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Optimization for LNG terminals routing in North China

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Optimization for LNG Terminals Routing in North China

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FORMAT OF THE DECLARATION

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Abstract

As the rapid development of LNG industry in the past ten years, the domestic LNG stations have stopped their approval. However some of them are still under construction or planning. This paper analyzes the newest development status of the LNG industry and the related data shows the necessity of reasonable planning to meet the demand of LNG. Then it comes to the special analysis of the current situation of LNG in North China, especially the imbalance relationship of supply and demand. Also the paper describes and compares the pros and cons of the 3 main LNG transport modes. In addition, the author discusses the basic news and latest status of LNG station and LNG fueling station. Additionally, a linear programming method is utilized to do research when all LNG terminals are completed. The prospective study is performed to work out the best solution to the LNG routing issues in North China and to bring some suggestions to LNG industry and government.

Key words: LNG; linear programming; routing

CONTENT

1 Introduction

Liquefied Natural Gas (LNG), a liquid mainly composed of methane, can be converted into natural gas after being compressed and cooled to its boiling point (-161.5 degrees centigrade) temperature. The density of LNG is about 430 - 470kg/m^3 (slightly different due to different components). The ignition point is about 650 and the calorific value is 52MMBtu/t. Normally, LNG needs to be stored in a special storage tank with -161.5 degrees Celsius and 0.1MPa, and needs to be transported by a special ship or LNG tanker. The components of LNG are very pure. When it burns, only water and carbon dioxide will be produced.

1.1 Research background and significance

The price of LNG of 1 cubic meter is 30% lower than that of gasoline and diesel, and its combustion calorific value is equivalent to that of 1.4 liters of gasoline or 0.9 liters of diesel. LNG transmission does not require piping and only the vehicle with special storage containers is enough. The pressure capacity of the LNG tank is about 200 times smaller than that of the CNG storage tank, and the safety is high. As a kind of clean, efficient and low carbon energy, LNG has been widely used in power industry, transportation, civil and commercial fields (LNG car, LNG power generation, city gas, energy peak etc.).

1.1.1 Global LNG market pattern

With the continuous deepening of global energy cleaning, natural gas is greatly favored in the industry in recent years, and liquefied natural gas (LNG) has become an "active" in the market. The GECF, based in Doha, Qatar, is expected to double the global volume of LNG trade by 2040.

According to the Gulf Times, GECF recently released a global gas outlook report, which showed that the total global LNG trade reached 2.577 million tons in 2016, 15 million tons more than the previous year. The report predicts that by 2020, the total volume of global LNG trade will rapidly increase to 356 million tons / year, with an increase of nearly 100 million tons / year. GECF said that since the Paris agreement was signed at the end of 2015, the low carbon future had gradually become the focus of the international community, and natural gas had become one of the main choices for many countries to achieve the goal of "national independent contribution". In recent years, the production and trade of both the pipeline natural gas and the LNG have increased rapidly, especially the LNG trade, which is in a "boom period", and the prospect of export growth is very optimistic. The average annual growth rate is expected to reach 2.8% by 2020. In the region, the traditional LNG export "heavy" Middle East region is still optimistic about its export level, but the share of the global market may decline. The report points out that until the beginning of this century, the Middle East is still the largest LNG exporter in the world. Among them, the export volume of four countries of Qatar, Oman, the United Arab Emirates and Yemen has taken over 1/3 of the total LNG export volume in the

Middle East. But with the rise of new LNG exporters, such as the US and Australia, the market share in the Middle East is gradually eroded.

GECF predicts that by the end of 2020, only 28% of global LNG exports will come from the Middle East. However, the industry is optimistic about the prospects for LNG exports in the Middle East. According to the industry, Qatar, the world's largest LNG exporter, has said it will lift LNG capacity limit and increase production by 30%, while Yemen is gradually restoring the production and export capacity of LNG. In addition, Iran has been actively promoting natural gas production in the near future with a view to join in the LNG export line. GECF's report predicts that by 2025, LNG exports in the Middle East will account for more than 30% of the global market. According to the GECF report, by 2020, the overall LNG exports of GECF member countries will decrease from 59% in 2016 to 47%; by 2025 that proportion will raise to 52%; by 2040 it will reach 50% further.

GECF also points out that, in addition to the Middle East, Australia and the United States will be the most growing LNG export countries. This is mainly because the two countries' natural gas liquefaction facilities will be on the line in the next few years and by then their export capacity will be significantly enhanced. Secondly, Energy In Depth company (EID) thinks that the US may become the world's largest exporter of natural gas in 2020. In addition to the subjective efforts of the Trump administration to promote the construction of LNG terminals, the challenges faced by other major LNG exporters also affect the direction of the ranking of LNG exporters: the shortage of natural gas in Australia, which will limit its LNG exports. At present, natural gas exports account for 50% of its total domestic output, and exports are expected to account for 2/3 of total output by 2030. To ease domestic concerns about natural gas shortages and stabilize natural gas prices, Australia recently issued regulatory measures to restrict natural gas exports. Australia's LNG exports will be limited to 80 million tons from 2019. Compared with Australia, the net exports of LNG in the next ten years will only account for 10% to 12% of the total domestic gas production, while Qatar is facing tension with its neighbor. Although the LNG capacity of Qatar will increase to 100 million tons / year from the current 77 million tons / year in 7 years, its relationship with Saudi Arabia, the United Arab Emirates, Egypt and other countries will affect its export volume and export lines. In addition, about half of the imported natural gas in Europe is from Russia, and the Eastern European countries are now trying to get rid of their relations with Russia, which will be an opportunity for the US LNG to enter the European market. The competition caused by the US export LNG will also prompt the sharp reduction of LNG prices in Europe and Asia.

Table 1 Globle LNG Supply and Demand (million tons)

Area(Globle)	2015	2016	2017	2018	2019	2020
LNG Produce	305	338	375	409	439	467
LNG Demand	251	269	295	326	359	395
Demand by Area	2015	2016	2017	2018	2019	2020
Asia	178	190	201	213	225	235

Africa	22	17	19	19	22	22
Europe	39	40	50	66	82	106
Other Area	12	22	25	27	30	31

The demand trend similar to that of LNG is also optimistic (see Table 1). In 2016, the global LNG imports amounted to about 2.63 million tons, and compared with the 14.9 million tons in 2015, it was increased by 6%. With Columbia, Jamaica and Malta joining in the importing of LNG, the global LNG importing countries / regions reached 37 in 2016 (the top 15 are listed in Table 2). Among them, LNG imports in Japan, South Korea, China, India and Taiwan of China ranked the top five in the world, and they accounted for 31.7%, 12.7%, 9.9%, 7.1% and 5.7% of the total LNG imports in the world, with a total ratio of 67.1%.

Table 2 2016 Global LNG Import status (ten thousand tons)

Country/Area	2015	2016	Change	Increasing rate	Occupied
Japan	8500	8330	-170	-2%	37%
Korea	3340	3340	0	0%	15%
China	1970	2610	640	32%	11%
India	1500	1860	360	24%	8%
China Taiwan	1460	1510	50	3%	7%
Spain	1000	1010	10	1%	4%
England	980	780	-200	-20%	3%
Egypt	270	680	410	152%	3%
France	470	660	190	40%	3%
Turkey	540	540	0	0%	2%

Italy	430	450	20	5%	2%
Argentina	390	350	-40	-10%	2%
Western Mexico	320	340	20	6%	1%
Kuwait	300	320	20	7%	1%

Source from Wood Mackenzie

Analyzing from the demand side, the Asia Pacific region is still the main force in the LNG import market. The report points out that Japan and South Korea will continue to lead the LNG import in the Asia Pacific region. It is estimated that by 2040, the total LNG imports in the Asia Pacific region will reach 1.44 billion tons per year, and the share in the global demand market will be around 29%.

