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Optimizing Supply Chain Resilience in Kuwait Oil Industry

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Abstract

Kuwait's oil supply chain is a critical pillar of the country's economy, yet it faces significant challenges due to fluctuating market demand, geopolitical risks, and environmental regulations. This study aims to enhance the resilience of Kuwait's oil supply chain by developing a Linear Programming (LP) model that optimizes crude oil extraction, transportation, refining, inventory management, and market distribution while incorporating disruptions such as shipping delays and refinery constraints. The model integrates key cost components, including crude oil procurement, desulfurization processing, inventory holding, and penalties for unfulfilled demand. Scenario analyses are conducted to evaluate the system's response to supply chain disruptions, including reduced shipping capacities and extreme weather events. Results indicate that while the supply chain demonstrates resilience in fulfilling demand, disruptions lead to increased costs and inventory fluctuations. Findings suggest that improving storage capacities, diversifying crude oil sources, and enhancing predictive scheduling can further strengthen resilience. This study provides a structured approach for policymakers and industry stakeholders to mitigate risks and ensure the long-term sustainability of Kuwait's oil supply chain.

Keywords
Kuwait Oil Industry, Linear Programming, Oil Supply Chains, Resilience, Supply Chain Optimization.

1. Introduction

Kuwait's oil supply chain is a critical component of both its national economy and the global energy market. The country holds approximately 7% of the world's proven oil reserves, estimated at 101.5 billion barrels (OPEC, n.d.). In 2023, it was among the leading oil producers worldwide, accounting for around 3% of global oil production (Statista, 2023). The oil and gas sector is fundamental to Kuwait's economy, contributing approximately 50% to the Gross Domestic Product (GDP) and accounting for over 90% of government revenue (ITA, 2023). However, the sector faces numerous challenges, including fluctuating market demand, geopolitical risks, environmental regulations, and operational disruptions such as shipping delays and refinery constraints. These disruptions can lead to increased costs, inefficiencies, and reduced supply chain resilience. The high sulfur content of Kuwait's crude oil further complicates refining processes, requiring additional desulfurization efforts to meet international environmental standards.

To address these challenges, this study develops a Linear Programming (LP) model that integrates key supply chain components, including extraction, transportation, refining, and inventory management. The model is designed to minimize costs while ensuring operational resilience by simulating disruption scenarios such as shipping capacity reductions and refinery shutdowns.

1.1 Objectives

This study aims to address the critical challenges faced by Kuwait's oil supply chain by enhancing its resilience, efficiency, and sustainability in the volatile global energy market. Key objectives include

- Improving operational efficiency by optimizing inventory management, minimizing transportation and production inefficiencies, and adopting proactive supply chain strategies (Figure 1).
- Strengthening the resilience of major entities such as Kuwait Oil Company (KOC), Kuwait National Petroleum Company (KNPC), and Kuwait Oil Tanker Co. S.A.K. (KOTC) to effectively manage disruptions caused by geopolitical instability, natural disasters, and fluctuating demand, while also developing flexible supply chain configurations.

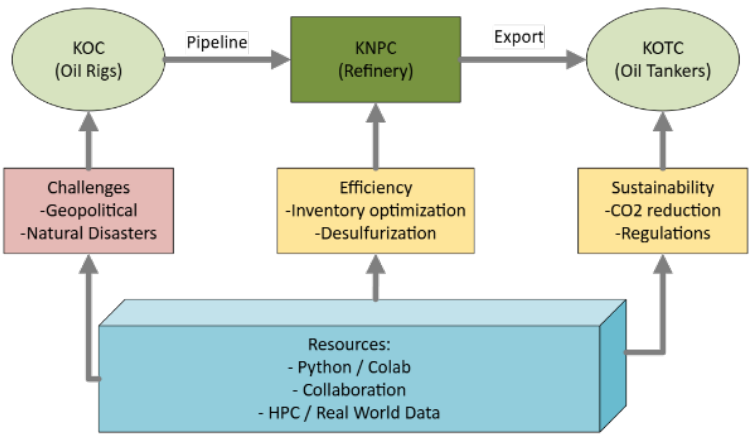

Figure 1. Kuwait oil supply chain structure and analysis framework

Environmental sustainability is prioritized by targeting low Sulphur oil production, adhering to international standards. Advanced optimization techniques, such as linear programming, are leveraged to address vulnerabilities, validate strategies through scenario analysis, and enhance competitiveness. Finally, the project ensures the availability of essential resources, including software like Python and Google Colab, high-performance computing infrastructure, comprehensive data from key entities, and collaboration with supply chain experts.

