	I. Fi.	O. Fi.	I. RD	O. RD	I. Pr.	O. Pr.	I. Sa.	O. Sa.
DMU1	24.999969	200000	0.061930	4.626992	-200000	951.685572	-0.338931	0.8	-1130039.931	-1150.476610	1120.008890	-1.7
DMU2	-154.999987	3200000	7.852001	-3.725324	-3200000	447.846511	0.656203	-2.2	-1630017.780	-875.815188	620.001318	1.3
DMU3	75.000013	-1800000	9.533874	-5.265821	1800000	-1050.879028	0.656203	-0.2	-1130023.000	427.349680	-379.989016	0.3
DMU4	-105.000031	-4800000	1.153842	0.669867	4800000	949.717626	-1.334064	0.8	2869816.730	1854.428877	-1880.020163	1.3
DMU5	44.999924	1700000	-6.075604	4.626992	-1700000	-3048.523764	-0.437468	0.8	869922.262	-1150.460383	1119.987336	1.3
DMU6	174.999924	-800000	2.112664	-1.049524	800000	-1051.863001	0.557665	6.8	369923.248	893.687075	-679.988596	-1.7
DMU7	105.000191	-3800000	-1.797040	0.085779	3800000	-551.959830	-1.432602	0.8	2370571.165	705.221927	-679.988621	-0.7
DMU8	-94.999987	5200000	-1.428180	-3.287258	-5200000	1449.620797	0.459127	-2.2	-2130008.329	-745.491827	519.993156	0.3
DMU9	54.999969	200000	-12.567330	-0.319414	-200000	952.669545	-0.437468	-2.2	-330068.598	77.323404	119.990375	0.3
DMU10	-124.999987	700000	1.153842	3.637711	-700000	951.685572	1.651336	-3.2	-130075.766	-35.766956	120.005321	-0.7
Legend	I: Input	Pu: Purchase	Fi: Financial	Sa: Sale								
	O: Output	Hu: Human resource	Pr: Produce	RD: R&D								

$$\begin{aligned}\pi_t &= \pi_C + \pi_g \\ &= \sum_{i=1}^{n}\left[D^{ex} * x_i^{ex} * p_{ex}^i + D^{in} * x_i^{in} * p_{in}^i\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right)\right. \\ &\quad \left. * O^i\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] - \sum_{i=1}^{n}\left[\frac{D^{in}}{Q^{in}}\right] \\ &\quad * C_{per-km}^{in} + \sum_{i=1}^{n}\left[\frac{D^{ex}}{Q^{ex}}\right] * C_{per-km}^{ex} - \sum_{i=1}^{n}\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right) \\ &\quad * C_N - \sum_{i=1}^{n}\left[\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right)\right. \\ &\quad \left. * \left(C_R + C_A + C_S + C_D\right)\right] - \sum_{i=1}^{n} C_{Bill}^i - \sum_{i=1}^{n}\left[C_p^i * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] - \sum_{i=1}^{n}\left[Z_c\right. \\ &\quad \left. * \left(D^{ex} * x_i^{ex} * p_{ex}^i\right)\right] - \sum_{i=1}^{n}\left(x_i^{in} * Q^{in} * h_i^{in} + x_i^{ex} * Q^{ex} * h_i^{ex}\right) + \sum_{i=1}^{n}\left(Z^i\right. \\ &\quad \left. * t^i\right) + \sum_{i=1}^{n}\left(\gamma_i * p_{ex}^i * D^{ex} * x_i^{ex}\right) + \sum_{i=1}^{n} w_i * \left(D^{ex} * x_i^{ex} * p_{ex}^i\right) \text{Model4}\end{aligned}$$

Once the above equations are derived and optimized, the necessary conditions can be controlled; obviously, the first order is secured and the sufficient conditions for the second order are also ensured.