1.1.2 Analysis on the current situation of LNG market in China

At present, China's LNG resources supply mainly includes two ways: trade import and domestic production. At present, China's natural gas market is still facing the problem that domestic gas supply is hard to meet the growing market demand, and its dependence on foreign countries is constantly improving. In 2016, in China, the proportion of natural gas to primary energy consumption rose to 6.2% (5.9% in 2015), while the dependence on foreign energy reached a new high of 35% (31.5% in 2015). In order to achieve the goal of "let the proportion of natural gas consumption to reach 10%" in the 13th Five-Year "energy development" plan, China not only needs to strengthen exploration and development of the natural gas resources so as to increase its supply capacity but also needs to emphasize the import of sky gas, including pipeline gas and LNG.

The supply of raw gas is under administrative monopoly. At present, China's LNG main raw materials (conventional natural gas) are monopolized by Petro China, Sinopec, CNOOC, and Yanchang Petroleum. A small number of enterprises have unqualified natural gas (such as shale gas and coal-bed methane) mining qualification, but the impact on the market is very limited. As the LNG import is under high monopoly, at present, China's LNG import qualification examination is very strict. To obtain the LNG import qualification, the enterprises do not only need to have stable foreign sources (1 million tons / year), but also need to hold at least one LNG station in China. At present, China's private enterprises with LNG import qualification are only one of the new Austrian energy companies. At present, the LNG domestic trade supply pattern is a competitive market. In addition to three barrels of oil, there are many private and state-owned enterprises in the LNG domestic market competition, and they have gradually formed a perfecter industrial chain. The monopoly degree of LNG domestic market is far lower than that of crude oil and refined oil market, and its supply and demand market and product price have obvious marketization characteristics.

For domestic LNG demand patterns, the LNG mainly comes into the terminal Chinese consumer market by two approaches. The first is to use LNG as the main air supply source for coastal cities, that is, LNG is directly vaporized at the station into the trunk pipeline and will be transported to the urban gas pipeline, Network, gas power plant or industrial enterprise. The second is transporting LNG to areas not covered by natural gas pipelines by roads or ships, and these LNG will be used by gas companies, gas-fired power plants, industrial users, and gas stations for secondary sales or vaporization.

1.2 Literature overview

Both scientists in China and abroad have done quite a lot of research on routing problem.The earliest research is to build models for simple random needs or incident needs analysis for routings, such as Federgruen (1984) and Gaur and Fisher (2004). Javid and Azad (2010) for the first time presents a novel model to simultaneously optimize upstream and middle reaches of supply chain, including inventory and routing decisions. Also, through probability analysis method, Chan et al.(1998) tried to solve the problem of supply chain fixed partition strategy and zero inventory ordering strategy. Aghezzaf and Landeghem (2006) were the first to start the study of how to solve the problem of routing under the condition of fixed demand and multi-stroke. On the basis of their model, FU Chenghong and FU Zhuo(2010) used a heuristic algorithm to optimize the routing for the stochastic demand of the two level system. Many scholars also focused their study on the location, supply chain, inventory and routing, and tried to establish a model based on the combination of three factor. For instance, Shen, Z. J. M., & Qi, L. (2007) proposed an integrated stochastic supply chain design model by taking the location, inventory, and routing costs into consideration.The shipment from a DC to its customers were also evaluated in the text by using a vehicle routing model and the linear direct shipping model.

On the other hand, Liu, S. (2006) combined integer programming model and a heuristic procedure to study the integrated production, inventory and distribution routing problem (PDRP) and optimization problem. As to the problem of inventory and path optimization for routes in supply chain，Christiansen et al. (2004, 2007) published two articles successively, and presents a review of ship routing problems in general and mathematical models to solve the inventory ship routing problems.

However, these articles only researched the supply chain of ordinary goods. Owning to the special properties of LNG, the routing strategy of LNG supply chain will be different. LNG routing can be considered as a special case of the MIRP. An excellent overview of the business cases and common characteristics for LNG routing can be seen in Andersson et al.(2010). Analogy an optimization model for the upstream to middle reaches of the supply chain for common goods，which is the article of Andersson et al.(2010). It mixed integer programs, optimize transportation planning and inventory management of producer and a vertically integrated company. On this basis, Sun Xiajun (2014) improved the routing problem of Dalian LNG project, fully considered the particularity of ship routing, and used the mixed integer programming model to optimize it. However, the decision on ship transportation has not taken into account the uncertainty of weather and other factors. Goel et al.(2012) proposed a model to optimize the ship schedule decisions together with inventory management at both production and re-gasification terminals. While as to the same theme, BV Asokan et al. address this issue by proposing several deterministic and non-deterministic parallel large neighborhood search algorithms for solving large LNG-IRPs as well as comparing parallel neighborhood search algorithms. NIU D X et al. (2015) also established a fleet deployment optimization model for LNG shipping.

And for the LNG station, the foreign Ghiami, Y.et al.(2015) studied the subject similar to this article. As to the research method, they combined LNG routing and deteriorating inventory management problem modeled with both an arc-flow and a path-flow formulation. Both models are tested and compared on instances motivated from a real-world problem, and the key part is the research on the liquefied natural gas distribution network in Holland. For the domestic research on LNG station inventory management, FU Zihang(2010) set up two stages of dynamic mathematical model of LNG station inventory and LNG transport ship and calculate LNG tank capacity and configuration from the description of logistics process. CAO Pengfei et al.(2012) has made a stereotyped classification of the impact of Qingdao's establishment on Shandong's LNG gas supply. The difference is that CHEN Shuai et al.(2015) studies the minimum transport volume for the different parameters of the LNG station itself. By browsing through the literature, it can be seen that few researches are made on the inland routing optimization of LNG station. So I think that the research about the routing between LNG station and fueling station is great significant for North China LNG stations to reduce the cost and increase profitability.

1.3 Research purpose and methodology

The main goal of this dissertation is to analyze the possible solutions about the product distribution between LNG and refilling stations by the economic model. The North China area is taken as an example. And 2 LNG stations under construction are taken into consideration and the distribution problem between six LNG station and LNG fueling stations of North China where take city for a unit will be optimized. And then the distribution of LNG during the simultaneous operation of six stations in North China in the future is proposed.

This dissertation will use linear programming and maybe some several mathematical forecasting methods to collect data. Based on the locations of LNG stations that are already operated and under construction of North China, the LNG fueling stations of five cities in North China are taken as the demand. In addition, 3 transport modes of tank car, tank box and pipage would be compared in the dissertation, and the ratio and the degree of impact on profits will be considered. The LNG routing would be discussed when adding two new LNG stations in the future.