2. Literature Review

This literature review synthesizes findings from various studies to establish a coherent framework for applying mixed integer programming to enhance supply chain management. Ivanov (2021) highlights the integration of digital technologies such as IoT, AI, and blockchain to enable real-time monitoring and predictive analytics, thereby enhancing supply chain resilience. Similarly, Hossain et al. (2019) propose using Bayesian Networks to identify resilience features and provide insights for mitigating risks and improving recovery capabilities. Shahnazi et al. (2022) analyze global oil trade networks using network theory, emphasizing strategic diversification to safeguard against disruptions. Urciuoli et al. (2014) further explore risks in European oil supply chains, proposing flexible contracting and collaboration strategies to secure energy supplies. Moosavi and Hosseini (2021) evaluate recovery strategies like backup suppliers and pre-positioned inventory during pandemic-induced disruptions. Ni et al. (2022) introduce inventory strategies for mitigating downstream supply chain disruptions caused by extreme weather events, demonstrating their effectiveness through simulations. Al-Haidous et al. (2022) employ Mixed Integer Programming to optimize Qatar's LNG supply chain, balancing cost efficiency and emission reduction through advanced techniques and cleaner fuels. Ekram et al. (2023) focus on enhancing resilience in Egypt's oil and gas industry by emphasizing flexibility, redundancy, and collaboration. Similarly, Piya et al. (2022) use fuzzy ISM and DEMATEL methodologies to analyze resilience drivers, offering practical insights. Finally, Ghaithan et al. (2017) develop a multi-objective optimization model for tactical decision-making in oil and gas supply chains. Ribas et al. (2011) address price and demand uncertainties using stochastic modeling, while Shehabi (2021) examines the economic impacts of COVID-19 and oil price shocks using an economy-wide model. Despite the range of research, a notable gap exists in integrating advanced optimization techniques, such as mixed integer programming, into comprehensive frameworks addressing both economic and environmental challenges in the oil supply chain. This study aims to bridge this gap by offering optimization methods to investigate resilience and improve efficiency while ensuring sustainability and adaptability.

3. Methods

In this study an LP model is developed to optimize the petroleum supply chain for Kuwait, incorporating desulfurization costs and throughput to meet market demands, minimize total costs, and handle the challenges posed by the high sulfur content of crude oil.

The LP model targets:

1. Optimizing overall costs, including production, transportation, desulfurization, inventory holding, and penalties for unsatisfied demand.
2. Accounting for the desulfurization process and its associated costs, ensuring compliance with environmental standards and the production of low-sulfur fuel.
3. Satisfying oil demand in various markets while addressing potential supply chain disruptions.

The formulation of the model is given below:

Decision Variables

CO_t : $Crude\ oil\ inventory\ on\ day\ t$
$D_{r,t}^t$: $Desulfurization\ throughput\ at\ refinery\ r\ on\ day\ t$
FP_t : $Finished\ product\ inventory\ on\ day\ t$
$E_{w,t}$: $Crude\ oil\ extracted\ at\ well\ w\ on\ day\ t$
RA_t : $Chemical\ A\ inventory\ on\ day\ t$
RB_t : $Chemical\ B\ inventory\ on\ day\ t$
RC_t : $Other\ chemical\ inventory\ on\ day\ t$
$S_{m,t}$: $Shipment\ to\ market\ m\ on\ day\ t$
T_t : $Crude\ oil\ transported\ via\ pipelines\ on\ day\ t$
$U_{r,t}$: $Production\ at\ refinery\ r\ on\ day\ t$
$Uns_{m,t}$: $Unsatisfied\ demand\ at\ market\ m\ on\ day\ t$

Parameters

CA, CB, CC : $Blending\ ratios\ for\ critical\ chemicals\ type\ A, type\ B, and\ other\ types\ of\ chemicals$
Cr : $Crude\ oil\ blending\ ratio$
C_t^A: $Chemical\ A\ supply\ amount\ on\ day\ t$
C_t^B: $Chemical\ B\ supply\ amount\ on\ day\ t$
C_t^C: $Chemical\ C\ supply\ amount\ on\ day\ t$
Des_c : $Desulfurization\ cost\ per\ unit$
$D_{m,t}$: $Demand\ at\ market\ m\ on\ day\ t$
H_c : $Inventory\ holding\ cost\ per\ unit$
Min_w^w : $Minimum\ production\ limit\ for\ well\ w$