$$\frac{\partial \pi_t}{\partial Q^{in}} = \frac{n * D^{in} * C_{per-km}^{in}}{\left(Q^{in}\right)^2} - \sum_{i=1}^{n} x_i^{in} * h_i^{in} = 0 \tag{47}$$

$$\frac{\partial^2 \pi_t}{\partial Q^{in^2}} = \frac{-2n * D^{in} * C_{per-km}^{in}}{\left(Q^{in}\right)^3} < 0 \tag{48}$$

Given the secured conditions for a second order equation, the optimal value of Q^{in} is obtained as follows:

$$\frac{\partial \pi_t}{\partial Q^{in}} = \frac{n * D^{in} * C_{per-km}^{in}}{\left(Q^{in}\right)^2} - \sum_{i=1}^{n} x_i^{in} * h_i^{in} = 0 \tag{49}$$

$$\frac{n * D^{in} * C_{per-km}^{in}}{\left(Q^{in}\right)^2} = \sum_{i=1}^{n} x_i^{in} * h_i^{in} \tag{50}$$

$$Q^{in} = \sqrt{\frac{n * D^{in} * C_{per-km}^{in}}{\sum_{i=1}^{n} x_i^{in} * h_i^{in}}} \tag{51}$$

The conditions for the first and second order equations may also be examined for Q^{ex}; it is clear from the following relations that the necessary conditions hold:

$$\frac{\partial \pi_t}{\partial Q^{ex}} = \frac{n * D^{ex} * C_{per-km}^{ex}}{\left(Q^{ex}\right)^2} - \sum_{i=1}^{n} x_i^{ex} * h_i^{ex} = 0 \tag{52}$$

$$\frac{\partial^2 \pi_t}{\partial Q^{ex^2}} = \frac{-2n * D^{ex} * C_{per-km}^{ex}}{\left(Q^{ex}\right)^3} < 0 \tag{53}$$

Given that the second condition is sufficient, the optimal value of Q^{ex} may be obtained as follows:

$$\frac{\partial \pi_t}{\partial Q^{ex}} = \frac{n * D^{ex} * C_{per-km}^{ex}}{\left(Q^{ex}\right)^2} - \sum_{i=1}^{n} x_i^{ex} * h_i^{ex} = 0 \tag{54}$$

$$\frac{n * D^{ex} * C_{per-km}^{ex}}{\left(Q^{ex}\right)^2} = \sum_{i=1}^{n} x_i^{ex} * h_i^{ex} \tag{55}$$

$$Q^{ex} = \sqrt{\frac{n * D^{ex} * C_{per-km}^{ex}}{\sum_{i=1}^{n} x_i^{ex} * h_i^{ex}}} \tag{56}$$

Substituting the values for Q^{in} and Q^{ex} in the total profit function will yield the following model:

Table 7
Non-negative values of the selected principal components.

DMUS	I. Pu.	O. Pu.	I. Hu.	O. Hu.	I. Fi.	O. Fi.	I. RD	O. RD	I. Pr.	O. Pr.	I. Sa.	O. Sa.
DMU1	181.0000	5000001	13.629259	10.89281	5000001	4001.2093	2.093671	5	999969.3977	1.00000	3001.02905	1
DMU2	1.0000	8000001	21.419330	2.54050	2000001	3497.3703	3.088804	2	499991.5491	275.66142	2501.02148	4
DMU3	231.0000	3000001	23.101204	1.00000	7000001	1998.6447	3.088804	4	999986.3289	1578.82629	1501.03115	3
DMU4	51.0000	1.00000	14.721172	6.93569	10000001	3999.2414	1.098538	5	4999826.059	3005.90549	1.00000	4
DMU5	200.9999	6500001	7.491726	10.89281	3500001	1.0000	1.995133	5	2999931.591	1.01623	3001.00750	4
DMU6	330.9999	4000001	15.679993	5.21630	6000001	1997.6608	2.990267	11	2499932.577	2045.16369	1201.03157	1
DMU7	261.0002	1000001	11.770290	6.35160	9000001	2497.5639	1.000000	5	4500580.494	1856.69854	1201.03154	2
DMU8	61.0000	10000001	12.139150	2.97856	1.000000	4499.1446	2.891729	2	1.0000	405.98478	2401.01332	3
DMU9	211.0000	5000001	1.000000	5.94641	5000001	4002.1933	1.995133	2	1799940.731	1228.80001	2001.01054	3
DMU10	31.0000	5500001	14.721172	9.90353	4500001	4001.2093	4.083938	1	1999933.563	1115.70965	2001.02548	2
Legend	I: Input	Pu: Purchase		Fi: Financial		Sa: Sale						
	O: Output	Hu: Human resource		Pr: Produce		RD: R&D						

