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Optimizing Production Planning and Supplier Selection in Petrochemical Supply Chains

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Abstract

In this research, the intricate world of the petrochemical supply chain was delved into, with a focus on the critical problem of production planning and supplier selection. The aim was to identify effective factors that contribute to the continuous supply chain process of petrochemical production. The study was conducted in two phases, first, the Analytic Hierarchy Process (AHP) method was employed to identify the best suppliers. In the second phase, an innovative model was developed to optimize production planning. The primary objective was to minimize the total cost associated with ordering, holding, and production. To ensure the practicality and relevance of the model, several constraints were incorporated. The results obtained from the AHP method revealed that Shiraz Petrochemical emerged as the optimal supplier for urea, Khorasan Petrochemical for ammonia, and Ilam Petrochemical for sulfur. Additionally, the optimization model provided valuable insights into the optimal production quantities, raw material procurement volumes, and raw material inventory levels for each period.

Keywords:
Production planning
Supplier selection
Petrochemical industry

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INTRODUCTION

In the petrochemical industry, making strategic decisions and planning for business is a challenging task, particularly in an ever-changing and uncertain market. The industry's sustainable profitability depends on its ability to provide a consistent supply of affordable raw materials, which is becoming increasingly important due to growing competition. To achieve this, companies must use sophisticated business models and precise optimization tools (Varma et al., 2007). The logistics and production planning involved in refinery and petrochemical processes present significant challenges (Kim et al., 2012). In the past, procurement and production activities were performed separately, which could lead to suboptimal performance and overall poor results (Goyal & Deshmukh 1992). To avoid this, it is essential to integrate these two activities since the ordered quantities of raw materials depend on the production quantities of the final product. So, Production planning is a crucial strategy for maintaining profit margins in the industry. It encompasses several decision-making issues, including resource management, product quality management, and inventory management based on market conditions (Kwon et al., 2020). Linear programming is a mathematical optimization technique that can be used to optimize production planning. Linear programming involves finding the best combination of inputs that yield the highest output while considering constraints such as production capacity and available resources (Akkerman, et al., 2010) and transportation (Niu, et al., 2017).

However, relying solely on the opinions of experts to establish the constraints and objectives of the linear programming model can lead to biased or incomplete results. To overcome this limitation, the Analytic Hierarchy Process (AHP) method can be used to incorporate the preferences and judgments of multiple stakeholders in the production planning process. AHP is a decision-making tool that allows decision-makers to evaluate and prioritize multiple criteria in a structured and systematic way (Saaty, 2008). AHP can help in determining the relative importance of each objective and constraint in the production planning process, which can then be used as input parameters in the linear programming model.

The problem of determining optimal production planning targets in process industries such as petrochemicals is challenging because it requires the integration of production planning, scheduling, purchasing and material requirement planning. In this study, the developed optimization model was carried out with the aim of managing production and procurement problems in an integrated manner. Considering the tactical decisions required for the timing and volume of purchases of multiple raw materials, where various products were delivered to customers. An AHP process was also used to evaluate the important criteria related to the selection of different suppliers. Then, the developed model was verified through a case study using the petrochemical industry. Finally, a sensitivity analysis was performed. The need for such study comes from the fact of integrating supplier selection decisions influence production planning decisions in the petrochemical industry. The main contributions of this study that differentiate it from the available works in the literature include:

- Developing an approach based on AHP and mathematical programming methods for the integration purpose
- Applying the proposed approach in the petrochemical industry.

