



## Supplier Selection and Order Allocation under Risk: Iranian Oil and Gas Drilling Companies

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### KEYWORDS

Supplier selection,  
Order allocation,  
Sanction risk,  
Multi-objective,  
AHP,  
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### ABSTRACT

*This paper addresses a supplier selection and order allocation problem while considering the losses arising from the risk of sanctions on Iran's Oil & Gas Drilling Industry. In the proposed study, two general classes of items and two different classes of suppliers are considered. Analytical Hierarchy Process (AHP) is first used to rank the potential suppliers. Then, a multi-objective linear programming model is proposed to determine the best suppliers and their allocated orders. A numerical example is presented to demonstrate the applicability of the proposed model.*

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### 1. Introduction

Given the current state of Iran's economy and its severe dependence on oil and gas incomes, it is obvious that oil and gas drilling industry has a vital role for the country. The major part of exports of Iran is related to oil and gas export. Therefore, this industry has a high contribution to the country's economy. Furthermore, this industry has the most important national resources at its disposal [1].

It is clear that the drilling industry, as an upstream oil and gas industry, occupies an important position in Iran's economic development. The need to increase oil and gas production in accordance with the policies of the country reflects the ever-increasing need for this industry. According to the goals stipulated in Outlook Document of Oil Industry in 1404 AHS (2025), Iran should increase oil and gas production up to 7% of global market demand in order to occupy OPEC's second largest oil

producer. Furthermore, Iran must be the world's third largest gas producer with a share of 8 to 10 percent of global gas trade [2]. The importance of this industry as well as the dire need to expand its domain has led to the advent of growing number of active drilling companies in recent years. Over the past 5 years, the number of companies operating in this area has approximately doubled and reached 13 active companies [3].

The Iranian drilling industry has been affected by sanctions imposed against Iran. Consequently, a large set of damages could be observed including importing specialized drilling equipment, importing rigs to increase production and productivity quality, and importing new technology requirements of the industry.

Sanctions against Iran affecting the transport of required goods and materials, tools and technologies for various industries cause particular and unique circumstances for selecting foreign suppliers and cooperating with them inside the country. More specifically, in an important industry such as oil and gas drilling industry, which is firstly productive of economy and, secondly, due to specific technologies used in this industry, is highly dependent on foreign

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suppliers. Some of the main suppliers of goods have been sanctioned; therefore, the required goods must be supplied through intermediaries. On the other hand, the transportation path of goods encounters many problems and difficulties, because, in many cases, a direct contact between Iran and the technology owner from a developed country is not possible, and goods must pass through several countries. This problem leads to extra transportation costs and delivery times compared to the normal conditions (i.e., the absence of economic sanctions and the related risks) and highlights their role in the selection of suppliers.

Therefore, the principal aim of this paper is to develop a novel supplier selection and order allocation decision model under risk of sanction on Iran's Oil & Gas Drilling Industry in order to achieve higher productivity and lower cost in that industry.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 develops problem definition and formulation. Section 4 provides an illustrative numerical example to validate the applicability of the presented supplier selection and order allocation (SS&OA) model. Finally, Section 5 reports conclusions and future research directions.

## 2. Literature Review

For reviewing the literature on supplier evaluation and selection models up to 2000, we refer the interested readers to Weber et al. [4], Degraeve et al. [5], and De Boer et al. [6].

Ho et al. [7] investigated multi-criteria decision-making (MCDM) techniques for supplier selection (SS) through analyzing 78 journal papers published from 2000 to 2008. The individual and integrated approaches were explained separately.

Agarwal et al. [8] reviewed different MCDM methods presented in the literature to solve the supplier evaluation and selection problem. The study was conducted based on sixty-eight research works, including eight review papers published from 2000 to 2011. Ware et al. [9] presented a deep review of literature and research articles on different aspects of supplier selection problem during the period 1991-2011. More than 200 research papers were collected and analyzed. Many new ideas, techniques, and approaches have been developed to the SS area over the recent years. A systematic review of the literature about the application of decision-making (DM) approaches to SS was presented by Chai et al.

[10], reviewing 123 papers published from 2008 to 2012.

Khodadadzadeh and Sadjadi [11] provided a study about the use of various MCDM approaches to supplier selection problems. The survey covered recent progress in MCDM techniques over the 126 published papers from 2000 to 2012.

Recently, Wetzstein et al. [12] used a systematic literature review (SLR) methodology to examine the developments and advancements in supplier selection topic. They reviewed 221 papers published in outstanding journals between 1990 and 2015.

Literature review indicates that DEA<sup>2</sup>, AHP, and TOPSIS<sup>3</sup> techniques have been used more frequently than other methodologies for solving supplier selection problems.

Furthermore, recent growing awareness about the environmental issues has led to the emergence of green supply chain problems; as a result, ecological criteria are also included in the supplier selection problems. Genovese et al. [13] extensively reviewed articles related to green supplier selection by focusing on applied methodologies and current issues.

Igarashi et al. [14] examined and reviewed 60 journal papers published from 1991 to 2011 about green supplier selection problem.

Govindan et al. [15] studied MCDM methodologies in the literature of supplier evaluation and selection with a focus on the implementation of ecological issues between 1997 and 2011.

Zimmer et al. [16] examined and reviewed the literature related to sustainable supplier management (SSM) using 143 peer-reviewed publications from 1997 to 2014. They focused on decision-making models about the selection, monitoring, and development of sustainable supplier.

Aissaoui et al. [17] presented a literature review of previous survey works about purchasing process with emphasis on the last selection stage that includes determining the best combination of suppliers and allocating orders among the selected suppliers in order to meet various purchasing requirements. They focused on studies that used operations research and computational methods.

Setak et al. [18] provided an extensive literature review on supplier selection and order allocation models. They investigated the contribution of 170 articles during 2000-2010 and presented the most frequently used approaches and criteria.

### **2-1. Supplier selection under risk**

For a long time, the multi-criteria decision of supplier selection has been an attractive issue for the researchers and practitioners. Over the recent years, the occurrence of different types of risks and disruptions, such as natural disasters, inland strikes and riots, terrorism attacks, etc., in all over the world indicates that the supply process is very vulnerable to such unexpected events.