$$\pi_t = \pi_C + \pi_g$$
$$= \sum_{i=1}^{n}\left[D^{ex} * x_i^{ex} * p_{ex}^{i} + D^{in} * x_i^{in} * p_{in}^{i}\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * O^i\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] - \sum_{i=1}^{n}\left[\frac{D^{in}}{\sqrt{\frac{n*D^{in}*C_{per-km}^{in}}{\sum_{i=1}^{n} x_i^{in}*h_i^{in}}}}\right]$$
$$* C_{per-km}^{in} + \sum_{i=1}^{n}\left[\frac{D^{ex}}{\sqrt{\frac{n*D^{ex}*C_{per-km}^{ex}}{\sum_{i=1}^{n} x_i^{ex}*h_i^{ex}}}}\right] * C_{per-km}^{ex} - \sum_{i=1}^{n}\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right)$$
$$* C_N - \sum_{i=1}^{n}\left[\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right)\right.$$
$$\left. * \left(C_R + C_A + C_S + C_D\right)\right] - \sum_{i=1}^{n} C_{Bill}^{i} - \sum_{i=1}^{n}\left[C_p^i * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] - \sum_{i=1}^{n}\left[Z_c\right.$$
$$\left. * \left(D^{ex} * x_i^{ex} * p_{ex}^{i}\right)\right] - \sum_{i=1}^{n}\left(x_i^{in} * \left(\sqrt{\frac{n * D^{in} * C_{per-km}^{in}}{\sum_{i=1}^{n} x_i^{in} * h_i^{in}}}\right) * h_i^{in} + x_i^{ex}\right.$$
$$\left. * \left(\sqrt{\frac{n * D^{ex} * C_{per-km}^{ex}}{\sum_{i=1}^{n} x_i^{ex} * h_i^{ex}}}\right) * h_i^{ex}\right) + \sum_{i=1}^{n}\left(Z^i * t^i\right) + \sum_{i=1}^{n}\left(\gamma_i * p_{ex}^{i} * D^{ex}\right.$$
$$\left. * x_i^{ex}\right) + \sum_{i=1}^{n} w_i * \left(D^{ex} * x_i^{ex} * p_{ex}^{i}\right) \text{Model5}$$

To obtain the percentage of domestic demand supplied by plant i (x_i^{in}) as well as the percentage of the international demand supplied by the same plant (x_i^{ex}), the following model may be used to maximize the profit of the entire supply chain based on a cooperative game theoretic approach; this has been solved using Gams. Eq. (57) as the first constraint requires that the total ratio of domestic remittances should not exceed the plant's domestic production capacity. This same requirement has been ensured in Eq. (58) for export products supplied to international markets. Constraints (59) and (60) state that the sum of both domestic and international demand ratios allocated to plants must be equal to one. The other constraints expressed by Relations (61), (62), and (63) pertain to the types of variables used.