RELATED LITERATURE

Studies in the fields of supplier selection and production planning can be divided into three categories: The first category includes studies that have focused on the issue of supplier selection. For example, Ghorbani et al. (2012) propose a two-phased model for supplier selection and order allocation, which is a multiple criteria decision-making problem affected by conflicting factors. In the first phase, suppliers are evaluated based on qualitative and quantitative criteria obtained from SWOT analysis, and the Shannon entropy method is used to calculate the weight of the criteria. In the second phase, an integer linear programming (ILP) model is used to allocate orders to the selected suppliers based on the results of the first phase, and Razmi and Maghool (2010) proposed a metaheuristic model to select suppliers and determine procurement plans under two types of discount offers. In this paper, a fuzzy bi-objective model is proposed for supplier selection and purchasing problem considering multiple items, multiple periods, capacity constraints, and budget limitations. The model considers different types of discounts, such as all-unit discounts, incremental discounts, and total business volume discounts, and different payment methods proposed by each supplier. The efficiency of each method is tested using an additive utility function offered by the decision maker. Wang et al. (2020) focus on supplier evaluation and selection in the oil industry. It proposes a Multi-Criteria Decision-Making (MCDM) model that integrates the Supply Chain Operation Reference (SCOR) model, Analytic Hierarchy Process (AHP), and the Data Envelopment Analysis (DEA) method. The SCOR model is used to determine evaluation criteria; AHP assigns weights to the criteria, and DEA ranks the suppliers. The study identifies the best suppliers based on the model's implementation and results. Islam et al. (2021) introduce a two-stage solution approach for supplier selection and order allocation planning, considering uncertain demand. It integrates a forecasting procedure with an optimization model. A novel Relational Regress or Chain method is proposed for demand forecasting. In the second stage, a multi-objective programming model is developed to identify suitable suppliers and order quantities. The study compares different forecasting methods and evaluates their impact on supplier selection and order allocation. Mina et al. (2021) focus on the selection of circular suppliers for collaboration in environmentally friendly operations. It integrates Multi-Criteria Decision-Making (MCDM) methods and a fuzzy inference system (FIS) to evaluate and rank suppliers in the circular supply chain. The fuzzy analytic hierarchy process (FAHP) method is used to determine criteria weights, and the fuzzy technique for order of preference by similarity to the ideal solution (FTOPSIS) is used to calculate scores for each supplier. The final ranking is determined using a FIS. Rezaei et al. (2021) address supplier selection and order allocation in a centralized supply chain, considering disruption and environmental risks. The study proposes a mixed-integer nonlinear programming model that incorporates risk reduction strategies and suppliers' reliability. The strategies include protected suppliers, back-up suppliers, additional capacity reservations, emergency stock, and geographical separation. The reliability of suppliers is considered using the failure mode and effects analysis technique. The proposed model is applied to a case study, and the results demonstrate the effectiveness of the risk reduction strategies. Ishizaka et al. (2023) focus on supplier selection in a closed-loop pharmaceutical supply chain. It presents a hybrid framework that combines the best-worst method (BWM) and the geometrical analysis for interactive aid (GAIA) plane. The BWM is used to evaluate supplier performance based on multiple criteria, and the GAIA plane visualizes the results. The study applies this methodology to evaluate the performance of five suppliers in the pharmaceutical industry. Liu et al. (2023) address the supplier selection problem under uncertainty in the public transport production industry. The study proposes a sustainable supplier selection model that incorporates economic, energy, and quality aspects. The multi-objective particle swarm optimization (MOPSO) method is employed to solve the problem. The model helps reduce supply chain risks and incorporates sustainability into supplier selection, considering design uncertainty and the environmental dimension. Ali et al. (2023) focus on global supplier selection and order allocation in an environment-friendly supply chain. The study proposes an integrated approach that combines fuzzy analytical hierarchy process (FAHP), fuzzy technique for order preference by similarity to the ideal solution (FTOPSIS), and multi-choice goal programming (MCGP). FAHP is used to calculate criteria weights, FTOPSIS evaluates supplier performance, and MCGP allocates optimal order quantities. A case study in the automotive industry demonstrates the effectiveness of the proposed approach.