In addition, recently, supply risks related to supplier selection problem have been studied from various aspects in the literature. Ip et al. [19] modeled a risk-based partner selection problem. The purpose of their problem was minimizing the project risk including the risks of project failure and project tardiness. Some of the main decision criteria, involving risk factors in developing an efficient global supplier selection system, were identified and discussed by Chan and Kumar [20]. Kull and Talluri [21] developed a framework of risk assessment based on diverse types of risks via considering existing research in supply management. Wu and Olson [22] proposed three kinds of supplier selection models by taking supply chain risks into consideration, which include chance-constrained programming (CCP), data envelopment analysis (DEA), and multi-objective programming (MOP) models. Micheli et al. [23] presented a new approach to analyzing whether or not the risk-efficiency-based supplier selection models have the expected positive economic effect on the average total cost of procurement in the EPC industry, where vital supplies are very frequent. Wu et al. [24] considered risk factors in the supplier selection problem of a three-level supply chain and developed a fuzzy multi-objective programming model.

Yücenur et al. [25] presented a global supplier selection model by AHP and ANP. They utilized a fuzzy AHP method to evaluate decision criteria for selecting the best global supplier. Some of these criteria were risk factors, cost, service quality, and characteristics of suppliers. In addition, they applied ANP to supplier ranking.

Nourbakhsh et al. [26] developed a new framework for supplier selection problem under the supply risks. The introduced framework included the determination of the reliability of provision elements by an expert relying on some of the proposed risk factors and the estimation of reliability scores using a trained Multi-Layer Perceptron (MLP) network, which played the role of the expert viewpoint.

Sharifabadi et al. [27] used Fuzzy Delphi to determine the significant factors in the supplier

selection of steel industry. They developed a comprehensive supplier selection model and used Interpretive Structural Modeling (ISM) to identify and prioritize different components of SS that would provide a comprehensive map for industry leaders in the decision-making process.

### **2-2. Supplier selection & order allocation under risk**

Ravindran et al. [28] proposed a multi-criteria risk-adjusted version of the supplier selection problem. They developed a two-phase solution method for the problem. In the first phase, a multi-objective ranking method was applied to reduce the initial set of primary suppliers to a smaller manageable one. Then, in the second phase, a multi-objective optimization model was used to determine the order quantities to the selected suppliers. They considered the minimization of four conflicting objective functions including two risk-based functions: price and lead time.

Sawik [29] investigated the problem of SS&OA under local and global disruptions at suppliers. The problem was modelled as a mixed integer program seeking to select the best supply portfolio in a make-to-order environment by computing value-at-risk of cost for each custom part and minimizing cost of expected worst-case for each part.

In addition, Sawik [30] proposed the SS&OA problem with disruption risks considering a protection strategy. In the presented problem, some of the suppliers were selected to be fortified against disruptions and to preposition emergency inventories.

Sheikhalishahi and Torabi [31] introduced the problem of maintenance supplier selection for a manufacturer, as a new version of supplier selection problem. In order to determine the best suppliers for each part and allocate the order quantity to them, they developed a multi-objective mathematical model. They considered the costs of total life cycle for purchased parts and diverse risks related to the potential suppliers.

More recently, SS&OA problem for building the resilient supply base under operational and disruption risks was addressed by Torabi et al. [32]. The proposed problem was formulated as a bi-objective mixed possibilistic, two-stage stochastic programming model.

Hamdi et al. [33] studied the supplier selection and order allocation problem under the make-to-order strategy and disruption risks in the suppliers. They presented two mixed integer

programming models. The first one was developed to consider viewpoint of a risk neutral decision-maker; so, it was aimed at maximizing the expected benefit, whereas the second one considered viewpoint of a risk-averse decision-maker with the objective of minimizing the expected operational loss.

Hajikhani et al. [34] developed a fuzzy multi-objective model for supplier selection and order allocation problem under epistemic uncertainty. They proposed the model at two levels considering wastage. In addition, Mohtashami and Alinezhad [35] presented a new multi-objective mathematical model for the supplier selection and order allocation problem under uncertainty and price discount.

### 2-3. Gap analysis

Reviewing the related literature over the past two decades, we found that there are still some avenues for further research in the area of supplier selection that need to be explored. Among them, we refer to the following issues:

- Global supplier issues
- Adaptability to IT (Information Technology)
- Supplier selection under risk
- Green supplier selection

The present study addresses the issue of selecting the foreign suppliers (i.e., global suppliers) along with local suppliers for some of certain goods under risks of economic sanctions. In addition, the subject of compliance with the environmental issues has been considered in the supplier selection criteria applying distance criterion (to reduce transportation and air pollution) and criterion of regarding environmental concerns by each supplier.

The research presented in this paper differs from previous studies about the supplier selection problem due to considering risks and uncertainty conditions in Iran. Sanctions against Iran in the transport of goods and materials, tools and technologies for oil and gas drilling industry, which uses specific technologies and is highly dependent on foreign suppliers, will cause special conditions in selecting foreign suppliers and their availability for Iranians' drilling companies.

## 3. Problem Definition and Formulation

### 3-1. Problem definition

The addressed problem is the evaluation and selection of suppliers and determination of their order quantities under the risk of sanctions for Iran's Oil & Gas Drilling Industry. In this industry, two groups of suppliers are available: domestic (or local) and foreign (or global) suppliers.

Depending on the company's needs, various criteria can be considered for the supplier selection. Therefore, it is necessary to survey different selection methods to meet and address the expectations of stakeholders.

In order to determine the most effective criteria, a committee of experts was formed, including top managers and experts from different departments of the organization such as engineering, procurement, planning and systems, financial and drilling operations.

The committee determined the following criteria to evaluate candidate suppliers:

Criterion 1: Quality ( $C_1$ )

Criterion 2: Environmental Concerns ( $C_2$ )

Criterion 3: Cost ( $C_3$ )

Criterion 4: Services ( $C_4$ )

Criterion 5: Suppliers' Backgrounds ( $C_5$ )

Criterion 6: Risk factors ( $C_6$ )

Considering economic sanctions in Iranian drilling industry, goods and equipment could be classified in two different classes. Categorizing goods (demands) for oil and gas drilling industry is as follows: (1) consuming goods and spare parts; (2) basic commodities and assets.

In addition, in order to purchase items, there are two groups of suppliers: (1) Local suppliers and (2) Foreign suppliers.

Therefore, in the proposed study, there are two general classes of items and two different classes of suppliers. Consuming goods and spare parts (i.e., class 1 of required items) are denoted by  $G_1$  and basic commodities and assets of drilling rig (i.e., class 2 of required items) are denoted by  $G_2$ . Also,  $LS$  and  $FS$  denote the local and foreign suppliers, respectively.