$$Max \quad \pi_t = \sum_{i=1}^{n}\left[D^{ex} * x_i^{ex} * p_{ex}^{i} + D^{in} * x_i^{in}\right.$$
$$\left. * p_{in}^{i}\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right)\right.$$
$$\left. * O^i\right] - \sum_{i=1}^{n}\left[\left(\frac{D^{in} * x_i^{in} + D^{ex} * x_i^{ex}}{\alpha^i}\right) * A^i\right] - \sum_{i=1}^{n}\left(\frac{D^{in}}{\sqrt{\frac{n*D^{in}*C_{per-km}^{in}}{\sum_{i=1}^{n} x_i^{in}*h_i^{in}}}}\right)$$
$$* C_{per-km}^{in} + \sum_{i=1}^{n}\left(\frac{D^{ex}}{\sqrt{\frac{n*D^{ex}*C_{per-km}^{ex}}{\sum_{i=1}^{n} x_i^{ex}*h_i^{ex}}}}\right) * C_{per-km}^{ex} - \sum_{i=1}^{n}\left(D^{in} * x_i^{in} + D^{ex}\right.$$
$$\left. * x_i^{ex}\right) * C_N - \sum_{i=1}^{n}\left[\left(D^{in} * x_i^{in} + D^{ex} * x_i^{ex}\right)\right.$$
$$\left. * \left(C_R + C_A + C_S + C_D\right)\right] - \sum_{i=1}^{n} C_{Bill}^{i} - \sum_{i=1}^{n}\left[C_p^i\right.$$
$$\left. * \left(\frac{D^{ex} * x_i^{ex}}{\rho^i}\right)\right] - \sum_{i=1}^{n}\left[Z_c * \left(D^{ex} * x_i^{ex} * p_{ex}^{i}\right)\right] - \sum_{i=1}^{n}\left(x_i^{in}\right.$$
$$* \left(\sqrt{\frac{n * D^{in} * C_{per-km}^{in}}{\sum_{i=1}^{n} x_i^{in} * h_i^{in}}}\right) * h_i^{in} + x_i^{ex} * \left(\sqrt{\frac{n * D^{ex} * C_{per-km}^{ex}}{\sum_{i=1}^{n} x_i^{ex} * h_i^{ex}}}\right)$$
$$\left. * h_i^{ex}\right) + \sum_{i=1}^{n}\left(Z^i * t^i\right) + \sum_{i=1}^{n}\left(\gamma_i * p_{ex}^{i} * D^{ex} * x_i^{ex}\right) + \sum_{i=1}^{n} w_i * \left(D^{ex}\right.$$
$$\left. * x_i^{ex} * p_{ex}^{i}\right) \text{Model6}$$

s.t:

$$D^{in} * x_i^{in} \le U_i^{in} \tag{57}$$

$$D^{ex} * x_i^{ex} \le U_i^{ex} \tag{58}$$

$$\sum_{i=1}^{n} x_i^{in} = 1 \tag{59}$$

$$\sum_{i=1}^{n} x_i^{ex} = 1 \tag{60}$$

$$0 \le x_i^{in} \le 1 \tag{61}$$

$$0 \le x_i^{ex} \le 1 \tag{62}$$

4. Implementation of the model

For the purposes of this study, a shortlist was prepared of plants involved in travertine stone exports from the cities of Tehran (Shams Abad Industrial Town), Isfahan (Mahmoud Abad Industrial Town), and Qom (Mahmudabad Industrial Towns and Sang Omid Town). From

Table 8
Subnet and total efficiency values calculated by the DEA model.

	Purchasing efficiency		Support efficiency		Production efficiency		Sales efficiency		Total efficiency- CRS	Total efficiency- VRS
	CRS	VRS	CRS	VRS	CRS	VRS	CRS	VRS		
Plant 1	0.665	0.713	1	1	0.873	0.879	0.488	0.569	0.729565	0.772765
Plant 2	1	1	0.884	1	0.943	1	0.895	1	0.929387	1
Plant 3	0.709	0.867	0.833	0.947	0.781	0.856	0.9	1	0.802687	0.91561
Plant 4	0.998	1	0.854	0.893	1	1	0.853	0.885	0.923388	0.942863
Plant 5	1	1	0.833	0.912	0.98	0.998	1	1	0.950534	0.976745
Plant 6	0.88	1	0.795	0.863	1	1	0.336	0.567	0.696301	0.83637
Plant 7	0.473	0.543	0.889	0.899	0.912	1	0.672	0.683	0.712495	0.75988
Plant 8	1	1	0.993	1	1	1	0.772	0.904	0.935711	0.975084
Plant 9	0.698	0.699	1	1	0.732	0.859	0.88	1	0.818865	0.880273
Plant 10	0.904	1	1	1	0.954	1	0.613	0.716	0.852696	0.919874

Table 9
Weight of each stone plant obtained via normalization.