$P^{w}_{w,t}$: $Well\ capacity\ for\ well\ w\ on\ day\ t$
TC_t: $Pipeline\ transport\ capacity\ on\ day\ t$
$P^{r}_{r,t}$: $Refinery\ capacity\ for\ refinery\ r\ on\ day\ t$
$Price_t$: $Daily\ crude\ oil\ price\ on\ day\ t$
Pen : $Penalty\ cost\ for\ unsatisfied\ demand\ per\ unit$
SC : $Crude\ oil\ storage\ capacity$
$SP_{m,t}$: $Shipment\ capacity\ at\ market\ m\ on\ day\ t$

Objective Function

$$Min\ Z = \sum_{t} H_c \cdot (CO_t + RA_t + RB_t + FP_t) + \sum_{m,t} Pen \cdot Uns_{m,t} + \sum_{w,t} Price_t \cdot E_{w,t} + \sum_{r,t} P^{r}_{r,t} \cdot U_{r,t} + \sum_{t} (CA \cdot C_t^A + CB \cdot C_t^B) + \sum_{r,t} Des_c \cdot D^{t}_{r,t}$$

Constraints

1. Well Capacity Constraints

$$E_{w,t} \le P^{w}_{w,t}, \qquad \forall w, \forall t$$

2. Minimum Production Limits for Wells

$$E_{w,t} \ge Min^{w}_{w}, \qquad \forall w, \forall t$$

3. Crude Oil Transportation Constraints

$$\sum_{w} E_{w,t} = T_t, \qquad \forall t$$

$$T_t \le TC_t, \qquad \forall t$$

4. Crude Oil Inventory Constraints

$$CO_{t-1} + T_t - \sum_{r} Cr \cdot U_{r,t}, \qquad \forall t$$

$$CO_t \le SC, \qquad \forall t$$

5. Raw Material Inventory Constraints

For Chemical A:

$$RA_t = RA_{t-1} + C_t^A - \sum_{r} CA \cdot U_{r,t}, \qquad \forall t$$

For Chemical B:

$$RB_t = RB_{t-1} + C_t^B - \sum_{r} CB \cdot U_{r,t}, \qquad \forall t$$

For Other Chemicals:

$$RC_t = RC_{t-1} + C_t^C - \sum_{r} CC \cdot U_{r,t}, \qquad \forall t$$

6. Blending Constraints

$$\sum_{r} Cr \cdot U_{r,t} \le CO_t, \qquad \forall t$$

$$\sum_{r} CA \cdot U_{r,t} \le RA_t, \qquad \forall t$$

$$\sum_{r} CB \cdot U_{r,t} \le RB_t, \qquad \forall t$$

$$\sum_{r} CC \cdot U_{r,t} \leq RC_t, \qquad \forall t$$

7. Finished Product Inventory Balance

$$FP_{t-1} + \sum_{r} U_{r,t} - \sum_{m} S_{m,t}, \qquad \forall t$$

8. Shipment and Demand Satisfaction

$$S_{m,t} + Uns_{m,t} = D_{m,t}, \qquad \forall m, \forall t$$
$$S_{m,t} \leq SP_{m,t}, \qquad \forall m, \forall t$$

9. Desulfurization Throughput Constraints

$$D_{r,t}^{t} = Cr \cdot U_{r,t}, \qquad \forall r, \forall t$$

10. Non-negativity restrictions

$$All\ decision\ variables \geq 0$$

The model aims to minimize the operating costs of Kuwait's crude oil supply chain, encompassing extraction, transportation, refining, inventory management, and market distribution. Well Capacity Constraints (1) ensure crude oil extraction remains within each well's daily capacity while meeting minimum production levels, as enforced by the Minimum Production Limits for Wells (2). Crude Oil Transportation Constraints (3) match extracted crude oil with transported quantities, adhering to pipeline and storage capacities. Crude Oil Inventory Constraints (4) maintain inventory consistency by balancing incoming, stored, and processed crude oil, while Raw Material Inventory Constraints (5) account for the supply, usage, and storage of chemicals (A, B, and others) required for production. Blending Constraints (6) enforce proper mixing ratios for crude oil and chemicals to meet refinery production needs. Finished Product Inventory Constraints (7) ensure inventory is balanced across production, previous stock, and shipments to markets. Shipment and Demand Satisfaction Constraints (8) align shipments and unmet demand with market requirements, within shipment capacity limits. Desulfurization Throughput Constraints (9) ensure that the amount of crude oil undergoing desulfurization at refineries aligns with the volume of processed crude oil. This maintains the required blending ratios to meet environmental and fuel quality standards. Lastly, constraint (10) satisfies non-negativity restriction for the decision variables. The model, implemented using Python's PuLP library (Mitchell, 2004) on Google Colab, integrates cost optimization with operational resilience to address the challenges of Kuwait's oil supply chain.