Different modes of supplying the items (demands) are:

$$\left\{ \begin{array}{l} \text{Consuming goods and spare parts} \\ \text{Fundamental commodities and assets} \end{array} \right. \left\{ \begin{array}{l} \text{Local Supplier } (g1 - LS) \\ \text{Foreign Supplier } (g1 - FS) \\ \text{Local Supplier } (g2 - LS) \\ \text{Foreign Supplier } (g2 - FS) \end{array} \right.$$

Considering the mentioned categories for goods and suppliers is because of two main reasons. Firstly, for supplying consuming goods or basic commodities, each criterion has different degrees of importance and priority in evaluating suppliers and, secondly, due to the impacts of sanction, it is more convenient and feasible to provide class 1 items from domestic manufacturers and suppliers rather than foreign suppliers (due to less sensitivity to quality of these goods and instead the need to provide them faster). On the other hand, in order to provide class 2 items, there is an essential need for high quality and original goods; so, organizations prefer to supply these items from foreign suppliers that are their original manufacturers.

Because of the abovementioned reasons and also due to the different effects of economic sanctions on foreign and domestic suppliers, priority and importance of supplier evaluation criteria are different in each of the four modes of supply. AHP method is used for evaluation of suppliers based on different categories in order to provide consistency in the supplier selection process. For evaluating the local and foreign suppliers, by utilizing the opinions of the committee's experts in the drilling industry, six main criteria are specified. Some of the important sub-criteria (29 sub-criteria) are also presented in Figure 1 to investigate the proposed problem more precisely.

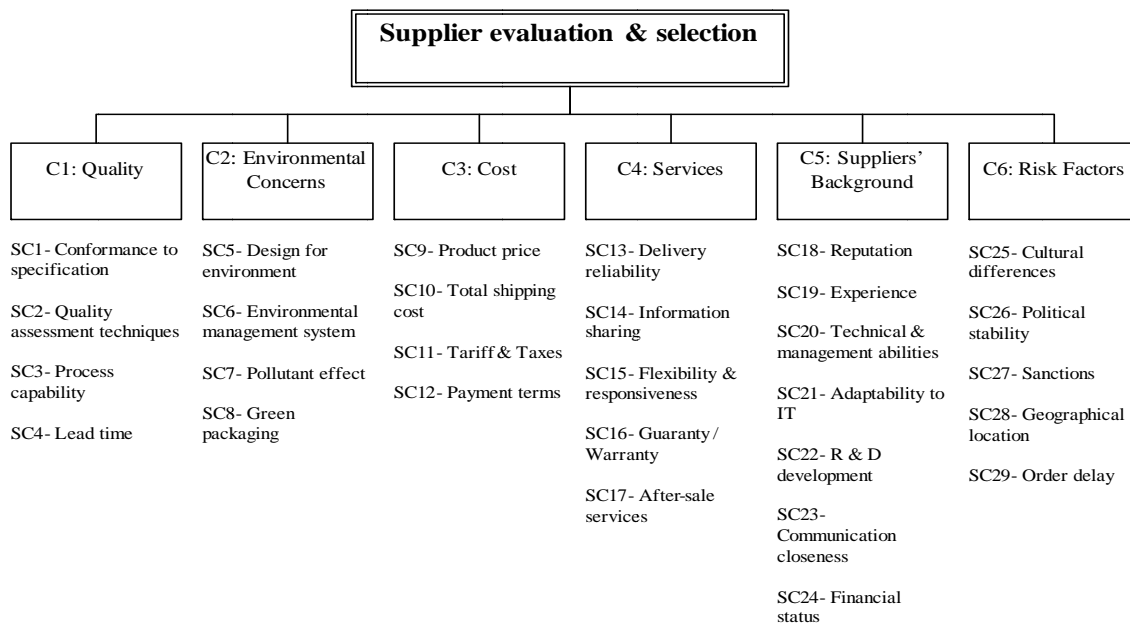


Fig. 1. Supplier evaluation criteria and sub-criteria

The evaluation committee determines the score of each sub-criterion according to Likert's spectrum as mentioned in Table 1.

Tab. 1. Likert's spectrum

Descriptive variable	Sign	Equivalent Score
Very Low (very inappropriate)	VL	1
Low (inappropriate)	L	2
Medium (partly appropriate)	M	3
High (appropriate)	H	4
Very High (very appropriate)	VH	5

Inputs of AHP method in order to determine the criteria weights and calculate the final score of each supplier are as follows:

1. Scores of each sub-criteria gained from the evaluation committee members.

2. Four priority matrices  $A_{g1-LS}, A_{g1-FS}, A_{g2-LS}, A_{g2-FS}$  (6\*6 matrices), which represent the respective priority and importance of the main criteria towards each

other for each of the supplying scenario (4 modes).

3. Four priority matrices  $A_{g1-LS}^{C1}, A_{g1-FS}^{C1}, A_{g2-LS}^{C1}, A_{g2-FS}^{C1}$  (4\*4 matrices), representing the respective priority and importance of the sub-criteria of the first main criterion towards each other for each of the supplying modes.

4. Four priority matrices  $A_{g1-LS}^{C2}, A_{g1-FS}^{C2}, A_{g2-LS}^{C2}, A_{g2-FS}^{C2}$  (4\*4 matrices), representing the respective priority and importance of the sub-criteria of the second main criterion towards each other for each of the supplying modes.

5. Four priority matrices  $A_{g1-LS}^{C3}, A_{g1-FS}^{C3}, A_{g2-LS}^{C3}, A_{g2-FS}^{C3}$  (4\*4 matrices), representing the respective priority and importance of the sub-criteria of the third main criterion towards each other for each of the supplying modes.

6. Four priority matrices  $A_{g1-LS}^{C4}, A_{g1-FS}^{C4}, A_{g2-LS}^{C4}, A_{g2-FS}^{C4}$  (5\*5 matrices), representing the respective priority and importance of the sub-criteria of the fourth main criterion towards each other for each of the supplying modes.

7. Four priority matrices  $A_{g1-LS}^{C5}, A_{g1-FS}^{C5}, A_{g2-LS}^{C5}, A_{g2-FS}^{C5}$  (7\*7 matrices), representing the respective priority and importance of the sub-criteria of the fifth main criterion towards each other for each of the supplying modes.

8. Four priority matrices  $A_{g1-LS}^{C6}, A_{g1-FS}^{C6}, A_{g2-LS}^{C6}, A_{g2-FS}^{C6}$  (5\*5 matrices), representing the respective priority and importance of the sub-criteria of the sixth main criterion towards each other for each of the supplying modes.