The second category comprises studies that have addressed the problem of production planning. For example, Chauhan and Kotecha (2016) discuss in their article the use of evolutionary computation techniques to solve the combinatorial optimization problem of determining optimal production planning. The authors present a strategy that enables the efficient use of evolutionary algorithms for solving single-level production planning problems. They demonstrate the effectiveness of this strategy using the Moth-flame optimization technique and show that it consistently solves the production planning problem. Duckwen et al. (2017) present a new formulation for optimizing production planning and blending problems in conventional oil reservoirs with fixed topology. The proposed model considers the production of each well and the blending of crude oils to meet client sulfur requirements. It also takes into account the nonlinear behavior of well-flowing pressure over time and uses Generalized Disjunctive Programming and mixed integer nonlinear programming to formulate the problem. The numerical results of this model show that sulfur specification affects well production planning. Kadambur and Kotecha (2016) propose a mathematical formulation for determining more profitable production plans in a petrochemical industry using multiple levels. The benefits of the proposed formulation are demonstrated through eight case studies taken from the literature, which showed an improvement of up to 16.31% in profit. Kwon et al. (2020) present a new decision-making framework for resource and production planning in the petrochemical industry that undervalues uncertainty. Their model is developed using mixed integer linear programming to establish optimal operational strategies for a given inventory capacity. The proposed model is applied to a real petrochemical plant producing six different products, resulting in a 5.50% improvement in total sales and a 13.8% increase in operating profit compared to the Business as Usual (BAU) case. Sung and Maravelias (2007) present a novel approach for solving production planning problems for multiproduct processes using a mixed-integer programming (MIP) scheduling model. This model also presents a rolling horizon algorithm for generating detailed schedules if necessary. Zhao et al. (2017) propose a multi-period enterprise-wide mixed-integer nonlinear programming (MINLP) model to optimize the processing units in the refinery and ethylene plant simultaneously. Results show that the integrated approach improves overall profit compared to the traditional sequential approach, and Al-Sharrah et al. (2006) describe the application of multi-objective optimization tools to plan a mixed-integer model of a petrochemical industry. The main objectives of the optimization were to maximize economic gain while minimizing the risk of plant accidents. The resulting Pareto optimal solutions were analyzed using an economical strategic tool to make the final decision. The proposed procedure was applied to the petrochemical industry in Kuwait and was successful in defining a balanced petrochemical network with acceptable risk. In the study by Kwon et al. (2022), a decision-supporting platform for supply chain management in the petrochemical industry is proposed. The platform integrates various decision-supporting models to address challenges both vertically and horizontally in the supply chain. The platform effectively supports supply chain management, plant planning, and process operation strategy, resulting in improved business profits. Tarei et al. (2022) address the petroleum supply chain network design problem, considering various uncertainties. They propose a Mean-Variance robust optimization model to minimize both operational risk and supply chain cost simultaneously. The results show a trade-off between supply chain cost and risk, and the model provides insights into managing operational risks while considering risk aversion levels. Karimi et al. (2022) focus on the quantification of the positive effects of flexibility dimensions in production planning. They propose a bi-objective mathematical model and employ two metaheuristic algorithms to solve it. The results demonstrate that applying the flexible model leads to a reduction in costs. Hamta et al. (2023) present a case study of HEPCO Company, focusing on the optimization of the supply chain design for assembled products. By using a three-level model and an integer-linear mathematical model, they aim to reduce the total cost of the supply chain. The results demonstrate a significant reduction in costs compared to conventional methods. In the research by Ding et al. (2023), a mathematical model is proposed to optimize economic ordering with preventive maintenance in a supply chain. The model considers production quantity, inventory ordering, and preventive maintenance to minimize costs. The results indicate that longer preventive maintenance periods increase reliability but also lead to higher total costs.

The third category encompasses studies that have simultaneously tackled both supplier selection and production planning. For example, Chen et al. (2023) propose a novel multi-objective mixed integer linear programming model to address the undefined mathematical relations between supplier capacities, material supply shortages, and the impact of material delays on construction projects. The model integrates decisions regarding supplier selection, inventory management, order quantities, and material order splitting. It optimizes the trade-off between overall procurement cost and weighted lateness, considering material prices, supplier capacities, and resulting delays as fuzzy scenario-based parameters. The model's performance is validated through computation experiments on a numerical example. Sensitivity analysis demonstrates that considering high variations in uncertain supplier capacities leads to lower procurement costs and less significant delay impacts. Moreover, greater variations in uncertain material prices increase the total procurement cost by 55%, while greater variations in uncertain delay durations increase the weighted lateness by over 70%. The paper emphasizes the importance of accurate estimates for uncertain parameters and highlights the superiority of the proposed scenario-adjusted model in solving supplier selection and material purchasing problems in construction supply chains. Shadkam (2023) addresses the complex and conflicting objectives involved in selecting the best supplier in the supply chain. The paper introduces a new approach called COTOP, which is a hybrid method combining the cuckoo optimization algorithm (COA) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The proposed COTOP method is applied to the evaluation and selection of suppliers. The results demonstrate the efficiency of the algorithm in solving multi-objective problems and its ability to identify the Pareto frontier. The use of the COA enables the method to handle large-scale problems, while the TOPSIS method removes concerns regarding the number of objective functions. Ustun and Demı (2008) propose an integrated approach of analytic network process (ANP) and multi-objective mixed integer linear programming (MOMILP) for supplier selection, which considers both tangible and intangible factors and defines the optimum quantities among selected suppliers to maximize the total value of purchasing (TVP) while minimizing the total cost and total defect rate and balancing the total cost among periods. ANP is used to calculate priorities for each supplier based on 14 criteria involved in four clusters: benefits, opportunities, costs, and risks (BOCR). The priorities of suppliers are used as parameters for the first objective function, and the multi-objective and multi-period problem is solved. The proposed approach is applied to four different plastic molding firms working with a refrigerator plant, and the results show its effectiveness in real-life supplier selection problems.