2 Analysis of LNG infrastructure in China

2.1 Status and distribution of LNG terminals and fueling station

China's LNG is mainly imported and produced by domestic natural gas liquefaction plants. In terms of imported LNG, since the launch of Guangdong Dapeng LNG station in 2006, a total of 11 LNG stations have been put into operation in China by the end of 2015, and LNG imports have been put into operation. At the same time, LNG imports have increased significantly. According to the national energy development master plan, combined with the supply of domestic natural gas and imported pipeline natural gas, China's demand for imported LNG is expected to be 310×108~560×108m3 by 2020, and it is expected that the demand for LNG imported by China in 2025 will be 130 × 108~ 560 × 108m3.

2.1.1 LNG terminal

LNG's primary storage devices mainly include LNG stations and natural gas liquefaction plants. In the past 10 years, the construction of China's LNG industry and supporting infrastructure have been booming. A number of LNG stations and a large number of small and medium-sized liquefaction plants have been built in the country and they basically grasped station process technology and liquefaction process technology. Most of the equipment has achieved localization. In addition, relatively complete natural gas pipelines and gas storage facilities have been established.

The LNG station is a liquefied natural gas station and and it mainly stores liquefied natural gas and then sends the natural gas out. LNG stations include LNG terminals and LNG tank farms. The implementation of LNG cold energy utilization at LNG stations can reduce cold pollution[1] and increase the level of comprehensive utilization of energy. The LNG cold energy can be used in a wide range of fields. The LNG cold energy can be used to select the gas turbine or expansion method according to the conditions of natural gas delivery; a low-temperature freeze warehouse can be built beside the LNG station to frozen food by LNG cold energy; LNG can also be used. Low-temperature drying and crushing of cold energy can be used in medicine and food industry; LNG cold energy can also be used to liquefy carbon dioxide; it can be used in welding, firefighting, foods freezing, etc. In addition, the LNG cold energy can be used to separate air to produce liquid nitrogen, liquid oxygen, and liquid argon.

By the end of 2015, 11 LNG stations had been established and distributed in Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan and other coastal provinces and cities. The annual capacity has reached 3850×104t (525×108m3). The tank capacity is 534×104m3, and the daily gas supply capacity is 18.6×104t. The average annual increase in the scale of reception from 2006 to 2015 is 32%. Five LNG stations are under construction and the annual capacity is 1500×104t (205×108m3). The tank capacity is 272×104m3. Geographic distribution of China's LNG stations: Besides the Guangxi LNG station

[1] Cold pollution: cold energy is a kind of low temperature energy, and the pollution caused by cold energy is called cold pollution. While, the use of LNG cold energy can reduce a certain degree of cold pollution.

in Beihai that is under construction, the other LNG stations are located in 11 coastal provinces and cities. The distribution of domestic LNG stations is shown in Table 3.

Table 3 Distribution of LNG reception stations in China

Order	Province/City	Terminal number	Project Status		
			Operational	Construction	Planning
1	Fujian	4	3		2
2	Guangdong	11	7		8
3	Guangxi	3	2		2
4	Hainan	3	2		2
5	Hebei	1	1		1
6	Hubei	1			2
7	Jiangsu	4	1	2	4
8	Liaoning	2	2		1
9	Shandong	4	1	1	4
10	Shanghai	2	2		1
11	Tianjin	2	2	1	1
12	Zhejiang	4			2

At present, the domestic LNG station basically adopts a recondensing process. The generated boil-off gas is pressurized by the BOG compressor and then enters the re-condenser to realize condensation. After being condensed with the external LNG, it is pressurized, gasified, and exported. The LNG storage tanks basically use full-capacity prestressed concrete top storage tanks. The common specification is 16×104 m3, and the largest domestic LNG storage tank is 20×104 m3.

From the foregoing analysis, it can be seen that in the future, the natural gas industry is expected to come into high-speed development, and LNG will become the biggest bottleneck in the entire industry chain. By then, it will become one of the sub-sectors with the highest demand growth rate in the energy sector. In the short term, the main beneficiaries are companies that now have stations, such as Sinopec, Petro China and Guanghui. Among them, Guanghui, due to its small scale, mainly sell products by tank trucks, with the largest price elasticity. Petro China and Sinopec Corp. mainly sell products by pipe networks, which is less price-elastic. However, as the turnover rate increases, the depreciation costs will drop sharply, and more low-cost spot gas can be purchased to lower raw material costs. The overall situation is also very benefit. In the long run, the most benefited ones are undoubtedly the large number of newly built stations in the future, such as Zhongtian Energy and Guanghui Energy. In addition, ENN group is also building China's largest private station at the group level, which is also worthy of attention.

Hereby a 3 million ton (4 billion party) station is taken as an example to analyze the long-term profit of the LNG station. If the long association price is 2000 yuan / ton, then the current average price of 80% will be 1.44 yuan / party, and the cost of and transporting is expected to be 0.13 yuan / party. The cost is 0.1 yuan per square, and the price is 2.4 yuan / party. The equivalent of a single profit is around 0.73 yuan; in the form of a tank car liquid to go out of sale, the gas price is about 3 yuan per square, considering the freight of 140 yuan / ton, the single profit will generally reach 1.33 yuan. For most stations, pipeline transportation and retail account for a general 70%vs30%, and the total gross profit margin is about 0.8 yuan. The total gross profit is 3.2 billion yuan, corresponding to the investment scale of 4 billion yuan, and both profitability and project investment recovery period are very considerable.

2.1.2 LNG fueling station

LNG fueling station can be mainly divided into two types which are the fixed station (LNG gas station and L-CNG gas station) and the pry loading station (ground type crowding station and mobile hydraulic truck), including LNG gas station, L-CNG gas station, skid-mounted station, mobile refueling vehicle.

In 2016, there were 2,460 LNG refueling stations nationwide, which increased by 8.85% compared with that in the same period of 2015, maintaining the growth rate last year. Judging from the nationwide distribution, China's LNG refueling stations are mostly located in the coastal areas of North China and East China, which coincides with downstream consumer regions. In 2016, the number of LNG refueling stations in the top 10 provinces with LNG consumption was 1,443, accounting for 58.66% of the total. In 2016, China's LNG refueling stations maintained a constant development pace and did not have great change. The main reason is still that the profit of the filling stations has fallen and the market is saturated. Affected by the supply-side reform, coal production declined significantly in 2016, and the transportation industry was limited for three months during the year, which indirectly led to a decline in LNG refueling stations. The decline in the national economic growth rate has become a fact. Markets in most industries are sluggish. Affected by this, the mainstream construction companies are cautious in investment and slow down the pace of market development. In addition, the current cost recovery cycle of LNG filling stations has continued to increase, resulting in a significant decrease in investment attention. This is the main reason causing the slowdown of the growth rate of LNG filling stations.

The top three provinces were Shandong, Hebei and Xinjiang. Among them, the total number of Shandong LNG refueling stations reached 295, accounting for 12% of the total, up 9.06% year-on-year. Hebei LNG refueling station holds 240 seats and accounts for 10%, increased by 6.33% over the same period of last year. The number of Xinjiang LNG filling stations was 198, accounted for 8% of the total, and the number of new additions in 2016 was relatively small.