Plant	1	2	3	4	5	6	7	8	9	10
Weight	0.0861	0.111	0.102	0.105	0.109	0.093	0.085	0.109	0.098	0.102

Table 10
Data collected from selected stone plants for use in the game theoretic model.

Parameter	Factory 1	Factory 2	Factory 3	Factory 4	Factory 5	Factory 6	Factory 7	Factory 8	Factory 9	Factory 10
Domestic stone sale price at the plant (*1000 Thomans)	120	100	250	150	300	85	220	100	350	200
International sales price at plant *i* (US$)	20	25	36	30	60	20	45	30	75	60
Coefficient of conversion of tons of stone to square meters of stone at plant *i*	8	10	8	10	10	9	8	10	12	9
Average purchase price of stone blocks at plant *i* (*1000 Thomans per ton)	500	500	950	800	1000	450	900	400	1200	600
Average order delivery cost including transportation from mine to plant i(per ton per kilometer(	200	250	200	300	220	330	200	200	200	300
Percent of costs covered by the government for participation in domestic exhibitions	5	5	5	10	5	5	12	8	5	10
Percent cost covered by the government for participation in international exhibitions to the factory i	10	10	10	10	10	10	10	5	10	5
Percent revenues from exports by plant *i* that returns to the country	100	100	100	90	100	85	100	100	90	100
Liquidity available to plant *i* over the study period (million Thomans)	200	0	50	100	150	0	0	100	250	200
Percentage of plant *i*'s liquidity considered as government's profit	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coefficient of conversion for converting stone meters to pallet numbers at plant *i*	12	18	12	12	12	16	16	18	18	12
Plant *i*'s production capacity for domestic market (m^2)	9000	10500	15000	18000	13500	9000	12000	16200	18000	12900
Plant *i*'s production capacity for international markets (m^2)	9000	7500	15000	15000	12000	9000	9600	12000	15000	9000
Cost of each pallet at plant I (*1000 Thomans)	168	150	120	170	200	150	170	180	160	170
Percentage of export tax rebate for plant *i*	100	100	100	0	100	0	100	100	0	100
Inspection cost per square meter of stone product for a one-time load recovery for the total domestic orders at plant *I* (*1000 Tomans)	1	1	1.5	1.5	1	0	1	0.5	1	0
Inspection cost per square meter of stone product for a one-time load recovery for the total international orders at plant *i* (*1000 Tomans)	5	5.5	6	10	5	5	10	8	5	5
Average mine-to-plant distance(km)	300	120	350	170	320	450	380	180	330	150

Parameters	**value**
Total domestic demand	75000
Total international demand	70800
Product volume supplied by plant *i* to domestic markets per loading	2400
Product volume supplied by plant *i* to international markets per loading	4000
Labor cost for cutting and resin application for 1 m^2 of stone (*1000 Thomans)	2000
Average cost of resin applied on 1 m^2 of stone (*1000 Thomans)	5000
Average cost of abrasive used for 1 m^2 of stone (*1000 Thomans)	4000
Average cost of diamond cutting segment consumed for 1 m^2 of stone (* 1000 Thomans)	2000
Average depreciation cost of stone cutter disc consumed for 1 m^2 of stone (*1000 Thomans)	1000
Percentage of customs tariffs levied for stone exports	12%
Average delivery cost to domestic markets for 1 m^2 of stone per kilometer (Million(	25
Average cost of transportation to customs for export per m^2 of stone per kilometer (Million(	30

Table 11
Results obtained from the game theoretic model.