Final score of local supplier  $i$ , is denoted by  $w_i$  and higher score means respective excellence of the supplier. Also, the final score of foreign supplier  $j$  is denoted by  $w_j$ . To obtain a list of admissible local and foreign suppliers, an acceptable level is specified for each of them ( $\alpha$  and  $\hat{\alpha}$ , respectively).

If  $w_i \geq \alpha \cdot w_T$ , then supplier  $i$  will be one of the admissible local suppliers. Also, if  $w_j \geq \hat{\alpha} \cdot w_T$ , then supplier  $j$  will be one of the admissible foreign suppliers; otherwise, it would be placed in the black list of organization for purchasing where  $\alpha$  and  $\hat{\alpha}$  are the acceptance score levels for the local and foreign suppliers, respectively, and  $w_T$  is the perfect score of supplier selection process.

### 3-2. Problem model and formulation

In this section, a multi-objective linear programming model for selecting the most favorite suppliers and allocation of orders among them is formulated. The model aims to find the minimum total cost: the minimum total risk and the maximum total value of purchasing. All indices, parameters, and variables used in the model formulation are listed below:

#### 3-2-1. Problem notation

##### Indices

$i$	Local suppliers; $i = \{1, 2, \dots, LS\}$
$j$	Foreign suppliers; $j = \{1, 2, \dots, FS\}$
$g_1$	Class 1 goods (consuming goods and spare parts)
$g_2$	Class 2 goods (basic commodities and assets)
$t$	Time periods; $t = \{1, 2, \dots, T\}$

##### Parameters

$w_i$	Evaluation score of local supplier $i$
$w_j$	Evaluation score of foreign supplier $j$
$\alpha$	Acceptable level for determining local admissible suppliers
$\hat{\alpha}$	Acceptable level for determining foreign admissible suppliers
$c_{it}$	Unit cost of transportation goods ( $g_1$ or $g_2$ ) from vendor $i$ in period $t$
$c'_{jt}$	Unit cost of transportation goods ( $g_1$ or $g_2$ ) from vendor $j$ in period $t$
$p_{ig_1t}$	Unit price of good $g_1$ from supplier $i$ in period $t$

$p'_{ig_2t}$	Unit price of good $g_2$ from supplier $i$ in period $t$
$f_{jg_1t}$	Unit price of good $g_1$ from supplier $j$ in period $t$
$f'_{jg_2t}$	Unit price of good $g_2$ from supplier $j$ in period $t$
$a_{ig_1t}$	Quality level of good $g_1$ from supplier $i$ in period $t$
$a'_{ig_2t}$	Quality level of good $g_2$ from supplier $i$ in period $t$
$b_{jg_1t}$	Quality level of good $g_1$ from supplier $j$ in period $t$
$b'_{jg_2t}$	Quality level of good $g_2$ from supplier $j$ in period $t$
$r_{ig_1t}$	Risk factor of purchasing one unit of good $g_1$ from supplier $i$ in period $t$
$r'_{ig_2t}$	Risk factor of purchasing one unit of good $g_2$ from supplier $i$ in period $t$
$s_{jg_1t}$	Risk factor of purchasing one unit of good $g_1$ from supplier $j$ in period $t$
$s'_{jg_2t}$	Risk factor of purchasing one unit of good $g_2$ from supplier $j$ in period $t$
$m_{it}$	Minimum required goods ( $g_1$ or $g_2$ ) to order from vendor $i$ in period $t$
$m'_{jt}$	Minimum required goods ( $g_1$ or $g_2$ ) to order from vendor $j$ in period $t$
$D_{g_1t}$	Demand of good $g_1$ in period $t$
$D_{g_2t}$	Demand of good $g_2$ in period $t$
$Cap_t$	Warehouse capacity for class 1 goods (G1) in period $t$
$Cap_t$	Warehouse capacity for class 2 goods (G2) in period $t$
$k_{ig_1t}$	Capacity of supplier $i$ for good $g_1$ in period $t$
$k_{ig_2t}$	Capacity of supplier $i$ for good $g_2$ in period $t$
$v_{jg_1t}$	Capacity of supplier $j$ for good $g_1$ in period $t$
$v'_{jg_2t}$	Capacity of supplier $j$ for good $g_2$ in period $t$
$TB_t$	Total budget of buyer for purchasing and transporting goods in period $t$
$QL$	Minimum acceptable quality level of class 1 goods (G1)
$QL$	Minimum acceptable quality level of class 2 goods (G2)
$E_{g_1}$	Earliest delivery date (EDD) for good $g_1$
$E_{g_2}$	Earliest delivery date for good $g_2$
$L_{g_1}$	Latest delivery date (LDD) for good $g_1$
$L'_{g_2}$	Latest delivery date for good $g_2$
$LTL_{ig_1}$	Lead time for good $g_1$ delivered by local supplier $i$
$LTL_{ig_2}$	Lead time for good $g_2$ delivered by local supplier $i$
$LTf_{jg_1}$	Lead time for good $g_1$ delivered by foreign supplier $j$
$LTf_{jg_2}$	Lead time for good $g_2$ delivered by foreign

	supplier $j$
$h_{g_1 t}$	Unit holding cost for inventory of good $g_1$ from period $t$ to period $t + 1$
$h'_{g_2 t}$	Unit holding cost for inventory of good $g_2$ from period $t$ to period $t + 1$
$MS_{g_2 t}$	Minimum required safety stock for good $g_2$ in period $t$
<b>Decision Variables:</b>	
$X_{ig_1 t}$	$\begin{cases} 1; \text{ if good } g_1 \text{ is supplied by vendor } i \text{ in period } t \\ 0; \text{ Otherwise} \end{cases}$
$X'_{ig_2 t}$	$\begin{cases} 1; \text{ if good } g_2 \text{ is supplied by vendor } i \text{ in period } t \\ 0; \text{ Otherwise} \end{cases}$
$Y_{jg_1 t}$	$\begin{cases} 1; \text{ if good } g_1 \text{ is supplied by vendor } j \text{ in period } t \\ 0; \text{ Otherwise} \end{cases}$
$Y'_{jg_2 t}$	$\begin{cases} 1; \text{ if good } g_2 \text{ is supplied by vendor } j \text{ in period } t \\ 0; \text{ Otherwise} \end{cases}$
$Q_{ig_1 t}$	Number of units of good $g_1$ supplied from vendor $i$ in period $t$
$Q'_{ig_2 t}$	Number of units of good $g_2$ supplied from vendor $i$ in period $t$
$O_{jg_1 t}$	Number of units of good $g_1$ supplied from vendor $j$ in period $t$
$O'_{jg_2 t}$	Number of units of good $g_2$ supplied from vendor $j$ in period $t$
$I_{g_1 t}$	Inventory level of good $g_1$ at the end of period $t$
$I'_{g_2 t}$	Inventory level of good $g_2$ at the end of period $t$

