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Optimizing Mazut Distribution Networks for Minimizing Transportation Costs: A Scenario-Based Approach

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ABSTRACT

Efficient transportation infrastructure plays a pivotal role in any nation's development, and the petroleum industry holds particular significance in Iran's economic landscape. The transportation of petroleum products stands as a critical component of this industry, directly impacting various facets of the economy. Reducing traffic congestion not only alleviates strain on infrastructure but also mitigates traffic-related risks, air pollution, and transport expenditures. This, in turn, empowers the government to allocate savings to other sectors and bolster exports to neighboring countries. This research employs a linear optimization model to analyze the transportation of petroleum products, specifically Mazut, within Iran. By employing a scenario-based approach, we compare transportation costs in two distinct scenarios: one involving the utilization of Swap trades and the other focusing on increasing internal refinery production to supply Northern provinces without Swap transactions. We meticulously calculate transportation costs, leveraging TORA software and considering supply-demand dynamics. Our findings reveal that the implementation of Swap transactions yields an annual 2% reduction in transportation costs for Mazut products. This substantial cost-saving underscores the imperative nature of embracing Swap strategies within the country's petroleum distribution network.

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1. Introduction

One of the key indicators of competition in the global economy is the cost of goods, with energy consumption for production, packaging, and distribution being a primary component (Long, 2003). To enhance transportation efficiency, a substantial investment in high-cost infrastructure is required. A solution to increase productivity in this regard is to eliminate redundancy in traffic and transportation, resulting in the efficient distribution of goods at minimal shipping costs. Minimizing shipping expenses entails identifying the shortest routes, utilizing the most suitable modes of transport, and optimizing transportation methods (Hamdollahi, 2003).

Each country receives fuels and energy resources at a single entry point, and they are distributed through a unified system based on their source and consumption across different regions. This distribution system resembles a global trade practice for high-volume and strategically significant goods known as swap trading or swaps, which can be traced back to the earliest forms of trade (Muzaffar Beigi et al., 2014). The term "swap" is rooted in English verbs and essentially signifies bartering, exchanging, and trading (Rahmanian and Karimi, 2015).

The significance of this research lies in its potential to reduce traffic, thereby preserving infrastructure and prolonging its useful life. Moreover, by reducing the need for transporting petroleum products, there is an opportunity to export excess goods to neighboring countries, yielding political, security, and economic advantages. The government can redirect these cost savings towards other construction and manufacturing sectors. Furthermore, reallocating the transportation fleet for other purposes and optimizing cargo movement in both directions can enhance the nation's shipping fleet productivity. Ultimately, this approach mitigates the risks associated with such fleets and reduces road accidents that occur annually.

1.1. Background

In In Palgrave Economics' specialized dictionary, swaps are defined as contracts involving the transfer of cash flows, with the specific amounts determined based on hypothetical or principal sums (Newman, 1998). Collins Dictionary, on the other hand, characterizes swaps as exchanges involving products, interest rates, currencies, or financial debts. These transactions encompass both cash and futures transactions and aim to protect against adverse exchange rate fluctuations. However, this definition falls short as it primarily covers currency swaps and, at most, some interest rate swaps, lacking the necessary comprehensiveness. Synonyms for "swap" include invasion, relocation, and replacement (Collin, 2006).

A product swap entails importing a product at one border point of a country and utilizing it while simultaneously exporting products with the same specifications from another exit border. The National Iranian Petroleum Products Distribution Company heavily engages in product swaps, which offer numerous advantages:

1. Fulfilling a portion of the country's power plants' and citizens' petroleum product needs in the northern, northeastern, and western regions.
2. Liberating a portion of the product transportation fleet for utilization in other areas, expediting and simplifying the refueling process.
3. Generating revenue for the company through swap fees, equivalent to transfer fees.
4. Exporting excess products to address domestic demand and prevent accumulation in company storage tanks.