4. Data Collection

The data utilized in this study, which investigates the resilience of Kuwait's oil supply chains, was sourced from key national organizations, including the Kuwait Oil Company (KOC), Kuwait National Petroleum Company (KNPC), and Kuwait Oil Tanker Company (KOTC). As can also be seen in Figure 2, the dataset contains critical production metrics, such as daily crude oil extraction rates, well capacities, and refinery outputs, providing a comprehensive view of upstream and downstream operations (KOC, 2023; KNPC, 2023). These metrics are essential for modeling supply chain dynamics and ensuring that production constraints are effectively incorporated.

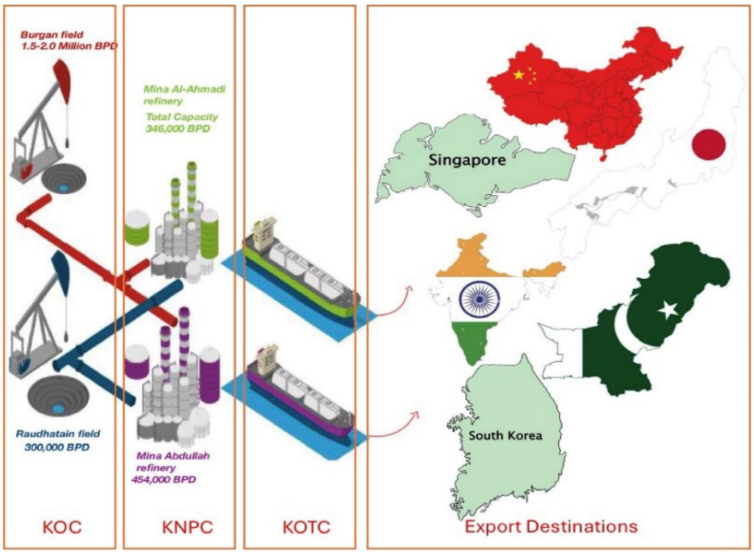

Figure 2. Kuwait oil supply chain network

Additionally, demand data was collected to align supply with market requirements, capturing the anticipated regional needs for refined petroleum products (KOTC, 2023). Transportation data, including pipeline capacities, tanker schedules, and routing information, was also incorporated to account for logistical constraints and delivery feasibility (KNPC, 2023). Inventory data detailing crude oil, chemicals, and finished product levels across different stages of the supply chain was included to ensure a robust representation of storage and flow dynamics. This comprehensive dataset used as an input to the linear programming model, enabling the analysis of cost optimization and resilience in Kuwait's oil supply chain.

5. Results and Discussion

The analysis of Kuwait's oil supply chains provides a detailed understanding of its performance and flexibility in dealing with of disruptions. It draws attention to important operational difficulties, such as changes in refinery output levels and transportation amounts, which illustrate the difficulties of controlling supply chain activities in dynamic environments. Figure 3 represents production metrics over 15 periods (0 to 14), including crude oil from wells, refinery output, shipments, and market demand. Well1 produces 1.5 million barrels during periods 0, 5, 7, 8, and 9, but after period 10, it drastically declines, which has an impact on refinery output. Well2 maintains a low production level (usually 50K barrels) with sporadic peaks. Refinery production follows well output, peaking at about 2 million barrels before starting to decrease after period 10. In line with production, total shipments decreased during periods 10, 11, and 14. Market demand slightly increases in periods 12 and 13, but supply constraints cause a shortfall in period 14.