These studies provide valuable insights and methodologies for addressing the challenges of supplier selection and production planning in various industries. They offer decision-support tools and optimization models that can assist practitioners in making informed decisions and improving operational efficiency. So, the current study uses the AHP process to evaluate the important criteria related to the selection of different suppliers and, based on these results, develops an optimization model for production planning in the petrochemical industry.

PROBLEM STATEMENT AND CASE STUDY

Urmia Petrochemical Plant has been built on a 110-hectare land in the southwestern part of Urmia, located 30 kilometers from the Urmia-Mahabad highway. The plant includes a 50-hectare industrial area, 60 hectares of green space, and wastewater treatment pools. The raw materials of the Urmia petrochemical unit are sulfur, urea and ammonia. These materials are converted into melamine, ammonium sulfate and sulfuric acid products during chemical processes. Urmia's petrochemical production and supply chain are presented in Fig. 1. After sending the orders, the surplus of final products produced is stored in the warehouses of the production unit. The considered planning horizon is one year, and each month is calculated as a time period, so we have 12 time periods. The proposed model is able to optimize the following decision variables: the purchase amount of each raw material, Production quantities of each of the final products, Inventory amount of each raw material, and Amount of each final product.

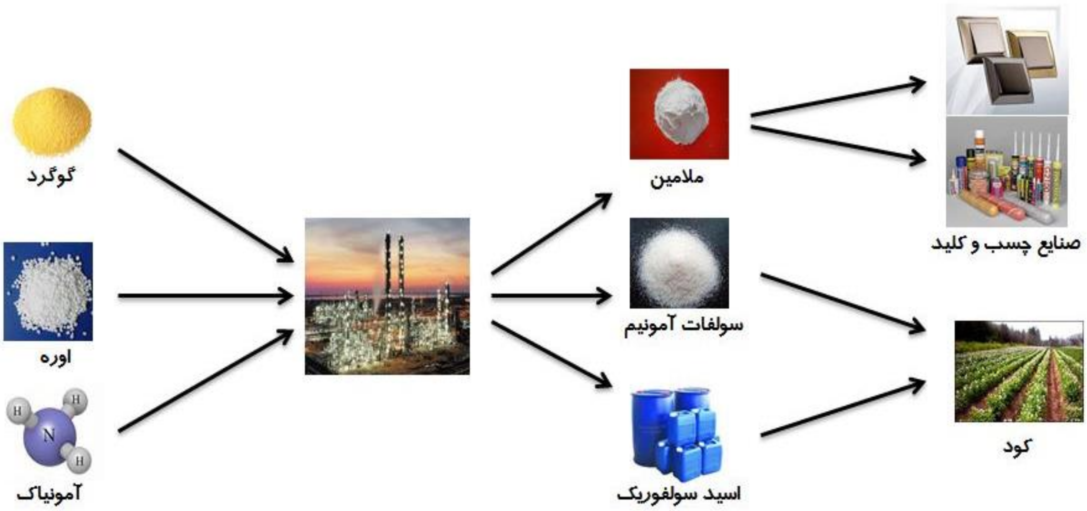

Fig. 1. Urmia's petrochemical production and supply chain

RESEARCH METHODOLOGY

The current research is a part of applied and developmental research. This research has been done in two phases. In the first phase, experts' opinions have been collected using the field method and questionnaire tool. In the second phase, modeling has been done to provide optimal production planning. The problem-solving approach in this research is presented in Fig. 2.

Phase 1: Calculate the weight vector of criteria via AHP

Step 1: Identification of alternatives
Step 2: Determination of principle criteria
Step 3: Formation of decision matrix
Step 4: Determination of criteria weights by AHP

Phase 2: Optimization of production planning

Step 1: Creating a linear optimization model based on the output of phase 1
Step 2: Validation of the model with the opinion of company managers
Step 3: Data collection
Step 4: Run the Model, results analysis, sensitivity analysis
Step 5: Providing management recommendations

Fig. 2. Problem-solving approach

Phase 1: Calculate the weight vector of criteria via AHP

The AHP method is in accordance with the opinion of experts, which means that the questionnaire of paired comparisons should be provided to experts and experts specific to the subject. In this research, 7 evaluation criteria were extracted from different articles. These criteria include the following:

- Delivery performance: requires timely delivery of raw materials according to schedule
- How to pay: Pay the amount of the purchased materials in installments
- Payment policies: the possibility of discounts in the type of purchase of raw materials
- Product quality: the degree of quality of purchased materials
- Credibility and work records: commitment to the concluded contracts according to the credit of the supplier
- Geographical location: the time interval depends on the ratio of distance in the delivery of raw materials
- Clean producer: compliance with environmental principles and valid standards

A questionnaire of paired comparisons of evaluation criteria for ranking suppliers was prepared and provided to the managers of the production and purchasing departments and the general manager of Urmia Petrochemical Unit. Analysis and results of the AHP method were obtained using Expert Choice software.