Since 2007, swap operations have encompassed Mazut and gasoline engine products, primarily imported from Central Asian countries via the northern border for consumption in facilities like the Neka power plant in the Sari region. Similarly, imports from Iraq along the western border supply power plants such as Sahand in Tabriz, Biston in Kermanshah, and Mofatteh in Hamadan. Conversely, Iran exports swap products from its southern ports (Mehregan et al., 2016).

Iran's unique geographical location enables it to conduct petroleum product swaps with Central Asian and Caspian countries, granting them access to the warm waters of the Persian Gulf and international markets. Furthermore, given that most of Iran's energy demand originates in the northern regions, distant from energy sources, engaging in swaps through Iran is a logical choice (Angiz and Keramatpour, 2021).

By The concept of "swap" in Iran's oil trade involves importing oil or petroleum products from the Caspian littoral countries at one of Iran's border areas, consuming them domestically, and subsequently exporting oil or its equivalent products with identical specifications from another exit frontier under non-sanctioned conditions. This practice serves to enhance trade relations, strengthen economic and political ties, and bolster the national security of the involved nations (Clawson, 1997).

Given Iran's pivotal role in global oil and gas supply and its economic reliance on earnings from oil and gas exports, managing risks in this industry has led to the adoption of swap financial derivatives as a novel approach (Rahimi and Resketi, 2017). In dealings with the Caspian littoral states, Iran can assume the roles of both a "swapper" and a "buyer and seller" in crude oil swap agreements. Moreover, the exchange of crude oil from the northern part of the country and the delivery of its equivalent value to the southern region can occur concurrently or at intervals. Research suggests that Iran benefits more from the role of a "buyer and seller" in longer-term oil contracts (Gadmor, 2006).

It is imperative to define swap by examining practical examples, as it did not originate from a pre-established financial device; rather, each type evolved over time to meet specific needs (Abrishami et al., 2018). The formal term for this trading method is "systematic mutual exchange cooperation," commonly abbreviated to "swap" in business and trade affairs. The inception of the first oil swap agreement is believed to have occurred in 1952, involving Exxon, Shell, and British Petroleum. Subsequently, this practice expanded systematically across various transactions, regions, and global oil companies (Hull, 2014).

Efforts to reduce transportation costs and maintain control over them are referred to as cargo swaps. In 2001, British Petroleum became the largest olefins producer in Germany through a swap arrangement with the German company A.N. In 2003, BASF collaborated with Chemical Industries for Germany, and Honeywell supplied special copolymer nylons to BASF. This mutually beneficial agreement proved profitable for both parties. During the same period, the Kuwait Oil Company and the Iraqi Sumo Oil

Institute entered into a comprehensive memorandum of understanding, involving the exchange of Kuwaiti gasoline and diesel for Iraqi natural gas (Angiz and Keramatpour, 2021).

In our literature review, this research contributes significantly in several key areas:

1. Examination of Transportation Costs and Routing Considerations for Mazut Transportation: This study delves into the practical aspects of mazut transportation, thoroughly analyzing transportation costs and route planning considerations.
2. Application of Optimization Techniques and Mathematical Modeling: To assess the viability of the proposed approach and its real-world applicability, we employ advanced optimization methods and mathematical modeling.
3. Quantification of Potential Cost Savings: Differing from previous research, we quantify potential cost savings using data from our case study. We approach the problem by formulating it as a linear planning model tailored to the specific hypotheses of this research. To solve this model and calculate costs for two swap scenarios, we utilize Tora linear modeling software.

In this research, we put forth two hypotheses:

1. Facilitating Petroleum Product Swap Transactions with Neighboring Oil-Producing Countries: We hypothesize that engaging in swap or exchange transactions of petroleum products with neighboring oil-producing nations will ensure a consistent supply to the northern provinces of our country.
2. Reduction of South-North Petroleum Product Transportation: Our second hypothesis posits that the outcome of swap exchange transactions will result in a decreased need for transporting such products from the southern oil-rich regions to the northern areas.