Among them, the total number of LNG refueling stations in more than 100 provinces is 1515, accounting for 61.58% of the total. From the perspective of LNG refueling stations, China's LNG refueling stations are mainly located in major LNG-consuming provinces and LNG-producing provinces such as Inner Mongolia, Shaanxi, and Shanxi. Among them, Shandong has developed rapidly. The main reason is that Shandong's LNG auto market has developed rapidly. By the October 2016, Shandong's LNG vehicle ownership had reached 22,000, accounting for 10.27% of the total, ranking the first place in China. Relying on the development of the Shandong logistics and transportation industry, the demand for downstream vehicles is higher. The growth of LNG filling stations in the province maintained a relatively high rate. In addition, the overall economic development of Shandong Province maintained the forefront of the country. Driven by the economic environment, the development of the LNG refueling station market in the province was relatively good. At present, the construction of LNG refueling stations in Shandong Province is at the forefront in terms of policy formulation, industry regulation, safety management, and development speed. The overall consumption of LNG also ranks in the forefront in the whole country. These are all LNG refueling stations. Development laid a good foundation. In terms of the distribution all over the country, China's LNG refueling stations are mainly distributed in regions with large demand for LNG and with rich gas sources. In 2015, the number of LNG refueling stations in the top ten provinces ranked among 1371, accounting for as much as 60.66. %. In 2015, the growth rate of China's LNG refueling stations declined significantly due to the economy slowdown, the sluggish logistics market, and a series of problems such as the sluggish industry and related issues, which led to a decline in demand for vehicles and a overall sluggish market. Affected by this, the attitude of mainstream companies in LNG refueling stations has changed, and the market expansion has been reduced. Besides, the number of new refueling stations has gradually decreased. In addition, the procedures for filling stations are cumbersome and the decline in profits leads to an increase in the return cycle, which is also an important reason for the current difficulties.

2.2 Comparison and selection of LNG transport mode

First of all, there are two strict approaches for LNG. The first one is transporting by pipelines through gasification model, which can supply for residents, such as natural gas at home, and can also supply for large-scale industrial users, such as power plants.

By the end of 2016, China has built 68,000 kilometers of natural gas pipelines, and the total transmission capacity of main pipeline networks exceeds 280 billion cubic meters per year. The pattern of gas supply in China is “West-East Gas Transmission, Air-Sea Landing, and Nearby Supply”. The national gas supply network mainly includes the West-East Gas Transmission System, Sichuan-East Gas Pipeline, Southwest Pipeline System, and Shaanxi-Beijing Pipeline System.

Secondly, it’s supply point for the terminal outputting in the form of a liquid, namely SSL (Small Scale LNG users). As an innovative LNG transport method, LNG tanks have not been applied to all stations. The LNG tanker, which is the most important tool for LNG land transport, is widely used because of its flexibility and economy. At present, mainly two forms of liquefied gas tankers are used in China: LNG semi-trailer tankers and LNG container tankers. Usually transported through the transport medium, the main medium is liquid oxygen, liquid nitrogen, liquefied natural gas and so on. The tanker has large volume and strong fluidity characters. All countries in the world are very strict on the safety management of tank trucks and China is no exception. Correspondingly, the Ministry of Labor and Personnel, the Ministry of Public Security, and the Ministry of Railways have expressly issued regulations about this. The clear and strict requirements are put forward on the design, manufacture, inspection, use, and management of tank trucks to ensure the safety of personnel, equipment, and property.

At present, domestic tankers are mainly used for distribution, but the biggest problem with tankers is that they cannot be multimodal. The tank box has this advantage, so it can be called as a breakthrough in the model. However, this breakthrough still requires many preparations, such as whether the LNG station can be filled with tank containers, whether the station's geographical location is close to the container terminal, and whether multimodal transportation is supported. All existing LNG stations can receive tank trucks. The filling port of the tanker is at the rear part, and the filling port of the container tank is at the side place.

As to the choice of transportation, almost all stations choose tanker transportation. Because of resource constraints, some stations choose the latest tank container transportation, and the main transportation terminals of the pipeline network are residents and industrial users. The general sales approach is to build a station first, then build a pipe network in the local area and connect it to the supervisory network. However, there is no inevitable connection between the construction of the pipe network and the station. For example, the Guanghui Energy Station in Qidong is not equipped with a pipe network. There are some other such stations, like PetroChina's station in Rudong, when the project was established in the name of security and custody networks. Therefore, this type of station is certainly synchronized with the construction of the pipeline network. Another example is the

Xinao Energy station that was newly built in Zhoushan this year under the name of vessel bunkering. Therefore, their stations mainly refueled ships, so the built-up transportation mode may be limited to LNG bunkers and small LNG carriers.

3 Status of North China LNG terminals routing problem

3.1 Supply and demand of North China LNG terminals

First of all, the gas shortage is mainly caused by the imbalance of supply and demand structure. There are two main types of domestic gas supply channels: one is domestic production; the other two is foreign imports. The domestic gas has gradually formed the conventional and unconventional multiple gas supply situation. The imported gas has formed pipeline gas and LNG multi-channel supply pattern, and more than 10 resources are imported. In recent years, with the rising dependence on natural gas in China, the proportion of imports has gradually increased. From January to October of 2017, the production of natural gas in China was 121.2 billion cubic meters which was increased by 11.2%, and the import of natural gas was 72.2 billion cubic meters, which was increased by 27.5%. What's more, and the consumption of natural gas was 186.5 billion cubic meters, which was increased by 18.7%. On the supply side of natural gas, the overall rally was obvious in 2017.

Even so, facing the rapid growth of downstream demand, especially with the advent of the winter heating season, the domestic natural gas market is obviously in short supply. Petro China estimated that in the whole winter heating period, the supply gap in northern China was about 4.8 billion cubic meters.

At present, there are no new imported pipelines in China. The number of LNG stations is not much and the potential of natural gas exploitation is limited in the short term. Besides, the construction of gas storage and peak regulation facilities is not enough. As a senior practitioner of the LNG industry, Yu Baodong said that with the promotion of clean energy policy in China, the proportion of natural gas in the primary energy was increasing, and the ten boom years of domestic natural gas industry has arrived, and we expected that natural gas will gradually become main supply after 2020.

Secondly, the current "gas shortage" has been particularly serious in North China, and downstream users have been hit harder. From the point of view of the supply and demand of LNG in North China, the main suppliers are Petro China, Sinopec and CNOOC. Besides these three, there are a number of second echelon enterprises, such as Beijing energy, Beijing gas, ENN and other enterprises. At present, the state is promoting the access of the infrastructure (LNG station and long-distance pipeline network) to third parties. The second echelon enterprises are actively involved in the mixed ownership reform of three major oil companies in order to make up the innate disadvantage of the lack of upstream resources. In terms of demand, North China is the main area because of the natural gas heating in winter.

And for the recent supply and demand gap solutions, the official report, Beijing newspaper, mentioned recently that we should speed up the construction progress of

Sinopec's Tianjin LNG reception station, quickly put into production air intake; In addition, actions shall be taken to promote the interconnection of natural gas pipeline network, and to realize the rational allocation of natural gas resources among North, South, East and West regions. Furthermore, we should solve the natural gas supply problem in Central Asia as soon as possible, and ensure the gas supply of this main channel. For the government, we can make use of comprehensive policy measures to solve the problem of supply shortage. First, we should furtherly promote the market reform of price, design the appropriate market incentive mechanism and improve the enthusiasm of the supply side. Secondly, from the angle of haze treatment, we can increase the subsidy to the "coal to gas". At the time, we can sacrifice a certain degree of industrial gas to meet the needs of the residents.