Phase 2: Optimization of production planning

In this section, we have defined the symbols, parameters, and decision variables for an optimization model for production planning and then the objective function and constraints are described mathematically, providing a framework for implementing the model in practice.

Definition of symbols:

Indices

I	Index of raw materials
J	Index of suppliers
K	Index of final production materials
T	Index of time period
R	Index of distance discounts

Definition of Parameters:

TC	Total Cost
TCO	Total cost of ordering
TCP	Total cost of production
TCH	Total cost of holding
x_{it}	The purchase price of raw material i in period t
a_{it}	Purchase amount of raw material i in period t
o_{it}	The cost of ordering product i in period t
pc_{kt}	Production cost of product k in period t
hf_{kt}	Cost of maintaining product k in period t
p_{kt}	Inventory amount of product K in period t
cap_t	Production capacity in period t
s_{kt}	Warehouse capacity for product k in period t
cap_{kt}^2	The production capacity of the final product k in the period t
vr_i	Unit index of required storage space for raw material i
W_k	The amount of storage space for the final product k
vf_k	Index of the storage space of the final product k
W_i	Amount of storage space for raw material i
d_{it}	The total demand of raw material i in period t
$d_{k,t}$	Demand quantity of final product k in period t
M_{jt}	The minimum order quantity of supplier j in period t
N_{jt}	The maximum order amount of supplier j in period t
$SS_{k,t}$	Safety stock capacity for product k in period t

Definition of Decision Variables:

q_{it}	The amount of raw material i to be purchased in period t
p_{kt}	The amount of the final product k in the period t
$Ir_{i,t}$	The amount of inventory of raw material i in period t
q_{ijt}	The amount of Purchase of raw material i from supplier j in period t

If_{kt} The amount of inventory of manufactured product k in period t

The proposed model

The objective function

The value of the objective function includes Total cost of ordering (TCO), Total cost of production (TCP), and Total cost of holding (TCH). Each of these branches of costs is calculated separately and is included in Eq. 1. Our goal in this equation is to reduce each of the costs as much as possible in the optimal mode of production.

$$TC = TCO + TCP + TCH \quad (1)$$

Total cost of ordering (TCO)

The total ordering cost includes the ordering cost and the purchase cost of raw material i in each period. The purchase cost is such that the purchase amount of each raw material is multiplied by the unit cost, which is calculated in Eq. 2.

$$TCO = \sum_i \sum_t a_{it} x_{it} + \sum_i \sum_t a_{it} . o_{it} \quad (2)$$

Total cost of production (TCP)

The total production cost includes the production cost of all products during the period. The production cost is calculated by multiplying the unit production cost of each product by the total amount of product production, and the total production costs of the products are obtained.

$$TCP = \sum_k \sum_t pc_{kt} . p_{kt} \quad (3)$$

The cost of holding the final manufactured products is caused by product storage and other costs related to the product. The cost related to this part is calculated in such a way that the unit cost of maintaining each of the products is multiplied by the total amount produced, and the total cost of maintaining the products is placed in objective function 1.

$$TCH = \sum_k \sum_t hf_{kt} If_{kt} \quad (4)$$

Constraints

Raw material constraint

At the stage of purchasing raw materials, some of the purchased material may still be available in the warehouse from the previous period, and this amount will be entered into the calculation section for production in the next period. This amount is considered as $Ir_{i,t-1}$. The amount required to buy raw material i from supplier j in period t is calculated as $\sum_j q_{ijt}$. Also, the remaining amount of raw material i in the current period t is deducted from the final amount, which is equal to the sum of the multiplication of the amount of raw material i needed to produce product k by the production amount of product k in period t.

$$Ir_{i,t-1} + \sum_j q_{ijt} - Ir_{it} = \sum_k b_{ik} . p_{kt} \; \forall i, t \quad (5)$$

Demand constraint

There is a limit to the amount of demand for production in each period. The amount of inventory of the final product k remaining from the previous period $If_{k,t-1}$ together with the amount of production of the final product k in the current period p_{kt} can answer the amount of demand for the final product k by the buyer c in the period t in the form of $d_{k,t}$. The remaining amount of the product If_{kt} is also kept in the warehouse in case of a decrease in demand for the next period.