The primary aim of this study is to quantify the extent of reduction in transportation costs and the transportation of petroleum products. We seek to determine how effective exchange transactions or swaps are in reducing these costs by employing a linear planning model.

2. Methodology

In the course of this research, a multifaceted data collection approach was adopted. This encompassed the utilization of available information and documents, engaging in telephone interviews, and conducting email correspondence with the National Oil Products Distribution Company. These efforts aimed to amass a comprehensive dataset that would underpin the study's objectives.

The data acquired for this research can be delineated into four principal categories. Firstly, it encompasses an in-depth review of prior studies and research that have probed into methods for reducing transportation costs and the intricacies of swap transactions. Secondly, the dataset encompasses essential information pertaining to provincial consumption patterns, quantities of petroleum products housed within the country's refineries, volumes of imported, exported, and swapped products during the year 2014, and the quantities of products stockpiled within the country during that same year—these statistics were meticulously sourced from 2014 records. Thirdly, it incorporates granular details concerning the expenses associated with transporting petroleum products through various modes of conveyance and the operational mechanisms behind executing swap transactions. This corpus of information extends to include specifics such as the source country, the region of origin, and the precise borders implicated in import and export transactions. The acquisition of this data was facilitated through face-to-face interviews with the National Company for Distribution and Refining of Oil Products, as well as the extraction of pertinent statistics related to the nation's rail transportation from Hussain et al.'s work in 2006. Finally, the fourth category involves intelligence regarding the distances traversed in the transportation of Mazut products and the methodologies employed for their conveyance—from their points of production or entry to the ultimate consumption centers or exit points.

In To analyze the data and generate reports, we utilized the Tora linear model solving software. Our approach involved first ensuring the equilibrium between supply and demand within the transportation system designated for Mazut products. This entailed determining the number of supply and demand points, calculating route distances, identifying the types of transportation means for each route, and assessing shipping costs for each route. Employing the Tora software, we then obtained the optimal transportation costs for oil products under two distinct scenarios. By comparing these scenarios, we quantified the reduction in costs. It's important to note that this study doesn't merely delve into the theoretical and mathematical aspects of transportation optimization. Rather, it employs a linear planning model to ascertain whether swaps conducted by the National Oil Products Distribution Company indeed lead to reductions in transportation expenses, and to determine the magnitude of these cost savings. In the context of swap transactions within Iran, envisioning the entire nation as a closed system, it comprises 9 production points or refineries, ports serving as import or supply points, 31 provinces as consumer points, as well as southern ports, export outlets, and bunkering facilities acting as points of demand.

One of the most prevalent approaches to determining the optimal quantity of transportation between these supply and demand points involves framing the system as a transportation problem. We begin by envisioning the system as if it could transition from its closed state, and we designate certain points as new suppliers while maintaining an equal volume of outputs for the system. This operation defines the concept of a Swap. In the case of the Mazut swap, a portion of the products is transported to the Neka oil terminal through the Turkmenbashi port in Turkmenistan via ship, while another portion is transported by land from Turkmenistan to the Sarakhs border in Mashhad, Iran. In exchange, an equivalent quantity of products is delivered to southern Iranian ports for Swap operations. To tackle this transportation model, we utilized the Tora software due to its ease of data input and the absence of a need to encode the problem in a programming language. We then compared the overall transportation costs in two distinct scenarios.

The first scenario involves fulfilling the requirements of the northern provinces through Swap transactions, whereas the second scenario excludes Swap activities within the country. In this second scenario, we redistributed the volume of Swap to the northern refineries and augmented their production capacities accordingly. Simultaneously, we added the same quantity to the expenses of the provinces, thus ensuring system equilibrium. By observing the reduction in transportation expenses in the first scenario relative to the second, we computed the resultant savings. Initially, we presented the entire oil product transportation system in the country in the form of a transportation problem. Recognizing that the general transportation model revolves around the distribution of goods from supply points, known as origins, to a set of receiving points, known as destinations, with the aim of minimizing distribution costs (Aghayan, 2014). As depicted in Table 1, we formulated the problem as per Equation (1). Additionally, we employed Equation (2) to compute the values of Cij, which represent the cost of transporting a ton of product from origin i to destination j. This formula aligns with the objective of minimizing shipping expenses, encompassing the movement of products from origin points, whether they involve production or imports, to destination points, which include consumption or exports.