### 3-2-2. Problem formulation

#### 3-2-2-1. Objective functions

According to the presented notations, objective functions are quantified as follows:

##### Minimization of the total costs

The total cost includes the total cost of purchasing (TCP), the total cost of transportation (TCT), and the total cost of warehousing (TCW). Therefore, the first objective function is as follows:

$$\text{Min } Z_1 = TCP + TCT + TCW$$

The total purchasing cost is simply calculated via multiplying order quantities by the unit purchasing prices for different modes of supplying the items (4 modes) as follows:

$$\begin{aligned} TCP = & \sum_i \sum_{g_1} \sum_t p_{ig_1 t} \cdot Q_{ig_1 t} \\ & + \sum_i \sum_{g_2} \sum_t p'_{ig_2 t} \cdot Q'_{ig_2 t} \\ & + \sum_j \sum_{g_1} \sum_t f_{jg_1 t} \cdot O_{jg_1 t} \\ & + \sum_j \sum_{g_2} \sum_t f'_{jg_2 t} \cdot O'_{jg_2 t} \end{aligned} \quad (2)$$

(1) The total transportation cost is calculated via multiplying order quantities by the unit transportation costs for local and foreign suppliers as follows:

$$\begin{aligned} TCT = & \sum_i \sum_t \sum_{g_1} \sum_{g_2} c_{it} \cdot (Q_{ig_1 t} + Q'_{ig_2 t}) \\ & + \sum_j \sum_t \sum_{g_1} \sum_{g_2} c'_{jt} \cdot (O_{jg_1 t} + O'_{jg_2 t}) \end{aligned} \quad (3)$$

In addition, the total warehousing cost is calculated via multiplying inventory quantities by



the unit holding costs for two kinds of goods as follows:

$$TCW = \sum_{g_1} \sum_t h_{g_1 t} \cdot I_{g_1 t} + \sum_{g_2} \sum_t h'_{g_2 t} \cdot I'_{g_2 t} \quad (4)$$

*Minimization of the supply risks*

In this paper, by taking into account possible supply risks at suppliers, a risk factor of purchasing one unit of any good is calculated for each supplier (unit risk percent). Then, the total supply risks are simply calculated via multiplying order quantities by the unit risk factor for different modes of supplying the required goods, and the second objective function is defined as follows:

$$Min Z_2 = \sum_i \sum_{g_1} \sum_t r_{i g_1 t} \cdot Q_{i g_1 t} + \sum_i \sum_{g_2} \sum_t r'_{i g_2 t} \cdot Q'_{i g_2 t} + \sum_j \sum_{g_1} \sum_t s_{j g_1 t} \cdot O_{j g_1 t} + \sum_j \sum_{g_2} \sum_t s'_{j g_2 t} \cdot O'_{j g_2 t} \quad (5)$$

**3-2-2-2. Model constraints**

$$\sum_i Q_{i g_1 t} + \sum_j O_{j g_1 t} + I_{g_1, t-1} \geq D_{g_1 t} \quad \forall g_1, t \quad (7)$$

$$\sum_i Q'_{i g_2 t} + \sum_j O'_{j g_2 t} + I'_{g_2, t-1} \geq D'_{g_2 t} \quad \forall g_2, t \quad (8)$$

$$I_{g_1 t} = I_{g_1, t-1} + \sum_i Q_{i g_1 t} + \sum_j O_{j g_1 t} - D_{g_1 t} \quad \forall g_1, t \quad (9)$$

$$I'_{g_2 t} = I'_{g_2, t-1} + \sum_i Q'_{i g_2 t} + \sum_j O'_{j g_2 t} - D'_{g_2 t} \quad \forall g_2, t \quad (10)$$

$$\sum_{g_1} I_{g_1 t} \leq Cap_t \quad \forall t \quad (11)$$

$$\sum_{g_2} I'_{g_2 t} \leq C\acute{a}p_t \quad \forall t \quad (12)$$

$$I'_{g_2 t} \geq MS_{g_2 t} \quad \forall g_2, t \quad (13)$$

*Maximization of the total value of purchasing*

The total value of purchasing measures the impact of qualitative performance criteria in suppliers' evaluation (such as quality of purchased goods; suppliers' backgrounds; environmental concerns and quality of after services). Thus, the third objective function can be estimated as follows:

$$Max Z_3 = \sum_i w_i \sum_t \sum_{g_1} \sum_{g_2} (Q_{i g_1 t} + Q'_{i g_2 t}) + \sum_j \acute{w}_j \sum_t \sum_{g_1} \sum_{g_2} (O_{j g_1 t} + O'_{j g_2 t}) \quad (6)$$

where  $w_i$  is the overall score (weight) of local supplier  $i$ , and  $\acute{w}_j$  is the overall score (weight) of foreign supplier  $j$ . These parameters could be estimated using multi-attribute decision-making (MADM) techniques. Herein, AHP is used for this purpose.

$$\sum_i \sum_{g_1} p_{ig_1t} \cdot Q_{ig_1t} + \sum_i \sum_{g_2} p'_{ig_2t} \cdot Q'_{ig_2t} + \sum_j \sum_{g_1} f_{jg_1t} \cdot O_{jg_1t} + \sum_j \sum_{g_2} f'_{jg_2t} \cdot O'_{jg_2t} + \sum_i \sum_{g_1} \sum_{g_2} c_{it} \cdot (Q_{ig_1t} + Q'_{ig_2t}) + \sum_j \sum_{g_1} \sum_{g_2} c'_{jt} \cdot (O_{jg_1t} + O'_{jg_2t}) \leq TB_t \quad \forall t \quad (14)$$

$$\sum_i \sum_{g_1} \sum_t a_{ig_1t} \cdot Q_{ig_1t} + \sum_j \sum_{g_1} \sum_t b_{jg_1t} \cdot O_{jg_1t} \geq QL \cdot (\sum_i \sum_{g_1} \sum_t Q_{ig_1t} + \sum_j \sum_{g_1} \sum_t O_{jg_1t}) \quad (15)$$