$$If_{k,t-1} + p_{kt} - If_{kt} = d_{k,t} \forall k, t \quad (6)$$

Production Capacity Constraint

The production capacity of products in the factory has logical limits. The production limit of product k in period t, which is entered as p_{kt}, must be less than or equal to the production capacity of product k in the same period.

$$p_{kt} \le cap^2_{kt} \quad \forall k, t \quad (7)$$

Raw material storage space constraint

The amount of storage space for stockpiling purchased materials is limited. The amount of storage space for raw material i in period t as Ir_{it} must be less than or equal to the storage volume of raw material i. The unit equality index vr_i should also be considered.

$$\sum_i vr_i . Ir_{it} \le W_{i,t} \qquad \forall t \quad (8)$$

Storage space for manufactured products constraint

The amount of storage space for products k produced in period t, which has the value of If_{kt}, is limited and depends on the storage space of product k in the form of W_k. The equality index vf_k of the product storage unit is also considered for the warehouse.

$$\sum_{k} vf_k . If_{kt} \leq W_k \quad \forall t \qquad (9)$$

Supplier constraints

Suppliers usually specify a minimum purchase amount for buying raw materials, which is calculated as a minimum order constraint in equation 10. The order quantity for raw material i from supplier j in period t is determined as q_{ijt}, which must be greater than the minimum order amount of supplier j in period t. Additionally, suppliers have production constraints in the supply of raw materials, which are considered in Eq. 11.

$$q_{ijt} \geq M_{jt} \quad \forall i, j, t \qquad (10)$$

$$q_{ijt} \leq N_{jt} \quad \forall i, j, t \qquad (11)$$

Constraint of having safety inventory

In case of any problem arising for a production unit, having inventory of the final product is necessary to respond to market demand. In this company, safety inventory has been considered in equation 12 for this purpose.

$$if(k,t) \geq SS_{k,t} \;\; \forall k, t \qquad (12)$$

The proposed model considers the main limitations and constraints of the petrochemical industry for production planning purposes. The decisions related to the amount of production, inventory, supply and transportation are optimized through the proposed model.

RESULTS

The output results of the AHP method for selecting suppliers, obtained by entering questionnaire information into the Expert Choice software, are shown in Table 1. For example, for the urea raw material supplier among the 3 options of Shiraz Petrochemical, Razi Petrochemical, and Khorasan Petrochemical, Shiraz Petrochemical with a score of 0.693 has been selected as the first choice for the purchase location, and Khorasan Petrochemical with a score of 0.22 and Razi Petrochemical with a score of 0.087 have obtained lower scores.

Table 1: results of AHP method

Criteria	Delivery performance	Payment method	Payment policies	Product quality	Credibility and work experience	Geographical location	Cleaner production
Weight	0.099	0.040	0.038	0.258	0.210	0.228	0.126

Sulfur	Score	Ammonia	Score	Urea	Score
Khangiran Refinery	0.149	Razi Petrochemical	0.111	Shiraz Petrochemical	0.693
Tabriz Refinery	0.177	Pardis Petrochemical	0.146	Razi Petrochemical	0.087
Ilam Refinery	0.203	Shiraz Petrochemical	0.164	Khorasan Petrochemical	0.22
Arak Refinery	0.101	Marvdashat Petrochemical	0.123		
Isfahan Refinery	0.123	Khorasan Petrochemical	0.241		
Tondguyan Refinery	0.166	Kermanshah Petrochemical	0.215		
Pars Jonoubi	0.081				

The results of AHP suggest that the quality of the product and the supplier's location, credibility, and work experience are the most important factors to consider when selecting a supplier for the petrochemical production process. These findings can be used to guide the supplier selection process and ensure that the most important criteria are given the appropriate weight in the decision-making process.

The results of the AHP method indicate that Shiraz Petrochemical has been selected as the best supplier for urea raw material, Khorasan Petrochemical for ammonia, and Ilam Refinery for sulfur. The results of the hierarchical analysis for production planning are used as inputs for our model. In production planning, we encountered various logical constraints and tried to consider most of them. Constraints related to raw materials, demand, production capacity, available space for storing raw materials and final products, constraints on suppliers in supplying raw materials, and the requirement for safety inventory are included in this model. The objective function of the developed model in this study consists of the sum of the costs of raw material ordering, production costs, and material holding costs. The model was coded in GAMS software, and the results are presented in Tables 2 and 3.