Table 1. Transportation problem plan.

i/j	**1**	**2**	**3**	**…**	**n**	**Symbol**
1	C11/X11	C12/X12	C13/X13	…	C1n/X1n	S1
2	C21/X21	C22/X22	C23/X23	…	C2n/X2n	S2
3	C31/X31	C32/X32	C33/X33	…	C3n/X3n	S3
…	…	…	…	…	…	…
m	Cm1/Xm1	Cm2/Xm2	Cm3/Xm3	…	Cmn/Xmn	Sm
	d1	d2	d3	…	Dn	

minimize $$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} \quad (1)$$

subject to

Supply constraint $$\sum_{j=1}^{n} X_{ij} = S_i \quad (i = 1,2,\ldots,m),$$

Demand constraint $$\sum_{i=1}^{m} X_{ij} = D_j \quad (j = 1,2,\ldots,n),$$

Non-negative variables constrain $X_{ij} \geq 0 \; (i = 1,2,\ldots,m; j = 1,2,\ldots,n),$

If the cost of transporting each ton-km of product for each vehicle in terms of money unit is f, the shipping distance with the vehicle in terms of km is d_{ij} and the cost of transporting each ton of product with the vehicle in terms of money unit is C_{ij}:

$$C_{ij} = f \times d_{ij}. \tag{2}$$

In our quest to address this intricate challenge, the indispensable use of computer software emerged as a fundamental tool. This undertaking was underpinned by a series of foundational assumptions:

Firstly, we took into account the presence of bunkered products within supply-related values. Secondly, our calculations were laser-focused on Mazut products due to their pivotal role in swap transactions during the designated year. Thirdly, we adopted an optimistic perspective by omitting considerations for intermediate products within our problem. Fourthly, the efficiency levels of different transportation methods were assumed to have no bearing on relevant rates. Furthermore, we opted to disregard losses stemming from product evaporation, contamination, and waste. Lubricants for product transportation via pipelines were not factored into our calculations. We also assumed a constant input and output volume of the product at the beginning and end of pipeline routes, overlooking potential fluctuations in product volume due to various factors. Finally, we established a fixed rate for transporting one ton of product per kilometer across the country, irrespective of the mode of transportation, be it pipelines or railways.

Notably, the transportation of Mazut products can be segmented into two principal categories:

1. Transportation from entry points, including refineries and import borders, to oil depots or major consumers.

2. Transportation from oil depots to distribution centers and major consumers.

This study predominantly homes in on the first category, as transportation from oil depots to distribution centers remains constant regardless of how the product is sourced, be it through refineries or swap transactions.

To derive the costs for the two scenarios, we gathered data from trusted sources such as statistics published by the N.I.O.P.D.C., the Energy Balance 2014 report from the Ministry of Energy, and insights from the Transport, Transit, and Customs Affairs Commission. Additionally, we engaged in telephone interviews with managers overseeing supply and distribution affairs at the N.I.O.P.D.C.

Our linear model categorizes data into two primary groupings: supply-related data encompassing production values from 9 refineries and swap imports drawn from the 2014 statistics, and demand-related data comprising consumption values from 31 provinces, exports, swap exports, and bunkering, also based on the 2014 statistics. This data was meticulously analyzed for Mazut products to ensure a state of equilibrium.

Furthermore, we possessed comprehensive knowledge about the cost of transporting one ton of product per kilometer across the country for different transportation modes, including tanker trucks, railways, sea transport, and pipelines, expressed in money unit per year, courtesy of statistical data from the N.I.O.R.D.C.