$$\sum_i \sum_{g_2} \sum_t a'_{ig_2t} \cdot Q'_{ig_2t} + \sum_j \sum_{g_2} \sum_t b'_{jg_2t} \cdot O'_{jg_2t} \geq QL \cdot (\sum_i \sum_{g_2} \sum_t Q'_{ig_2t} + \sum_j \sum_{g_2} \sum_t O'_{jg_2t}) \quad (16)$$

$$Q_{ig_1t} \leq k_{ig_1t} \cdot X_{ig_1t} \quad \forall i, g_1, t \quad (17)$$

$$Q'_{ig_2t} \leq k'_{ig_2t} \cdot X'_{ig_2t} \quad \forall i, g_2, t \quad (18)$$

$$O_{jg_1t} \leq v_{jg_1t} \cdot Y_{jg_1t} \quad \forall j, g_1, t \quad (19)$$

$$O'_{jg_2t} \leq v'_{jg_2t} \cdot Y'_{jg_2t} \quad \forall j, g_2, t \quad (20)$$

$$Q_{ig_1t} \geq m_{it} \quad \forall i, g_1, t \quad (21)$$

$$Q'_{ig_2t} \geq m'_{it} \quad \forall i, g_2, t \quad (22)$$

$$O_{jg_1t} \geq m'_{jt} \quad \forall j, g_1, t \quad (23)$$

$$O'_{jg_2t} \geq m'_{jt} \quad \forall j, g_2, t \quad (24)$$

$$E_{g_1} \leq LTL_{ig_1} \cdot X_{ig_1t} \leq L_{g_1} \quad \forall i, g_1, t \quad (25)$$

$$E'_{g_2} \leq LTL'_{ig_2} \cdot X'_{ig_2t} \leq L'_{g_2} \quad \forall i, g_2, t \quad (26)$$

$$E_{g_1} \leq LTF_{jg_1} \cdot Y_{jg_1t} \leq L_{g_1} \quad \forall j, g_1, t \quad (27)$$

$$E'_{g_2} \leq LTF'_{jg_2} \cdot Y'_{jg_2t} \leq L'_{g_2} \quad \forall j, g_2, t \quad (28)$$

$$X_{ig_1t}, X'_{ig_2t}, Y_{jg_1t}, Y'_{jg_2t} \in \{0,1\} \quad \forall i, j, g_1, g_2, t \quad (29)$$

$$Q_{ig_1t}, Q'_{ig_2t}, O_{jg_1t}, O'_{jg_2t}, I_{g_1t}, I'_{g_2t} \geq 0 \text{ and integer} \quad \forall i, j, g_1, g_2, t \quad (30)$$

Constraints (7) and (8) ensure that the required goods are supplied from the available suppliers, and the demand of each commodity in each period is met. Equations (9) and (10) denote the inventory flow constraints in every time period. Constraints (11) and (12) guarantee that the inventory amounts in each period meet the corresponding capacities. Constraints (13) indicate the minimum safety stock requirements for basic commodities and assets in each period. Constraints (14) show the total procurement budget (for purchasing and shipping items) in each period. According to constraints (15) and

(16), the quality level of supplied goods should be greater than the respective minimum acceptable quality level. Constraints (17)-(20) ensure that the amount of each kind of goods ordered from each supplier does not exceed the respective supplier's capacity in each period. According to constraints (21) to (24), the amount of goods ordered from a supplier should be at least equal to the minimum amount determined by that supplier in each period. Constraints (25)-(28) denote the acceptable time windows for delivery times of required goods in each period.

Finally, constraints (29) and (30) are non-negativity constraints.

**4. Numerical Example**

In this section, a practical example is considered including supply of three basic goods for a

private company engaged in oil and gas drilling. Basic materials are Drill collar, Rams and Kelly. These goods can be supplied from 3 local suppliers (A, B, C) and 2 foreign suppliers (D, E). The general characteristics of the suppliers are briefly described in Table 2.

**Tab. 2. Characteristics of local and foreign suppliers**

Supplier	Quality level	Price	Operate systematically	Environmental issues
A	High	Partially high	Medium	Medium
B	Medium (acceptable)	Reasonable	Medium	Medium
C	Medium (acceptable)	Reasonable	High	High
D	High	Partially high	Partially high	Partially high
E	Medium (acceptable)	Reasonable	Partially high	Partially high

In order to evaluate and select admissible suppliers, the priority and importance matrices of the main criteria as well as the priority matrices

of the sub-criteria for each main criterion are defined by the supplier evaluation committee's experts as follows:

$$A_{g2-LS} = \begin{bmatrix} 1 & 7 & 1 & 2 & 3 & 4 \\ & 1 & \frac{1}{8} & \frac{1}{5} & \frac{1}{3} & \frac{1}{2} \\ & & 1 & 2 & 3 & 4 \\ & & & 1 & 3 & 3 \\ & & & & 1 & 2 \\ & & & & & 1 \end{bmatrix}, \quad A_{g2-FS} = \begin{bmatrix} 1 & 7 & 2 & 5 & 5 & 3 \\ & 1 & \frac{1}{8} & \frac{1}{3} & \frac{1}{3} & \frac{1}{4} \\ & & 1 & 4 & 3 & 2 \\ & & & 1 & 2 & 1 \\ & & & & 1 & 1 \\ & & & & & 1 \end{bmatrix}$$

As seen from these two matrices, for selecting a foreign supplier, the service factor has less impact than a local one; instead, the risk factor is much more important. In addition, according to

the following chart, obtained from the prioritization matrix of the main criteria, it can be seen that the price and quality factors are more important for the supply of basic commodities.



**Fig. 2. Priority coefficients for the main criteria**

$$A_{g2-LS}^{C1} = \begin{bmatrix} 1 & 5 & 4 & 2 \\ & 1 & 1/3 & 1/5 \\ & & 1 & 2 \\ & & & 1 \end{bmatrix}, \quad A_{g2-FS}^{C1} = \begin{bmatrix} 1 & 6 & 5 & 1 \\ & 1 & 1/4 & 1/6 \\ & & 1 & 2 \\ & & & 1 \end{bmatrix}$$

$$A_{g2-LS}^{C2} = \begin{bmatrix} 1 & 3 & 2 & 2 \\ & 1 & 1/3 & 1/2 \\ & & 1 & 3 \\ & & & 1 \end{bmatrix}, \quad A_{g2-FS}^{C2} = \begin{bmatrix} 1 & 5 & 2 & 2 \\ & 1 & 1/5 & 1/3 \\ & & 1 & 3 \\ & & & 1 \end{bmatrix}$$