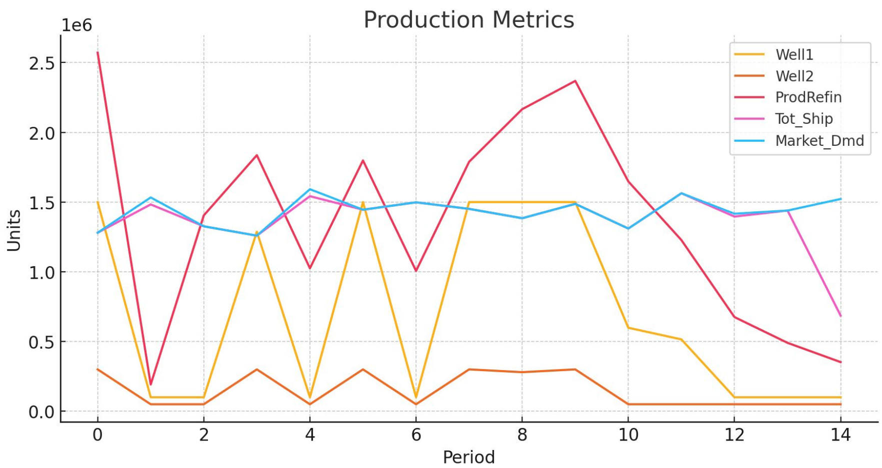

Figure 3. Production metrics over time

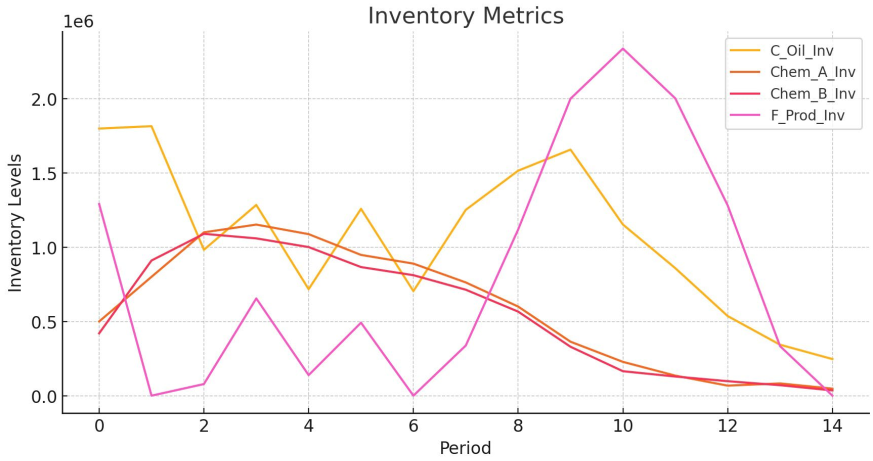

Figure 4. Inventory metrics over time

Figure 4 below shows inventory trends across 15 periods. As a result of continuous refining, the inventory of crude oil decreased from 1.8 million barrels in period 0 (first period) to 246,642 barrels in period 14. Due to increasing demand, Chemical A and B inventories peak at roughly 1.1 million barrels in periods 2-4. As they are consumed, they decrease, reaching between 35,000 and 47,000 barrels by period 14. The finished product inventory varies the most, dropping sharply to zero in period 6 peaking at 2.3 million barrels in period 10, and then dropping to zero by period 14 (last period) most likely as a result of higher shipments and lower output. Periods 8–10 show the biggest changes, indicating a peak in production output before a decrease.

5.1 Numerical Results

In the model, there are 15 periods representing 15 working days. Figure 5 presents the cost breakdown structure of total cost calculated by the objective function.

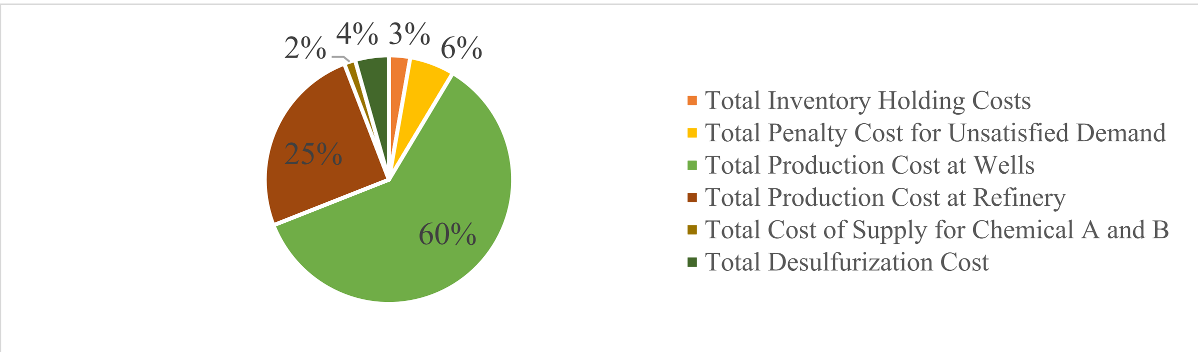

Figure 5. Cost breakdown as percentage of total

In the supply chain, KOC is the supplier of KNPC. Therefore, KNPC purchases crude oil from KOC as per the daily crude oil price. Because of this the majority of the cost, i.e. 60%, belongs to crude oil purchased from KOC. Also, purchasing crude oil versus keeping it in inventory is a strategic decision for KNPC. Given the objective, the model identifies key markets where resource allocation and supply chain resilience enhancements are required to lessen unfulfilled demand.

5.2 Validation

To guarantee the precision and efficacy of the suggested LP model, its outputs were compared to data from Kuwait's oil sector as a baseline. Demand fulfillment, inventory balance, and cost reduction were among the metrics that were examined. Given Kuwait's actual 1.5-2 million bpd crude oil production capacity, obtained results showed consistency with the real data. Detailed outputs are presented in Table 1.