3.2 Importance of study on North China LNG terminals routing

As previously analyzed, as the main LNG consumption area, there is an imbalance and great gap between the supply and demand of LNG resources in East China. In addition, the economic performance of the LNG industry is not very good, either.

The main goal of this dissertation is to use economic model to analyze the possible solutions for product distribution between LNG and refilling stations. Then take 2 LNG stations under construction into consideration and optimize distribution problem between 6 LNG stations and LNG fueling stations of North China. And offer a proposal on the distribution of LNG during the simultaneous operation of six stations in North China in the future. In addition, 3 commonly used transport modes of tank car, tank box and pipage would be compared in the dissertation. The application ratio and the degree of impact on profits will be analyzed. The LNG routing would be discussed when adding two new LNG stations in the future.

In my opinion, the research of the routing problem between LNG station and fueling station is greatly significant for North China LNG stations to reduce the cost and increase profitability.

4.Theoretical model establishing of LNG inventory and routing optimization

4.1 The Expression of LNG Routing in North China

The LNG routing problem can be solved by the linear programming method. With the development of LNG and the establishment of stations, more and more people are paying attention on the routing optimization issue. The locations of the station and the filling station are different, and the design scale and annual demand are also different. In addition to a certain percentage of self-sufficiency within the North China region, it is still necessary to import from external regions or countries to meet the demand of LNG refueling stations in North China. This can help to achieve reasonable development and to achieve the lowest transportation cost. Therefore, it is necessary to optimize the LNG routing. Therefore, in this paper, relevant restrictions data and restrictions on the reasonable allocation of LNG resources are analyzed.

4.2 Problem analysis

This problem is a linear programming problem based on the mathematical model. After the model is established, an optimized solution can be clearly analyzed based on the existing data. Gathering gas station requirements, the LNG obtained through the distribution should meet the needs of gas stations as far as possible. The station, as an LNG supplier, should not exceed its annual design scale. Because the objective function of the linear programming model is the total cost, the data of the distance between each station and the filling station is also required. The total transportation cost is calculated by multiplying the unit cost (Yuan/ton kilometer) and the volume of traffic between locations.

4.3 Model assumption

(1) Assume that the demand for refueling stations remains stable, and prices will not be subject to crazy price increases or price declines. Also, other factors will not affect the annual demand.

(2) Assume that the utilization rate of the stations in each place is 100% and there will be no shortage. That is, the annual supply of LNG is equal to the annual design scale.

(3) Tanker transportation costs will not rise sharply and ensure the rationality and stability of costs.

4.4 Symbol conventions and model establishment

To sum up, the model can be expressed by the following formula:

$$minz = \sum_{i=1}^{n} \sum_{j=1} a_{ij} x_{ij} k$$

$$\begin{cases} \sum_{i=1}^{n} \sum_{j=1} a_{ij} x_{ij} k = z \\ \sum_{j=1}^{n} x_{ij} \leq S_i \qquad (i = 1,2, \ldots, m) \\ \sum_{i=1}^{m} x_{ij} \geq D_j \qquad (j = 1,2, \ldots, n) \end{cases}$$

D_j Annual demand of LNG at filling station j

S_i Annual supply of station i

k Unit cost (yuan / ton km)

z Total cost

a_{ij} The transport distance from station i to filling station j

x_{ij} The transport volume from station i to filling station j5 Practical model application of LNG terminals routing optimization

5 Practical model application of LNG terminals routing optimization

5.1 Actual factors of model application

First, the basic data was collected. Before the deadline, China's LNG station has stopped its approval. The distribution of LNG stations in North China is shown in Table 4.

Table 4 LNG stations distribution in North China

Province/Code	Terminal Name	Designed Scale (000tons/year)		Object Status	
		No.1	No.2	No.1	No.2
Hebei	HB TangShan LNG Terminal Station	350	300	Operating	Planning
TianjinA	TJ LNG Floating Station	220	380	Operating	Constructing
TianjinB	TJ LNG Station	300	700	Operating	Planning

From the table, it can be seen that the LNG stations currently operating in North China include Tangshan Phase 1 station, Tianjin Phase 1 LNG station and Tianjin Phase 1 LNG floating station, with design scales of 350,300,220,000 tons/year respectively. The planned stations include the Tangshan Phase 2 station and the Tianjin Phase 2 LNG station with a design scale of 3,007 million tons/year. The LNG station under construction is Tianjin Phase 2 LNG floating station with a designed capacity of 3.8 million tons/year.

Generally, station is located in in the upstream of LNG supply chain, and then transports the LNG to the midstream storage facilities. These stations include LNG satellite station, LNG onshore bunkering station, LNG bunkering pontoon, LNG refueling station and regasification station by LNG bunker, small LNG carrier, LNG intermodal, LNG trailer and LNG train. The LNG can also be transported to industry and civil through gas pipeline. Finally, LNG would be used by LNG fueled ships and vehicles after transported by LNG trailer. The distribution of LNG refueling stations in North China is shown in Figure 1, with 27 in total, 11 in Hebei, 11 in Shanxi, 1 in Beijing, and 4 in Tianjin. Daily sales and details are shown in the table.

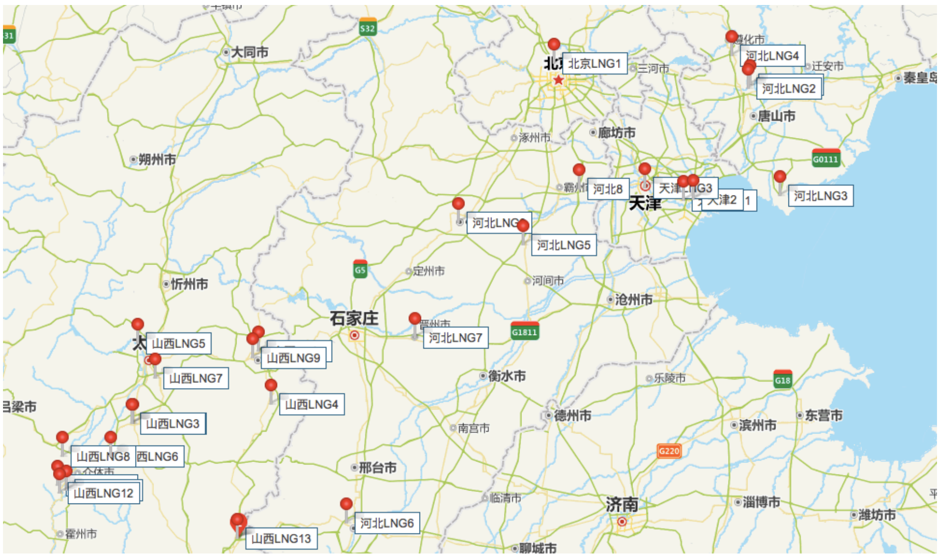

Figure 1. LNG refueling stations in North China

Table 5. Details of North China LNG refueling station (1000m^3/day)