$$\begin{aligned}
 A_{g2-LS}^{C3} &= \begin{bmatrix} 1 & 7 & 8 & 1/2 \\ & 1 & 2 & 1/7 \\ & & 1 & 1/6 \\ & & & 1 \end{bmatrix}, & A_{g2-FS}^{C3} &= \begin{bmatrix} 1 & 4 & 6 & 1/2 \\ & 1 & 2 & 1/5 \\ & & 1 & 1/4 \\ & & & 1 \end{bmatrix} \\
 A_{g2-LS}^{C4} &= \begin{bmatrix} 1 & 5 & 4 & 3 & 6 \\ & 1 & 1/2 & 1/3 & 1/5 \\ & & 1 & 1/3 & 1/6 \\ & & & 1 & 1/3 \\ & & & & 1 \end{bmatrix}, & A_{g2-FS}^{C4} &= \begin{bmatrix} 1 & 3 & 6 & 4 & 4 \\ & 1 & 2 & 3 & 3 \\ & & 1 & 1/2 & 1/4 \\ & & & 1 & 5 \\ & & & & 1 \end{bmatrix} \\
 A_{g2-LS}^{C5} &= \begin{bmatrix} 1 & 3 & 1/3 & 5 & 6 & 3 & 1/5 \\ & 1 & 1/3 & 6 & 3 & 5 & 1/5 \\ & & 1 & 8 & 5 & 4 & 1/3 \\ & & & 1 & 1/6 & 1/4 & 1/9 \\ & & & & 1 & 2 & 1/6 \\ & & & & & 1 & 1/7 \\ & & & & & & 1 \end{bmatrix} \\
 A_{g2-FS}^{C5} &= \begin{bmatrix} 1 & 4 & 1/5 & 7 & 7 & 5 & 1/5 \\ & 1 & 1/3 & 6 & 5 & 7 & 1/5 \\ & & 1 & 8 & 5 & 7 & 1/2 \\ & & & 1 & 1/6 & 1/3 & 1/9 \\ & & & & 1 & 4 & 1/8 \\ & & & & & 1 & 1/7 \\ & & & & & & 1 \end{bmatrix} \\
 A_{g2-LS}^{C6} &= \begin{bmatrix} 1 & 1/3 & 1/5 & 1/7 & 1/9 \\ & 1 & 1/3 & 4 & 1/5 \\ & & 1 & 2 & 1/4 \\ & & & 1 & 1/7 \\ & & & & 1 \end{bmatrix}, & A_{g2-FS}^{C6} &= \begin{bmatrix} 1 & 1/4 & 1/9 & 1/5 & 1/8 \\ & 1 & 1/2 & 3 & 1/2 \\ & & 1 & 4 & 3 \\ & & & 1 & 1/4 \\ & & & & 1 \end{bmatrix}
 \end{aligned}$$

The average scores given by the supplier evaluation committee to the suppliers in each sub-criteria are presented in Table 3.

**Tab. 3. Scores of suppliers in each sub-criterion**

Sub-Criteria	Suppliers				
	A	B	C	D	E
SC1	5	3	4	5	3
SC2	3	2	3	3	2
SC3	4	2	3	4	2
SC4	4	2	3	3	2
SC5	2	3	4	4	4
SC6	3	2	4	4	5
SC7	1	1	3	4	4
SC8	1	2	3	4	3
SC9	2	5	3	2	5
SC10	3	4	3	2	2
SC11	3	3	3	3	3

SC12	3	4	4	3	4
SC13	4	3	4	4	4
SC14	2	2	3	3	3
SC15	3	2	3	4	4
SC16	2	3	2	4	4
SC17	3	3	3	2	2
SC18	4	3	3	3	3
SC19	5	4	3	4	4
SC20	2	2	4	4	4
SC21	1	2	4	3	3
SC22	1	1	3	3	3
SC23	2	3	4	3	3
SC24	3	2	3	3	3
SC25	5	4	4	2	3
SC26	5	5	5	3	2
SC27	3	3	3	2	2
SC28	4	5	4	1	1
SC29	4	4	5	4	3

The required data and parameters related to the case study are provided in Appendix A.

### 5. Results and Discussion

Acceptable level of determining local and global admissible suppliers is considered as 0.6, and

perfect score of supplier selection process is 30. Based on the available information, the results of supplier evaluation using AHP is presented in Figure 3.



Fig. 3. Supplier evaluation according to AHP method

Accordingly, the suppliers' scores are as follows:  
 $w_1 = 18$ ,  $w_2 = 17.397$ ,  $w_3 = 20.689$ ,  $w_4 = 19.241$ ,  $w_5 = 18.62$

Since supplier B score is less than the permissible score, it is placed in the list of unacceptable suppliers.

After determining the admissible suppliers, to find the best order allocation pattern, the model

presented is coded in the GAMS optimization software and solved using the real data presented in the appendix.

The model is solved within the computational time of 13.26 seconds, and the results are as follows.

Number of units of good  $g_2$  supplied from vendor  $i$  in period  $Q_{ig_2t}$ :

		1	2	3	4
1	1			30	20
1	2	20			20
2	1	25		25	25
2	3	25	25	25	25

Number of units of good  $g_2$  supplied from vendor  $j$  in period  $t$   
 $O_{jg_2t}$ :

		1	2	3	4
1	1	50		50	50
1	2	50	50	50	50
1	3	50	50	50	50
2	1	55	55	55	55
2	2	55	55	55	55
2	3	55	55	55	55

Objective function values:

$$\text{Total Costs: } Z_1 = TCP + TCT + TCW$$

$$TCP = 614500, \quad TCT = 124300, \quad TCW = 15850 \quad \xrightarrow{\text{yields}} \quad Z_1 = 754650$$

$$\text{Total Risks: } Z_2 = 235.5$$

$$\text{Total value of purchasing: } Z_3 = 26532.1$$

**Tab. 4. Scores of suppliers in factors corresponding to the objective functions of the mathematical model**

Factor	Local Suppliers ( <i>i</i> )		Global Suppliers ( <i>j</i> )	
	1	2	1	2
Cost	11	16	10	14
Risk	21	21	12	11
Evaluation score	18	20.689	19.241	18.62

After analyzing the optimal order quantities assigned to the candidate suppliers and taking into account the scores of suppliers in each evaluation criterion corresponding to the objective functions of the mathematical model (Table 4), the following consequences could be concluded:

The second local supplier outperforms the first local supplier in two factors and is similar to the first supplier in another factor. Therefore, as expected, a higher order quantity would be assigned to the second supplier. For foreign suppliers, although the second supplier has a less evaluation score than the first supplier, it would have higher order quantity due to its better score in the cost criterion (as it is one of the main objective functions of the mathematical model and, also, is the most important supplier evaluation criterion with the highest weight among all the evaluation criteria).