Table 1. Production, inventory, shipping, and market demand metrics over time for the base model (in barrels)

Period	Well1 production	Well2 production	Crude Oil Inventory	Production at Refinery	Final Product Inventory	Total Shipment	Market Demand
1	1,500,000	300,000	1,800,000	2,571,429	1,291,429	1,280,000	1,280,000
2	100,000	50,000	1,815,900	191,571	0	1,483,000	1,533,000
3	100,000	50,000	982,950	1,404,214	78,214	1,326,000	1,326,000
4	1,287,503	300,000	1,285,227	1,836,038	655,252	1,259,000	1,259,000
5	100,000	50,000	717,613	1,025,162	138,414	1,542,000	1,592,000
6	1,500,000	300,000	1,258,807	1,798295	491,710	1,445,000	1,445,000
7	100,000	50,000	704,403	1,006,290	0	1,498,000	1,498,000
8	1,500,000	300,000	1,252,202	1,788,860	337,860	1,451,000	1,451,000
9	1,500,000	280,000	1,516,101	2,165,858	1,119,718	1,384,000	1,384,000
10	1,500,000	300,000	1,658,050	2,368,644	2,001,361	1,487,000	1,487,000
11	598,497	50,000	1,153,274	1,647,534	2,338,895	1,310,000	1,310,000
12	515,000	50,000	859,137	1,227,338	2,003,233	1,563,000	1,563,000
13	100,000	50,000	536,568	675,098	1,282,331	1,396,000	1,416,000
14	100,000	50,000	343,284	490,406	333,737	1,439,000	1,439,000
15	100,000	50,000	246,642	352,346	0	686,083	1,522,000

According to the base model outputs Well1 showed a high output capacity over the study period, especially during periods 1, 6, 8, 9, and 10. Well2 consistently produced 50,000 barrels for several periods. Considerable drops in Crude oil production levels are in line with refinery outputs, which peak in periods 1, 6, 9, and 10. Because there was less crude available, output was decreased during periods 11 and 12. Production trends were reflected in shipping volumes, with lower exports during periods 11 and 12 most likely as a result of Well1's lower output. The market's demand peaked in periods 2 and 5 and stayed constant.

5.3 Scenario Analysis

Simulated scenarios that reflected actual conditions in Kuwait's oil supply chain were used to evaluate the model. Different market demand levels, transportation capacity, refinery limitations, and outside disturbances like sandstorms or shipping delays were all considered in these scenarios. Table 2 summarizes scenarios investigated and the details of the selected scenarios are presented afterwards.

Table 2. Investigated disruption scenarios

Scenario	Impact Summary	Response Summary
Sandstorm	Caused Well 1's output capacity to drop by 30% across five periods due to operational difficulties.	Logistics are adjusted to reduce supply chain interruptions, and production is shifted to Well 2.
Marine Weather	Delays transportation schedules by reducing shipping capacity by 100,000 units for five periods.	Temporarily, production at Wells 1 and 2 is reduced, and other routes and schedules are optimized.
Geopolitical Tensions	Affects export quantities by 20% for eight periods due to increased transit risks and trade restrictions.	Focus shifts to local markets; output is adjusted to accommodate limited export potential.
Transportation Strike	Causes a halt in oil distribution by stopping pipeline transportation entirely for four periods.	Wells reduce output to match storage capacity, and backup procedures are implemented for quick recovery.

Marine weather disruption:

In this scenario, including rough seas and strong winds, decrease 100,000 units of transportation capacity across five periods, resulting in a large amount of unsatisfied demand in important markets. Due to export delays, inventories peaks at 2.71 million units, while shortages in China, South Korea, and Japan can reach 100,000, 90,000, and 70,000 units, respectively. The objective function value rises to \$1.662B as holding costs and penalty costs for unsatisfied demand increase to \$49.98M and \$113.75M, respectively. Although there are later variations, such as decreases in unmet demand in Singapore and Japan and increases in Pakistan and India, unmet demand stabilizes to zero by Period 5, indicating recovery. Production adapts to prevent overstock, and the system exhibits resilience by recovering from interruptions despite immediate operational and financial consequences due to dynamic scheduling and adaptive techniques.