Code	Province	City	Company	Sales

SX1		LVLIANG	SHANXI GAS	1.5
SX2		TAIYUAN	SHANXI GAS	1.5
SX3		TAIYUAN(QIXIAN)	HUARUN GAS	1.5
SX4		TAIYUAN(QIXIAN)	SHANXI JINCHEN MINING	1.5
SX5		XIYANG	SHANXI JINCHEN MINING	2
SX6	SHANXI	LINFEN(GOUYUTAN)	GANGHUA GAS	3
SX7		LINFEN(YONGJI)	GANGHUA GAS	1.5
SX8		LINFEN(JUNYINGFANG)	GANGHUA GAS	1.5
SX9		YANGQUAN	HUARUN GAS	1
SX10		YANGQUAN	GANGHUA GAS	1
SX11		CHANGZHI	SHANXI GAS	1.5
HB1		JINZHOU	ENN	3
HB2		JINZHOU	CNPC KUNLUN	1
HB3		BAODING	CHINA GAS	3
HB4		BAODING	CNPC KUNLUN	1
HB5		HANDAN	ENN	2
HB6	HEBEI	TANSHAN(XIANGKE)	CHINA GAS	2
HB7		TANSHAN(JIZHOU)	CNPC KUNLUN	2
HB8		TANSHAN(ZUNHUA)	CHINA GAS	2
HB9		TANSHAN(RENQIU)	CNPC KUNLUN	2
HB10		TANSHAN(CAOFEIDIAN)	CNPC KUNLUN	2
HB11		TANSHAN(FENGRUN)	CNPC KUNLUN	5
BJ1	BEIJIN	CHAOYANG AREA	GREEN ENERGY	3
TJ1		WUQING	CNOOC	2
TJ2	TIANJIN	BINHAI NEW AREA	CNPC KUNLUN	1
TJ3		BINHAI NEW AREA	CNOOC	2
TJ4		TANGGU	CNOOC	1

The shortage of LNG resources in North China has become more and more serious. The pipeline network connected with industrial and civil aspects can not be optimized in the short term, and they are greatly related with the purpose and scale of LNG stations, which is difficult to change. We will then conduct an optimization study on another route to the LNG station, that is, transporting it to a LNG refueling station via a tanker. Through the establishment of a model, we will study the allocation of LNG refueling stations at various LNG stations in North China based on the completion of the currently approved LNG stations, and will make judgments on whether or not the pressure of natural gas shortages can be alleviated after completion of all the constructions. How to realize the lowest transport cost and meet the overall needs of the gas station will be also analyzed.

5.2 Solution of north China LNG terminals routing optimization model

First of all, the relationship between freight cost and transport distance of LNG tanker is calculated as follows (generally)：

Table 6. Basic data of calculation

Basic data	
Load	19.5 tons/car
Total mileage in 8 years	1 million km
100 km fuel consumption	35L

Diesel price	7.4 Yuan/L
Manual	6000 Yuan/person/month
Depreciation time	Reserve 10% Residual Value
Original value	1200 Thousands

Calculation process: Unit: RMB/ton/km

1. Miles per year: 1 million/8=12.5 million km;

   Mileage per month: 125,000/12=10,400 km;

2. Fuel cost: 35*7.4/100/19.5=0.133 Yuan

3. Artificial: 6000/10400/19.5*2=0.059 Yuan

4. depreciation: 1200000/8/125000/19.5 = 0.0615 Yuan

5.Vehicle inspection: 20,000 Yuan/year

   20000/125000/19.5=0.0082 Yuan

6. Maintenance: 70% of the annual depreciation expense

   1200000/8*70%/125000/19.5=0.043 Yuan

7. Insurance: 60000 Yuan/year

   60000/125000/19.5=0.024 Yuan

8. Management fees: 0.015 Yuan

9. Funds interest: According to the loan of 70% and the annual interest rate of 7%:

   1200000*70%*7%/125000/19.5=0.024

10. Toll fee: 0.045 Yuan

Total: 0.49 Yuan/ton/km

Annual supply of Hebei, Tianjin A and B terminal, All 27 fueling station annual demand as well as transport distance between every LNG terminal and fueling station as showed in the following table.

Table 7. LNG transport distance among North China

	SX1	SX2	SX3	SX4	SX5	SX6	SX7	SX8	SX9	Scale
Hebei	839.3	650.7	702.9	705.5	798.2	820.8	789.1	790.9	561.1	650
TianjinA	743.3	554.8	607	609.4	702.3	724.9	693.3	694.9	465.6	600
TianjinB	744.6	565.2	608.3	610.5	703.6	726	694.3	696.2	466.4	1000
Sales(D)	1.5	1.5	1.5	1.5	2	3	1.5	1.5	1	
Sales(Y)	547.5	547.5	547.5	547.5	730	1095	547.5	547.5	365	
Volume	240.9	240.9	240.9	240.9	321.2	481.8	240.9	240.9	160.6	
	SX10	SX11	HB1	HB2	HB3	HB4	HB5	HB6	HB7	Scale
Hebei	559.1	716.5	424.7	427.8	325	315.3	599.6	5.3	124.9	650
TianjinA	463.3	599.9	307.9	310.8	231.5	223.9	483.1	103.5	127.6	600
TianjinB	464	598.4	306.3	309.4	236.2	228.6	481.5	144.6	181.3	1000
Sales(D)	1	1.5	3	1	3	1	2	2	2	
Sales(Y)	365	547.5	1095	365	1095	365	730	730	730	
Volume	160.6	240.9	481.8	160.6	481.8	160.6	321.2	321.2	321.2	
	HB8	HB9	HB10	HB11	BJ1	TJ1	TJ2	TJ3	TJ4	Scale
Hebei	143.7	289.4	11.7	131.5	257.6	177.2	112.6	115.1	118.3	650
TianjinA	146.3	193.6	102.5	134	183.3	96.2	8.3	9.1	11.2	600
TianjinB	200	197.2	143.7	187.7	209.1	124.6	49.4	47.9	50	1000
Sales(D)	2	2	2	5	3	2	1	2	1	
Sales(Y)	730	730	730	1825	1095	730	365	730	365	
Volume	321.2	321.2	321.2	803	481.8	321.2	160.6	321.2	160.6	

The objective function of the model is set to SUMPRODUCT (Turnover). The LNG station's transshipment volume shall not exceed the annual design scale. The LNG transshipment volume shall meet the annual demand of the LNG refueling station (known LNG refueling station daily demand LNG As mentioned), and it is known that the LNG density is 0.42-0.46 tons/m^3 and the calculation is 0.44 ton/m^3.

It can be seen that the total design size of the three stations is 22.5 million tons/year, and the demand for 27 refueling stations is 82.709 million tons/year. Therefore, in the future, all the 1st and 2nd-stage stations in North China will be built and LNG resources will still not be able to be completed. Some 22.5 million tons of LNG can be consumed internally each year, but about 60.09 million tons of LNG from external areas still needs to be imported to meet the local needs. The self-sufficiency ratio is about 27%. A variety of solutions will appear. The first one is based on the orderly requirements of single regions. If Hebei is the first priority, the related results calculated based on SOLVER are shown in the following Table 8. There is commercial intercourse among only 9 fueling stations; the rest is 0 in transportation.