Plant	Monthly allocation of international orders to each plant	Proportion of the total international allocations	Monthly allocation of domestic orders to each plant	Proportion of the total domestic allocations
1	0	0	0	0
2	0	0	0	0
3	20850	0.294491525	14930	0.199066667
4	0	0	5305	0.070733333
5	11230	0.158615819	13970	0.186266667
6	0	0	0	0
7	10258.5	0.144894068	12390	0.1652
8	9274.8	0.131	0	0
9	11129	0.157189266	16425	0.219
10	8057.7	0.113809322	11980	0.159733333
Total	70800	1	75000	1
$\pi_t = 1.009509 \times 10^{11}$				

among these, plants that ranked equal in terms of product quality and also production quantity as judged by their production capacity were selected for data collection. The decision-making units were selected based on a case study and all units that had sufficient information were reviewed. In addition, since the performance of each subnet is calculated separately, the number of criteria of each subnet is much less than the total criteria, and this creates a balance between the number of decision units and the number of criteria. Furthermore, since the number of decision-making units is small compared to the number of criteria and due to the limitations related to access to the data of the factories, the PCA approach was used to reduce the dimensions of the data.

To clarify the reason why we have raised the point in this article that separate modeling of these parts causes the need for fewer units, we present an example. If the entire network is modeled at once, all the input and output criteria should be considered, which in this article is about 23 criteria. Therefore, in order to reach a better answer, at least 69 decision-making units should be considered, as the data of this number of factories is not accessible. But if each network is considered separately, only the criteria related to the same section should be considered in order to obtain the optimal number of decision-making units. For example, in the first stage (purchase), the total number of input and output criteria is 5, so the minimum number of decision-making units is 15, which is far less than 69 units, even to reduce these 15 units, the PCA approach has been used. Using the PCA approach reduces the dimensions of the data and ultimately reduces the number of required decision-making units.

The reason that only the data of 10 units was used in this article and we were forced to use an approach to reduce the dimensions of the data is that in our chosen area, only this number of factories had a share in the export of stone and in a homogeneous way behave towards each other.

The supply chain network of each plant was then determined based on the administrative, support, production, and sales records of the plant as well as the input and output criteria of each stage using the national strategic documents on construction stone production and the expert opinions collected.

Based on the inputs and outputs of the sub-networks within the network data analysis model reported in Table 1, data were collected from 10 stone plants in the three cities of Tehran, Qom, and Isfahan, a summary of which is reported in Table 3. It should be noted that the criterion used in Set 6 is a qualitative criterion and is converted to quantitative numbers based on the Likert scale.

It must be borne in mind that certain inputs and outputs in the network data envelopment analysis model might be irrelevant to the objectives of the present study. The goal of data envelopment analysis is to reduce the number of inputs but to increase that of outputs; in this study, however, some of the criteria used do not conform to this requirement so that there are more inputs but less outputs. This is because some criteria are not only the output of a subnet but also the input to the next step; hence, such criteria might seem relevant in one sub-network but irrelevant in another. Moreover, such criteria are given in advance and help enhance model efficiency. Nevertheless, the irrelevant inputs and outputs were converted into relevant ones and the optimal data outputs were fed into the model before the efficiency of the subnetworks could be calculated.

Table 4 also shows the statistical characteristics and the correlation matrix between the input and output criteria used in the data envelopment analysis method.

The results of using PCA to the above data in MATLAB are presented in Table 6. In this analysis, the principal components that were able to preserve the highest percentages of the total variance in the data were chosen for use in the rest of the study. The amount of variance preserved by these principal components is shown in Table 5.