Sandstorm disruption:
Production of crude oil in Kuwait can be severely disrupted by sandstorms. In this scenario, especially at Well 2, production capacity drops to 200,000 barrels per day. Although flexibility decreases, Well 1 makes up for this by running at maximum capacity (1,500,000 barrels) during crucial times. During disruptions, refinery production falls below 1,200,000 barrels, which results in unmet demand in important markets like India, Pakistan, and South Korea. This is particularly true during peak periods like Period 14, when shortage total 1,133,916 barrels. Although the cost of keeping inventory is reduced, the disruption leads to production inefficiencies and increased penalty costs ($109.8 million) due to unsatisfied demand. Production and refinery outputs must be stabilized by boosting stocks, diversifying crude oil sources, and improving sandstorm resilience.

Table 3 presents key performance indicators comparing the base scenario with the two selected disruption scenarios, marine weather disturbances and sandstorms. The minor decrease in service rate from 95.56% in the base scenario to 95.49% during marine weather interruptions and 94.89% during sandstorms suggests that sandstorms have a stronger impact. The primary reasons for the increase in overall spending from $1,635M to $1,651M during marine weather disturbances and $1,645M during sandstorms are delays and storage costs. The crude oil inventory rises to 17,191 million barrels during marine weather disturbances, indicating shipping delays; during sandstorms, the inventory falls to 15,559 million barrels, most likely due to supply chain interruptions.

Table 3. Findings from the scenario analysis for marine weather and sandstorm disruptions

	Base scenario	Marine weather disruption	Sandstorm disruption
Service rate (%)	95.56	95.49	94.89
Total cost ($million)	$1,635	$1,651	$1,645
Total crude oil inventory (million barrel)	16,131	17,191	15,559
Total finished product inventory (million barrel)	12,072	14,688	10,916

Marine weather disruptions result in the highest level of finished product inventories at 14,688 million barrels, as refineries continue to produce despite shipping delays, while sandstorms cause the lowest level at 10,916 million barrels, most likely due to disruptions in refinery operations and product distribution. While marine weather disruptions frequently lead to higher prices and inventory accumulation due to transit delays, sandstorms have a greater impact on production and logistics, reducing the availability of crude oil and finished products.These findings suggest that while the supply chain demonstrates robustness in mitigating disruptions, targeted improvements as summarized in Table 2 could further enhance resilience and cost efficiency.

6. Conclusion

This study aimed to investigate the resilience of Kuwait's oil supply chain by using an LP approach while considering key factors such as fluctuating market demand, environmental constraints, and disruptions in shipping capacity. The proposed model provides a structured approach to balancing crude oil extraction, transportation, refining, inventory management, and distribution under varying conditions. The study achieved several milestones:

Data Collection: Overcoming challenges related to data accessibility and confidentiality, this study utilized publicly available information and valuable industry insights from professionals at the Kuwait Oil Tanker Company (KOTC), Kuwait National Petroleum Company (KNPC), and Kuwait Oil Company (KOC).

Model Development: A comprehensive LP model was developed to optimize operational decisions, dynamically adjust production levels, and manage inventory efficiently under various disruption scenarios.

Scenario Testing: The model's robustness was tested through simulations of critical disruption scenarios, including decreased shipping capacity and shipment delays.

Optimization: The LP model effectively balanced crude oil production, transportation, and refining operations while minimizing penalties for unfulfilled demand. It also helped us understand insights into how inventory management strategies could mitigate the impact of disruptions.

While this study provides a foundation for resilience analysis in oil supply chains, several areas offer opportunities for further research. Future studies could explore additional resilience metrics, such as supply chain recovery time, financial risk exposure, and adaptive capacity, to offer a more comprehensive assessment. Incorporating regulatory constraints, including emissions limits, fuel quality standards, and geopolitical trade restrictions, would enhance the model's applicability in real-world policy planning. Additionally, the LP model's scalability allows for potential extensions to include new refineries, alternative sources, or expansion into international markets.

This study demonstrates that with robust inventory strategies, and scenario-based planning, the LP model serves as a valuable decision-support tool for policymakers and industry stakeholders. As global energy markets continue to evolve, refining and expanding this methodological approach will be crucial for ensuring the long-term sustainability and competitiveness of Kuwait's oil industry.

References

Al-Haidous, A., Govindan, K., Elomri, A., & Al-Ansari, T, Optimization of LNG supply chain operations: A case study of Qatar. *Journal of Cleaner Production, 350*, 131470, 2022. https://doi.org/10.1016/j.jclepro.2022.131470

Ekram, A., Elmesmary, M., & Sakr, A, Enhancing logistics resilience in the oil and gas supply chain: A strategic framework. *International Journal of Logistics Research and Applications, 2023*. https://doi.org/10.1080/13675567.2023.2234721

Ghaithan, A., Attia, A., & Duffuaa, S, Multi-objective optimization model for downstream oil and gas supply chain tactical planning. *Computers & Industrial Engineering, 112*, 114–125, 2017. https://doi.org/10.1016/j.cie.2017.07.032