Our analysis involved integrating distances between all supply and demand points, employing equations (1) and (2), and incorporating information regarding various transportation methods. The result was a set of values for Cij, representing shipping costs for each transportation route within our problem's overarching objective. These values were subsequently input into the Tora software alongside the identities of the source and destination points and their respective supply and demand quantities.

Ultimately, this study's core objective revolves around quantifying the reduction in transportation costs for Mazut products through the application of a linear planning model tailored to the realm of swap transactions.

3. Results

The utilization of Tora software played a pivotal role in this research, enabling us to extract valuable insights from the data pertaining to Mazut product transportation. This data facilitated the determination of optimal distribution patterns between source and destination points in each scenario, ultimately shedding light on the cost reductions achievable through swap transactions. In the first scenario, where Mazut swap operations were conducted within the country, the model encompassed 11 sources and 33 destinations, each associated with specific data points such as C_{ij} values representing transport costs in Money Unit (MOU), as well as S_i and D_j values denoting supply and demand quantities (in tons per year). Upon inputting this data into the Tora software, it yielded a total annual Mazut transportation cost of 1,038,605 MOU. Following 22 iterative steps, the Tora software efficiently converged to the optimal solution for the problem, providing us with the optimal distribution of Mazut products between each source and destination, alongside the associated costs for each transfer.

This analysis's comprehensive nature and Tora software's application allowed us to discern the intricacies of Mazut product transportation costs in both scenarios, highlighting the potential savings attributed to swap transactions. The findings underscore the significance of this research in elucidating how linear planning models, in conjunction with real-world data, can play a pivotal role in cost reduction strategies within the realm of swap transactions.

Ultimately, this research serves as a testament to the practical utility of mathematical modeling and optimization techniques in addressing complex logistical challenges, and it contributes valuable insights into the cost dynamics of Mazut product transportation, particularly within the context of swap operations (Table 1).

Table. 1. Input of Tora software in case of doing Mazut Swap.

Province (refinery) / Import border	**Mazandaran**	**East Azarbaijan**	**Qazvin**	**Khuzestan**	**Hormozgan**	**Kermanshah**	**Khorasan Razavi**	**Sistan**	**Hamedan**	**Alborz**	**Kerman**	**Refineries' produced mazut/imported swap mazut**
Abadan	169438	15937	130977	0.83	175824	48.7	262548	26121	94743	14627	18265	6411899
Bandar Abbas	238	287050	216068	189783	6.75	262696	204029	23738	211018	196168	48.5	4717563
Esfahan	104841	103	71280	110632	144342	969705	181467	176715	44550	73210.5	981585	3787339
Tehran	26.7	59.9	15	87.4	421101	87111	89.4	23269	50044.5	5.42	1541	2558115
Arak	83160	116572	449955	86278.5	196168.5	54202	176269	21948	17.6	45589.5	140926	2059781
Tabriz	128601	3.07	67567	159637	273685.5	87318	221710	321651	90436.5	86724	243094	1362113
Lavan	244393	28730	38019	122424	5800464	20192	20855	266816	21405	22597	19182	730890
Shiraz	176863	226165	143303	97861.5	91921.5	165132	20419	1633	140936	12216	84793	564779
Kermanshah	117760.5	87318	64300	48.7	239530.5	0.49	210870	26982	28066	72022	19126	431890
Neka Borde	0.003	0.09	68	167	217	120	106	211	93	52	167	75263
Sarakhs Borde	131	250	173	290	499	238	28	169	210	163	1556	35236
Provincial Mazut consumption	1971216	18271	13144	1004562	950543	898420	853878	73636	562934	52881	28051	-

In the second scenario, our analysis began by closely examining the geographical positioning of the northern provinces in relation to the surrounding refineries. It became evident that the capacity entering the country through swap transactions should be integrated into the consumption patterns of North Khorasan, Khorasan Razavi, Golestan, Mazandaran, Gilan, and South Khorasan provinces. Additionally, considering the varying distances of these provinces from the refineries, we allocated larger quantities of Mazut to the more distant regions, such as North Khorasan, Khorasan Razavi, Golestan, and South Khorasan, while the allocations for other provinces remained unchanged.