Since DEA models cannot accept negative inputs, the following Eqs. (63 and 64) were used to make all the figures related to principal components non-negative:

$$Z_j = PC_j + Q \tag{63}$$

$$Q = -\min\{PC_j\} + 1 \tag{64}$$

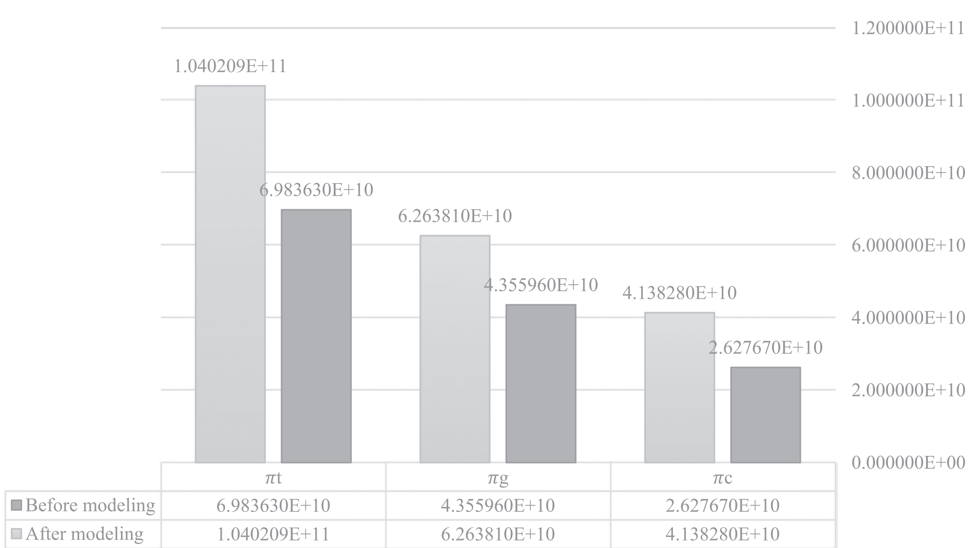

Fig. 3. Comparison of the current values and those obtained by the proposed model.

The final results are presented in Table 7.

After preparing the data related to the inputs and outputs of the sub-networks of the supply chain, the efficiency of each sector was calculated by solving the relevant models for production and sales support sub-networks; the results obtained are reported in Table 8. In Table 8, in addition to the results obtained from the VRS approach, the results of the CRS approach are also given so that the reason for choosing the variable return to scale approach can be clearly seen. Based on the obtained results, because the efficiency obtained from VRS for each decision unit is better than the efficiency of that unit from the CRS approach., the results of the VRS are used for the game theory model. The efficiency of the whole network was calculated based on the assumption that all the subnets are of equal significance and, thus, total efficiency was calculated by manipulating the weights assigned to the sub-networks. The results obtained from the VRS model are the result of the problem being solved by the analyst and these results can be used for a group or individual decision depending on how the problem is posed.

The calculated efficiency of each plant may be normalized to obtain the weight of each plant. The results obtained are reported in Table 9.

Using the weights thus obtained and the values for the parameters reported in Table 10, Model 13 is obtained for determining optimal domestic and export production percentages to be allocated to each stone plant. Solved using a collaborative game theoretic approach, the model contains parameters that are all based on actual data collected from the study plants. Meanwhile, attempts had been made to select plants with the greatest impacts not only on both domestic and international markets but also on the decision-making process of the government.