Table 2: Results obtained for the objective function and decision variables

objective function				Optimal Results		
Total cost (Rials)				2565430000000		
	Optimum purchase quantities of each raw material			Optimum amounts of products		
Period	urea	Sulfur	Ammonia	Ammonium Sulfate	Sulfuric Acid	Crystal Melamine
$t = 1$	5241740	14763080	7021080	3271340	4110200	328400
$t = 2$	6213600	14996000	6977600	3332000	4166000	313600
$t = 3$	4156200	15298000	6816200	3331000	4018000	304200
$t = 4$	6331000	14200000	6999000	3333000	4067000	333000
$t = 5$	4134000	15123600	6605000	3136000	4125800	333000
$t = 6$	6231160	14170400	7033360	3279000	4106200	325360
$t = 7$	4279280	14878400	6840380	3333000	4106200	324380
$t = 8$	6227560	15458800	7131760	3333000	4096400	315760
$t = 9$	4331000	14898000	6849000	3333000	3333000	333000
$t = 10$	5327520	14082400	6998420	3333000	4008200	332420
$t = 11$	6232000	15162800	6801000	3234000	4047400	333000
$t = 12$	4237120	14021600	6873720	3273200	4037600	327320

Table 2 provides the optimal purchase quantities of each raw material (urea, ammonia and sulfur) from suppliers at each time period to minimize the total cost of production while satisfying the considered constraints. The optimal amounts of products to produce in each time period are also provided.

Table 3: Optimal results of inventory amounts

	Optimum inventory quantities of each raw material			Optimum inventory of products		
Period	urea	sulfur	Ammonia	Ammonium Sulfate	Sulfuric Acid	Crystal Melamine

$t = 1$	0	0	150000	5000	33400	5000
$t = 2$	1000000	0	150000	5000	5000	5000
$t = 3$	0	600000	0	102000	5000	15200
$t = 4$	1000000	0	0	5000	5000	15000
$t = 5$	0	600000	0	5000	5000	5000
$t = 6$	1000000	0	150000	50000	5000	5000
$t = 7$	0	0	0	100000	5000	5000
$t = 8$	1000000	600000	150000	101000	5000	6180
$t = 9$	0	600000	0	53000	5000	5000
$t = 10$	0	0	0	5000	5000	15000
$t = 11$	1000000	600000	0	5000	5000	5000
$t = 12$	0	0	0	5000	5000	5000

The optimal inventory levels for each product and raw material at each time period are also given in Table 3. These levels ensure that there are enough inventories to meet the demand in the next time period while minimizing the total costs. Overall, the results of the optimization model provide a framework for efficient and cost-effective production planning, taking into account demand, supply, and capacity constraints. The results can be used to guide the decision-making process and optimize the production process to minimize costs.

SENSITIVITY ANALYSIS

The importance of sensitivity analysis arises from the fact that, under certain conditions and assuming the other variables remain constant, by changing an independent variable, we can determine the effect on the dependent variables. In evaluating the behavior of a system, sensitivity analysis measures the response of the system's output to the values of input and independent variables to which it is sensitive.

Sensitivity Analysis of the Increase in Raw Material Prices

In Figure 3, the impact of increasing raw material prices on the total cost while other influential factors remain constant is shown. This increase has been analyzed for changes of +5%, +10%, +20%, and +30%.

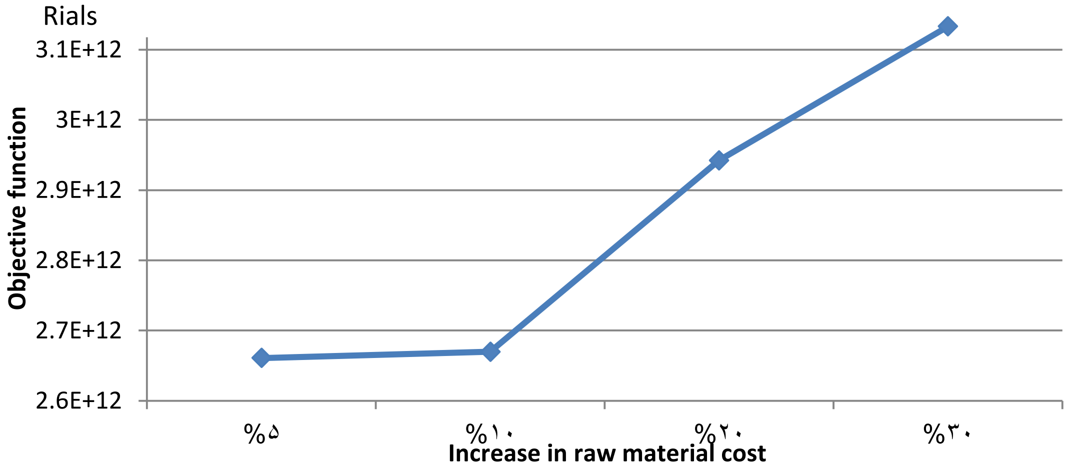

Fig. 3. The amount of increase in total cost per increase in the cost of raw materials

According to the Fig. 3, increasing raw material prices up to about 10% has a minor impact on the total cost of the production unit, but after an increase of more than 10%, the intensity of the increase in the total cost becomes higher. In Fig. 4, the effect of decreasing prices of the produced products on the total cost while other influential factors remain constant is shown. Increasing the raw materials leads to an increase in total costs.