To uphold the equilibrium between supply and demand and to meet the augmented consumption needs of the northern provinces, we correspondingly increased the production capacities of the country's refineries by an equivalent amount. This expansion of refinery output generated fresh quantities available for production. Subsequently, upon inputting the data for the second scenario into the Tora software, we calculated the cost of transporting Mazut from the nine sources, excluding Neka and Sarakhs border bases, to the 33 destinations within the country, without involving swap operations. The total cost amounted to 1,059,645,491 MOU per year.

The Tora software efficiently solved the model after a mere 20 iterations, providing us with the optimal distribution patterns between each source and destination. The values within Table 2, marked by darker-colored cells, represent the C_{ij} values in MOU. Additionally, the quantities of production and consumption, denoted by S_i and D_j, are depicted in tons per year, as shown in Table 2.

Table 2. Input of Tora software in case of not doing Mazut Swap.

Province (refinery) / Import border	Mazandaran	East Azarbaijan	Qazvin	Khuzestan	Hormozgan	Kermanshah	Khorasan Razavi	Sistan	Hamedan	Alborz	Kerman	New Mazut productions of refineries
Abadan	16944	1596	1310	0	1758	0	2625	2612	947	1463	1827	64242
Bandar Abbas	2	2871	2161	1898	0	2627	2040	23739	21102	1962	0	47298
Esfahan	1048	1	713	1106	1443	9697	1815	1767	446	732	9816	37996
Tehran	0	1	0	1	4211	871	1	2327	500	0	1541	25704
Arak	832	1166	4500	863	1962	542	1763	2195	0	456	1409	20721
Tabriz	1286	0	676	1596	2737	873	2217	3217	904	867	2431	13744
Lavan	2444	2873	3804	1224	580046	2019	2085	2668	2184	2260	1918	7432
Shiraz	1769	2262	1433	979	919	1651	2040	1634	1409	1222	848	5771
Kermanshah	1178	873	643	0	2395	0	2109	2698	281	720	1913	4442
Provincial Mazut consumptions	19850	18272	13145	10046	9505	8984	8746	7364	5629	5288	2805	-

4. Conclusion

In this study, we conducted a comprehensive analysis of transportation costs for Mazut products using a linear planning model within the Tora software. Our investigation encompassed two distinct scenarios: one involving national-level Swap transactions specifically for Mazut products. The results are striking, indicating a substantial reduction in shipping costs.

Beyond the evident cost savings, the advantages of Mazut Swap transactions extend to various facets. Notably, these transactions help reduce vehicle depreciation, minimize air pollution, mitigate the occurrence of accidents, alleviate traffic congestion on transportation routes, and foster diplomatic relations with neighboring countries. These multifaceted benefits underscore the pivotal role of Swap transactions in the petroleum product industry.

To further enhance our understanding of this subject and lay the foundation for future research, we propose several avenues for exploration. Firstly, expanding the analysis to encompass additional scenarios for cost comparison against Swap transactions. Secondly, promoting private sector involvement in establishing refineries within the northern regions of the country to bolster domestic production capabilities. Thirdly, encouraging and facilitating private sector investments in the construction of product transportation pipelines due to their cost-effective nature. Fourthly, exploring alternative modes of Swap transactions, including the receipt from the west and withdrawal from the south or east, involving surplus product quantities from eastern provinces. Lastly, investigate the feasibility of Swap transactions with neighboring countries such as Kazakhstan and Azerbaijan, focusing on southern withdrawals.

These avenues for future research hold significant promise in providing valuable insights and contributing to the ongoing optimization of transportation strategies in the petroleum industry.

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