Table 8. SOLVER result 1

	SX1	SX2	SX3	SX4	SX5	SX6	SX7	SX8	SX9
Hebei	0.0	0.0	0.0	0.0	0.0	166.6	240.9	240.9	1.6
TianjinA	0.0	0.0	0.0	0.0	284.8	315.2	0.0	0.0	0.0
TianjinB	240.9	240.9	240.9	240.9	36.4	0.0	0.0	0.0	0.0

Therefore, the second solution is proposed, which reflects the best deliver ratio among all the fueling stations. The SOLVER is applied to find the optimal solution for distribution in North China under the background of satisfying the 27% demand. The results are calculated as following:

Table 9. SOLVER result 2

	SX1	SX2	SX3	SX4	SX5	SX6	SX7	SX8	SX9
Hebei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tianjin A	0.0	65.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tianjin B	65.5	0.0	65.5	65.5	87.4	131.1	65.5	65.5	43.7
	65.5	65.5	65.5	65.5	87.4	131.1	65.5	65.5	43.7
	SX10	SX11	HB1	HB2	HB3	HB4	HB5	HB6	HB7
Hebei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87.4	87.4
Tianjin A	0.0	0.0	0.0	0.0	131.1	43.7	0.0	0.0	0.0
Tianjin B	43.7	65.5	131.1	43.7	0.0	0.0	87.4	0.0	0.0
	43.7	65.5	131.1	43.7	131.1	43.7	87.4	87.4	87.4
	HB8	HB9	HB10	HB11	BJ1	TJ1	TJ2	TJ3	TJ4
Hebei	87.4	0.0	87.4	218.4	82.0	0.0	0.0	0.0	0.0
Tianjin A	0.0	48.5	0.0	0.0	49.0	87.4	43.7	87.4	43.7
Tianjin B	0.0	38.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	87.4	87.3	87.4	218.4	131.0	87.4	43.7	87.4	43.7

It was concluded that after the planned LNG stations are all completed and put into operation, if the three stations meet the average requirement of 27.2% for each LNG refueling station in North China, the optimal solution for delivery will be like the above shown figure. The lowest cost is about 1581519*0.49=774944 Yuan/year. In addition, about 73% of the remaining demand needs to be satisfied by other LNG stations outside North China.

5.3 Analysis of the sensitive report

The sensitive report is as following:

Table 10. Sensitive report-1

Name	Final Value	Reduced Cost	Objective Coeffient	Allowable Increment	Allowable Decrement
Hebei SX1	0	24	839.3	1E+30	24
Hebei SX2	0	21.6	650.7	1E+30	21.6
Hebei SX3	0	23.9	702.9	1E+30	23.9
Hebei SX4	0	24.3	705.5	1E+30	24.3
Hebei SX5	0	23.9	798.2	1E+30	23.9
Hebei SX6	0	24.1	820.8	1E+30	24.1
Hebei SX7	0	24.1	789.1	1E+30	24.1
Hebei SX8	0	24	790.9	1E+30	24
Hebei SX9	0	24	561.1	1E+30	24
Hebei SX10	0	24.4	559.1	1E+30	24.4
Hebei SX11	0	47.4	716.5	1E+30	47.4
Hebei HB1	0	47.7	424.7	1E+30	47.7
Hebei HB2	0	47.7	427.8	1E+30	47.7
Hebei HB3	0	19.2	325	1E+30	19.2
Hebei HB4	0	17.1	315.3	1E+30	17.1

Hebei HB5	0	47.4	599.6	1E+30	47.4
Hebei HB6	87.3786407	0	5.3	172.5	5.3
Hebei HB7	87.3786407	0	124.9	77	124.9
Hebei HB8	87.3786407	0	143.7	76.9	143.7
Hebei HB9	0	21.5	289.4	1E+30	21.5
Hebei HB10	87.3786407	0	11.7	165.1	11.7
Hebei HB11	218.446601	0	131.5	76.8	131.5
Hebei BJ1	82.0388349	0	257.6	6.7	70.7
Hebei TJ1	0	6.7	177.2	1E+30	6.7
Hebei TJ2	0	30	112.6	1E+30	30
Hebei TJ3	0	31.7	115.1	1E+30	31.7
Hebei TJ4	0	32.8	118.3	1E+30	32.8
TianjinA SX1	0	2.3	743.3	1E+30	2.3
TianjinA SX2	65.5339805	0	554.8	6.8	629.1
TianjinA SX3	0	2.3	607	1E+30	2.3
TianjinA SX4	0	2.5	609.4	1E+30	2.5
TianjinA SX5	0	2.3	702.3	1E+30	2.3
TianjinA SX6	0	2.5	724.9	1E+30	2.5
TianjinA SX7	0	2.6	693.3	1E+30	2.6
TianjinA SX8	0	2.3	694.9	1E+30	2.3
TianjinA SX9	0	2.8	465.6	1E+30	2.8
TianjinASX10	0	2.9	463.3	1E+30	2.9
TianjinASX11	0	5.1	599.9	1E+30	5.1
TianjinA HB1	0	5.2	307.9	1E+30	5.2
TianjinA HB2	0	5	310.8	1E+30	5
TianjinA HB3	131.067961	0	231.5	1.1	305.8
TianjinA HB4	43.6893203	0	223.9	1.1	298.2
TianjinA HB5	0	5.2	483.1	1E+30	5.2
TianjinA HB6	0	172.5	103.5	1E+30	172.5

TianjinA HB7	0	77	127.6	1E+30	77
TianjinA HB8	0	76.9	146.3	1E+30	76.9
TianjinA HB9	48.5436892	0	193.6	2.3	1.1
TianjinAHB10	0	165.1	102.5	1E+30	165.1
TianjinA HB11	0	76.8	134	1E+30	76.8
TianjinA BJ1	49.0291262	0	183.3	22.2	6.7
TianjinA TJ1	87.37864078	0	96.2	6.7	170.5
TianjinA TJ2	43.68932039	0	8.3	30	82.6
TianjinA TJ3	87.37864078	0	9.1	31.7	83.4
TianjinA TJ4	43.68932039	0	11.2	32.8	85.5
TianjinB SX1	65.53398058	0	744.6	2.3	815.3
TianjinB SX2	0	6.8	565.2	1E+30	6.8
TianjinB SX3	65.53398058	0	608.3	2.3	679
TianjinB SX4	65.53398058	0	610.5	2.5	681.2
TianjinB SX5	87.37864078	0	703.6	2.3	774.3
TianjinB SX6	131.0679612	0	726	2.5	796.7
TianjinB SX7	65.53398058	0	694.3	2.6	765
TianjinB SX8	65.53398058	0	696.2	2.3	766.9
TianjinB SX9	43.68932039	0	466.4	2.8	537.1
TianjinB SX10	43.68932039	0	464	2.9	534.7
TianjinB SX11	65.53398058	0	598.4	5.1	669.1
TianjinB HB1	131.0679612	0	306.3	5.2	377
TianjinB HB2	43.68932039	0	309.4	5	380.1
TianjinB HB3	0	1.1	236.2	1E+30	1.1
TianjinB HB4	0	1.1	228.6	1E+30	1.1
TianjinB HB5	87.37864078	0	481.5	5.2	552.2
TianjinB HB6	0	210	144.6	1E+30	210
TianjinB HB7	0	127.1	181.3	1E+30	127.1
TianjinB HB8	0	127	200	1E+30	127

TianjinB HB9	38.83495146	0	197.2	1.1	2.3
TianjinB HB10	0	202.7	143.7	1E+30	202.7
TianjinB HB11	0	126.9	187.7	1E+30	126.9
TianjinB BJ1	0	22.2	209.1	1E+30	22.2
TianjinB TJ1	0	24.8	124.6	1E+30	24.8
TianjinB TJ2	0	37.5	49.4	1E+30	37.5
TianjinB TJ3	0	35.2	47.9	1E+30	35.2
TianjinB TJ4	0	35.2	50	1E+30	35.2