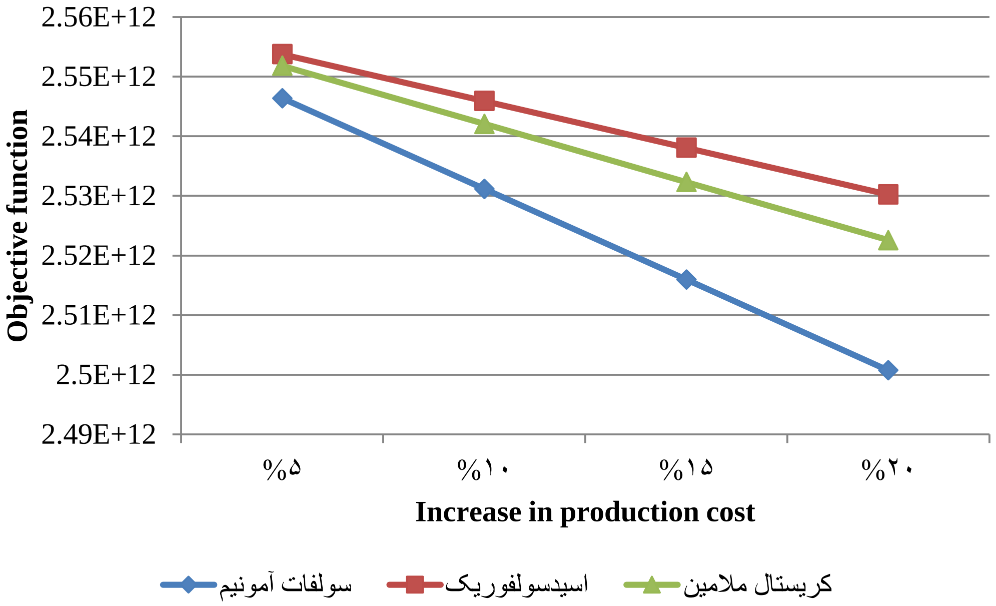

Fig. 4. The amount of reduction in total cost per decrease in the production cost of each product

According to the analysis conducted, it was observed that the impact of decreasing the price of Ammonium Sulfate product on the trend of the total cost is greater than that of the other two products. Therefore, to reduce production costs, managers of this company should make this product a priority. Increasing the production costs leads to a decrease in total costs. This may be due to low inventory costs. In other words, the model prefers to use inventory instead of more production.

CONCLUSION

The current research is a two-phase applied and developmental study focused on optimizing production planning for Urmia's petrochemical production. In the first phase, experts were consulted, and their opinions were gathered using a field survey and questionnaire. In the second phase, a model was developed to provide optimal production planning. The results of the model show the optimal purchase quantities of each raw material, total cost, and optimum inventory quantities of each product in different time periods. These findings provide valuable insights for managers to make informed decisions regarding supplier selection and production planning to optimize costs and improve performance. This study highlights the importance of supplier selection and production planning for Petrochemicals to improve their performance and competitiveness. The hierarchical analysis method has been used to select optimal suppliers, which takes into account the opinions of multiple managers and provides a comprehensive and coherent approach to decision-making.

The production planning model developed in the study considers various logical constraints related to raw materials, demand, production capacity, storage space, supplier constraints, and safety inventory requirements. The results of the model show the optimal purchase quantities of each raw material, total cost, and optimum inventory quantities of each product in different time periods.

These findings can help managers optimize production costs, improve performance, and respond more effectively to market demand. The study also demonstrates the value of using a two-step approach to simplify the model and speed up the process of obtaining results, which can be useful for managers who need to make decisions quickly.

One limitation of the proposed model is that it does not consider the potential impact of external factors such as changes in government regulations or economic conditions, which may have a significant impact on production costs and demand for products.

However, the model presented in this research has limitations, for example, it does not consider the potential impact of external factors such as changes in government regulations or economic conditions, which may have a significant impact on production costs and demand for products. Future researchers could consider these limitations to improve and expand upon the findings of this study.

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