Hossain, M., Uddin, N., & Masud, M., Resilience assessment in oil and gas supply chains using Bayesian networks. *Energy Policy, 134*, 110922, 2019. https://doi.org/10.1016/j.enpol.2019.110922

International Trade Administration (ITA, *Kuwait - Oil and Gas*. U.S. Department of Commerce, 2022. Retrieved from https://www.trade.gov/country-commercial-guides/kuwait-oil-and-gas

Ivanov, D. , Supply chain resilience: A comprehensive framework and its application to oil and gas industries. *International Journal of Production Research, 59*(22), 6780–6805, 2021. https://doi.org/10.1080/00207543.2021.1895018

Kuwait National Petroleum Company, *Refining operations*.2023 https://www.knpc.com/

Kuwait Oil Company, *Annual report*. 2023. Retrieved from https://www.kockw.com/

Kuwait Oil Tanker Company, *Fleet information*. 2023. https://www.kotc.com.kw/

Mitchell, S, *PuLP: A Linear Programming Toolkit for Python*. 2004. https://github.com/coin-or/pulp

Moosavi, J., & Hosseini, S. , Simulation-based resilience assessment of supply chains during COVID-19 disruptions. *Sustainability, 13*(15), 8512, 2021. https://doi.org/10.3390/su13158512

Ni, M., Li, J., & Zhang, Y. , Simulation of downstream oil supply chain resilience under extreme weather conditions. *Transportation Research Part E: Logistics and Transportation Review, 162*, 102747, 2022. https://doi.org/10.1016/j.tre.2022.102747

Organization of the Petroleum Exporting Countries (OPEC)., *Kuwait*.n.d. Retrieved from https://www.opec.org/opec_web/en/about_us/165.htm

Piya, S., Shamsuzzoha, A., & Khadem, M, Integrated fuzzy ISM and DEMATEL approach for assessing resilience in oil and gas supply chains. *Expert Systems with Applications, 199*, 117088, 2022. https://doi.org/10.1016/j.eswa.2022.117088

Ribas, G., Leiras, A., & Hamacher, S., Two-stage stochastic programming for tactical planning in oil supply chains. *Energy, 36*(11), 6099–6106, 2022. https://doi.org/10.1016/j.energy.2011.08.041

Shahnazi, R., Sajedianfard, M., & Melatos, M, Resilience in the global oil trade: A network analysis approach. *Energy Economics, 113*, 106088, 2022. https://doi.org/10.1016/j.eneco.2022.106088

Shehabi, M, COVID-19, oil price shocks, and their economic impact in Gulf economies: Insights from Kuwait. *Economic Modelling, 94*, 213–227, 2021. https://doi.org/10.1016/j.econmod.2020.09.001

Statista., *Oil production in Kuwait from 1998 to 2023 (in 1,000 barrels per day)*. 2023. Retrieved from https://www.statista.com/statistics/265189/oil-production-in-kuwait-in-barrels-per-day

Urciuoli, L., Hintsa, J., & Tan, Y., Mitigating security risks in energy supply chains: Lessons from European case studies. *Supply Chain Management: An International Journal, 19*(2), 125–137, 2014. https://doi.org/10.1108/SCM-07-2012-0233

Biographies

Dalal Boland is an industrial engineering student at the American University of the Middle East (AUM). She is very curious about how to fix problems in systems and make everything work smoother. She likes to study supply chain because it helps her understand how to move things faster and save time for companies. She likes to work in groups with her classmates because sharing ideas make her learn more.

Danah Malallah student studying industrial engineering at the American University of the Middle East (AUM). She is very interested in learning how to improve systems and solve problems in a simple way. She studies things like supply chain and operations because she believes these things are very important for companies in Kuwait. She thinks hard work and smart ideas can make a big difference.

Retaj Al Hammadi, industrial engineering student at the American University of the Middle East (AUM), is dedicated to advancing efficiency and innovation within industrial systems. With a strong focus on supply chain optimization and operational excellence, Retaj aims to contribute meaningful solutions to real-world challenges in Kuwait's industrial sector.

Sarah Alroumi, industrial engineering student at the American University of the Middle East (AUM), is passionate about optimizing systems and solving real-world challenges. A graduate of The English Academy School, Sarah focuses her research on supply chain management and operations optimization, aiming to contribute to Kuwait's industrial growth through innovative solutions.

Alperen Bal is currently serving as an Assistant Professor at the American University of the Middle East in Kuwait, His research focuses on circular economy, sustainable logistics, supply chain optimization, and simulation-based optimization.