In addition, the optimal amount of goods supplied from foreign suppliers is more than that of local suppliers, because the foreign suppliers generally have more appropriate procuring costs and, as already stated, the cost factor has the highest weight among all the evaluation criteria; moreover, it is considered as one of the main objective functions of the problem model.

## 6. Conclusion and Future Researches

In this paper, a novel SS&OA problem was addressed under the risk of sanctions tailored for Iran's Oil & Gas Drilling Industry. A three-objective MILP was developed whose objectives were: minimization of total cost, including the purchasing, transportation and inventory holding costs; minimization of total supply risks; maximization of total value of purchasing. In the proposed study, two general classes of items and two different classes of suppliers were considered. In order to evaluate and select the admissible suppliers, AHP technique was used. A numerical example was presented to demonstrate the applicability of the proposed model whose instance was solved by GAMS optimization software in a few seconds.

For further research, some possible directions could be considered. First of all, the evaluation process can be performed in two phases, including the initial and periodic (after purchase) evaluations at appropriate time intervals due to the possibility of identifying new potential suppliers and the possibility of changing conditions and criteria used in the evaluation of existing suppliers.

Secondly, due to the lack of accurate and precise data in practice, extending the current model to

cope with uncertain data could be a valuable avenue for further research. Furthermore, the model can be extended by considering “quantity discounts or business volume discounts. Finally, considering “payment terms” and “conditions, in which a supplier is able to respond to a certain set of goods (not all demands)”, could lead to a more realistic model.

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**Appendix A-** Case study data

There are four seasonal time periods.

Unit cost of transportation goods ( $g_2$ ) from vendor  $i$  in period  $t$

$c(i, t)$ :

	1	2	3	4
1	20	20	40	30
2	20	20	30	20

Unit cost of transportation goods ( $g_2$ ) from vendor  $j$  in period  $t$

$c(j, t)$ :

	1	2	3	4
1	80	80	80	80
2	100	100	100	100

Unit price of good  $g_2$  from supplier  $i$  in period  $t$

$p_{ig_2t}$ :

	1	2	3	4
1.1	500	500	500	500
1.2	300	300	300	300
1.3	650	650	650	650
2.1	450	450	450	450
2.2	350	350	350	350
2.3	550	550	550	550

Unit price of good  $g_2$  from supplier  $j$  in period  $t$

$f_{jg_2t}$ :

	1	2	3	4
1.1	550	550	550	550
1.2	300	300	300	300
1.3	600	600	600	600
2.1	400	400	400	400
2.2	250	250	250	250
2.3	500	500	500	500

Quality level of good  $g_2$  from supplier  $i$  in period  $t$

$a_{ig_2t}$ :

	1	2	3	4
1.1	0.95	0.95	0.95	0.95
1.2	0.9	0.9	0.9	0.9
1.3	0.95	0.95	0.95	0.95
2.1	0.85	0.85	0.85	0.85
2.2	0.9	0.9	0.9	0.9
2.3	0.8	0.8	0.8	0.8

Quality level of good  $g_2$  from supplier  $j$  in period  $t$

$b_{jg_2t}$ :

	1	2	3	4
1.1	0.97	0.97	0.97	0.97
1.2	0.92	0.92	0.92	0.92
1.3	0.92	0.92	0.92	0.92
2.1	0.85	0.85	0.85	0.85
2.2	0.85	0.85	0.85	0.85
2.3	0.8	0.8	0.8	0.8

Risk percent of purchasing one unit of good  $g_2$  from supplier  $i$  in period  $t$

$r_{ig_2t}$ :

	1	2	3	4
1.1	0.1	0.1	0.1	0.1
1.2	0.1	0.1	0.1	0.1
1.3	0.1	0.1	0.1	0.1
2.1	0.1	0.1	0.1	0.1
2.2	0.1	0.1	0.1	0.1
2.3	0.1	0.1	0.1	0.1

Risk percent of purchasing one unit of good  $g_2$  from supplier  $j$  in period  $t$

$s_{jg_2t}$ :

	1	2	3	4
1.1	0.15	0.15	0.15	0.15
1.2	0.15	0.15	0.15	0.15
1.3	0.15	0.15	0.15	0.15
2.1	0.2	0.2	0.2	0.2
2.2	0.2	0.2	0.2	0.2
2.3	0.2	0.2	0.2	0.2

Minimum required goods ( $g_2$ ) to order from local supplier (1) in each period is equal to 20 and from local supplier (2) in each period is equal to 25.

Minimum required goods ( $g_2$ ) to order from foreign supplier (1) in each period is equal to 50 and from local supplier (2) in each period is equal to 55.

Demand of good  $g_2$  in period  $t$

$D_{g_2t}$ :

	1	2	3	4
1	130	55	160	150
2	125	105	105	125
3	130	130	130	130

Warehouse capacity for class 2 goods (G2) in each period is equal to 200.

Capacity of supplier  $i$  for good  $g_2$  in period  $t$

$k_{ig_2t}$ :

	1	2	3	4
1.1	200	200	200	200
1.2	150	150	150	150
1.3	150	150	150	150
2.1	200	200	200	200
2.2	150	150	150	150

2.3	150	150	150	150	Earliest delivery date for good $g_2$ is considered as the 3 <sup>rd</sup> week in each period.
Capacity of supplier $j$ for good $g_2$ in period $t$					Latest delivery date for good $g_2$ is considered as the 7 <sup>rd</sup> week in each period.
$v'_{jg_2t}$ :					Lead time for good $g_2$ delivered by local supplier $i$
1	2	3	4		$LT^L_{ig_2}$ :
1.1	200	200	200	200	1 2 3
1.2	150	150	150	150	1 4 5 4
1.3	150	150	150	150	2 5 5 6
2.1	200	200	200	200	Lead time for good $g_2$ delivered by foreign supplier $j$
2.2	150	150	150	150	$LT^F_{jg_2}$ :
2.3	150	150	150	150	1 2 3
Total budget of buyer for purchasing and transporting items in period $t$					1 5 6 6
$TB_t$ :					2 6 7 6
1; 500000					Unit warehouse holding cost for inventory of good (1) in each period is equal to 10, for good (2) is equal to 15, and for good (3) is equal to 20.
2; 400000					
3; 350000					
4; 500000					
Minimum acceptable quality level of class 2 items ( $G_2$ ) is equal to 0.85					

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