For further explanation of the parameters in Table 10, domestic stone sale price at the plant, shows the selling price per square meter of stone in the domestic market for each factory. International sales price at plant i, shows the selling price per square meter of stone in international markets. Coefficient of conversion of tons of stone to square meters of stone at plant i, indicates that for each ton of stone purchased from the mine, how many square meters of stone are produced ready to be sent to the customer? This is related to the quality of the stone purchased from the stone mines. Average purchase price of stone blocks, also shows the average purchase price per ton of stone from stone mines. Average order delivery cost including transportation is related to the cost of transportation from mine to plant i. Percent of costs covered by the government for participation in domestic or international exhibitions is the amount of government subsidy to participate in exhibitions. Percent revenues from exports by plant i that returns to the country is intended to examine the positive effects of stone exports on the country's economy and is based on money transfers between factories and buyers in international markets. Liquidity available to plant i over the study period shows the amount of cash in the factory to deal with unplanned changes. Percentage of plant i's liquidity considered as government's profit is the amount of profit that the government derives from the cash in the bank accounts of industry owners. Coefficient of conversion for converting stone meters to pallet numbers at plant i, indicates how many square meters of stone fit in each pallet? This issue should be considered for packing stones and sending them to international markets. Cost of each pallet at plant is the cost of purchasing each pallet. Plant i's production capacity for both domestic and international market represents the maximum production capacity of stone. To encourage industries to export, the government provides tax breaks in certain circumstances, as shown in percentage of export tax rebate. The costs of inspecting the final stones are also included in two separate criteria, which, as it is clear, the cost of inspecting the export stones is higher than the stones sent to the domestic markets. Average mine-to-plant distance, also considers the average distance between mines and factories in kilometers.

Solving the model yields the results reported in Table 11 indicating the optimal percentages of domestic and international order allocations to the different plants studied.

The domestic and international allocations to each plant obtained from the model were compared with the current orders received by the plants, the results of which are reported in Fig. (3). Clearly, the proposed model increased the target values in each case, thereby enhancing the profits earned by both the plants and the government with enhanced overall profit of the supply chain.

5. Conclusion and further implications

The fact that the more than 6000 stone cutting plants operating in Iran hold only 1% of the world stone market signifies the importance of building stone exports and its expected impacts on national economy. This while the Iranian stone industry enjoys the potential capacity for annual production of about 5 million tons of decorative stones to be supplied to both domestic and international markets. The present study employed a combination of game theory and data envelopment analysis to assist decision makers in their efforts to share out and allocate the total domestic and international orders for building stones among the existing stone-cutting plants based on government policies. Another objective pursued was to maximize the total profit of the supply chain considering the studied plants' production and sales network efficiencies. The successful implementation of the proposed model to the studied stone plants revealed its potential for application to other industrial environments and organizations. The results obtained from the integrated model showed that, compared to the current situation, the supply chain profits earned increased significantly as a result of proper allocation of orders to different plants. Using the travertine manufacturing stone industry, the novelty of the present study was the identification of the most important criteria for assessing and ranking plants. The results have been well received by many stone mining and engineering plants across the nation.

For future research, the model data may be investigated from both fuzzy and probabilistic viewpoints. It is also possible to extend the model into more realistic ones based on more real-world assumptions. Moreover, the integrated model proposed herein can be implemented in many organizational and industrial situations aimed at improving upon the process of allocating total demand for different products to various industrial units. It is also possible to extend the current study by including more stone plants and to consider different sales conditions in foreign countries. One specific aspect that can be investigated arises from the fact that the travertine stone enjoys a vast variety in terms of quality, color, quality of the Rosin content and its sub components; hence, different types of travertine stone of varied prices can be used in the model. Meanwhile, many of the items and parameters used in this study might be affected by the quality of the stone blocks used and these might be considered for further improvement of the model. From a different aspect, minimum order limits might be determined for each plant in order to share out job opportunities among all the industrial units involved in stone production.

For further researches, different suppliers as well as different distributors can be included in the supply chain network of stone industrial units. To use the approach proposed in this paper based on this type of networks, in addition to calculating the efficiency of factories as producers of that SCN, the efficiency of suppliers and distributors must also be calculated by considering their internal structure.

The calculated efficiency, along with the efficiency of stone factories, enters the next stage, ie using the game theory approach, and considering the utility function for all members of the supply chain, including suppliers (stone mines), manufacturers (stone factories) and distributors, we can find the optimal amount of purchase from suppliers, the optimal amount of sales to domestic and foreign markets, as well as the optimal amount of shipping to each distributor.

Other models of game theory, such as the non-cooperative games, could be studied in lieu of the cooperative model employed in the present study. Finally, It is hoped that in the future, with the development of the article, the scope of the case study can be expanded and more units can be used.

Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the journal of computational Science.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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