The "final value" in the variable cell table represents the production plan of the problem, and its best combination is shown in the chart. "Objective coefficient" represents the cost per unit product. At the same time, the "allowable increment" and "allowable decrement" are listed, indicating that the profit of the unit product is changed between the "known number + allowable increment / - allowable decrement", and the production plan can be unchanged. If we exceed this range, the production plan needs to be changed. This range is the sensitivity of the optimal solution. Take Hebei-HB7 as an example：unit cost is 124.9+77=201.9，124.9-124.9=0，Therefore, if the value changed between 0- 201.9,the transfer volume wouldn't be affected，And so on. If all the products increase or decrease at the same time, the production plan will not be influenced. For reduced costs, comparing it and the results of calculation, we can find that the reduced cost equals the final test digit of variables. Take Hebei-HB8,9 as examples，the reduced cost are 0 and 21.5，so the test digits are 0, 21.5 respectively. Then the test digit of Hebei-HB8 is 0，which means it is a basic variable(see from the table, its final value is 87.4). And the test digit of Hebei-HB9 is 21.5，which means it is a nonbasic variable. In the other words, there is no transfer from Hebei terminal to HB, and so on. Therefore, when other conditions are unchanged, only if the unit cost for Hebei-HB9 transfer reduce from 289.4 to 267.9, it start to transfer LNG in this routing (or worth transporting), and the rest data is the same.

Table 11. Sensitive report- 2

Name	Final Value	Shadow Price	Constraint Value	Allowable Increment	Allowable Decrement
Hebei	650	0	650	1E+30	-2.41585E-1
TianjinA	600	-74.3	600	82.038834	0
TianjinB	1000	-70.7	1000	48.543689	0
SX1	65.5339805	815.3	65.5339805	0	48.54368932
SX2	65.5339805	629.1	65.5339805	0	65.53398058
SX3	65.5339805	679	65.5339805	0	48.54368932
SX4	65.5339805	681.2	65.5339805	0	48.54368932
SX5	87.3786407	774.3	87.3786407	0	48.54368932
SX6	131.067961	796.7	131.067961	0	48.54368932
SX7	65.5339805	765	65.5339805	0	48.54368932
SX8	65.5339805	766.9	65.5339805	0	48.54368932
SX9	43.6893203	537.1	43.6893203	0	43.68932039
SX10	43.6893203	534.7	43.6893203	0	43.68932039
SX11	65.5339805	669.1	65.5339805	0	48.54368932
HB1	131.067961	377	131.067961	0	48.54368932
HB2	43.6893203	380.1	43.6893203	0	43.68932039
HB3	131.067961	305.8	131.067961	0	82.03883495

HB4	43.6893203	298.2	43.6893203	0	43.68932039
HB5	87.3786407	552.2	87.3786407	0	48.54368932
HB6	87.3786407	5.3	87.3786407	0	87.37864078
HB7	87.3786407	124.9	87.3786407	0	87.37864078
HB8	87.3786407	143.7	87.3786407	0	87.37864078
HB9	87.3786407	267.9	87.3786407	0	48.54368932
HB10	87.3786407	11.7	87.3786407	0	87.37864078
HB11	218.446601	131.5	218.446601	0	218.4466019
BJ1	131.067961	257.6	131.067961	0	82.03883495
TJ1	87.3786407	170.5	87.3786407	0	82.03883495
TJ2	43.6893203	82.6	43.6893203	0	43.68932039
TJ3	87.3786407	83.4	87.3786407	0	82.03883495
TJ4	43.6893203	85.5	43.6893203	0	43.68932039

As to the shadow price, it reflects the value of unit resource. In this case, the three LNG terminal, Hebei, TianjinA and Tianjin, whose shadow price is 0, -74.3, -70.7 respectively, which means that the cost would be reduced more, when increasing transfer product from TianjinA terminal. The shadow prices of 27 fueling stations are variety, which is the additional cost of transporting more than 1 unit of LNG products to the fueling station. Therefore comparing the shadow prices among these 27 fueling stations, product with lower shadow price should be selected, to reduce the total cost.

6 Summary and Suggestion

6.1 Further clarify the strategic positioning of natural gas in China's energy revolution

Natural gas is a high-quality, efficient, green and clean low-carbon energy source. To solve atmospheric pollution problems, U.S., UK, Japan, South Korea, and other developed countries will all make use of natural gas on a large scale. Natural gas has significant energy saving and emission-reduction effects, and it is a realistic choice for effectively controlling atmospheric pollution and actively responding to ecological and environmental issues such as climate change. The natural gas combustion efficiency is high. Take Beijing in North China as an example. In 2016, natural gas consumption was 16 billion cubic meters. According to the calculation that 160,000 tons of water vapor will be generated from the burning of 100 million cubic meters of natural gas, the annual water vapor produced by Beijing natural gas burning accounts for only about one-thousandth of the total annual evaporation of 22 to 29 billion tons of Beijing's water vapor.

From the perspective of the world’s energy transition in recent 100 years, natural gas has played an important role in the transformation of the world’s energy. In the future, “coal reduces, gas rises” will be a main trend in the energy structure adjustment in major economies. However, the construction of LNG stations is progressing slowly. If the demand is still in short supply, the price of LNG will also increase. In the long run, it will cause the reverse development of “gas drops and coal rises”. Therefore, the country and the city must furtherly clarify the strategic positioning of one of their main sources of energy, and gradually cultivate natural gas as one of China's main sources of energy in accordance with established development plans, goals, and implementation paths.

6.2 Overall planning and rational layout

Through the analysis of the status situation and data, it can be seen that the supply and demand of LNG energy in North China is unbalanced. Meanwhile, other regions also have similar problems owning to the lacking of scientific planning. For example, the imbalance of economic development and energy supply in the southeast coastal areas will make the introduction of LNG a top priority for natural gas strategies in these areas. Although coastal areas have long coastlines, the resources of deep-water ports are scarce. Therefore, the rational planning should be fully considered when planning LNG projects.

At the same time, the distribution and construction scale of LNG projects should also be considered together with the supply of “West Gas”, “Russian Gas” and “Sea Air”. Some unsuccessful cases in the world show that the implementation of LNG projects is a huge and systematic project. It must be very prudent and be acted according to objective laws; otherwise it will cause huge economic losses. Moreover, the functional positioning of LNG projects in different provinces and cities should be different. In some regions (such as Northeast China, Bohai Rim, Shandong, Jiangsu, Shanghai, etc.) LNG is a supplemental origin and serves as a gas storage, peak regulation, and rational supplement deployment. In these regions, the LNG station shall not built in large number. Based on some projects (such as Zhejiang LNG, Fujian, Guangdong, etc.) , it will be the main source of energy for a period of time, and several more points can be arranged.

6.3 Multiple introduction and expansion of reserves

Before the completion of LNG station construction, the LNG import method should continue to be adopted. In terms of resource replacement and continuous supply issues, we should adhere to the principle of diversified supply. While actively pursuing long-term supply contracts, we must also pay close attention to futures and spot trading. We can also make use of the off-season of the international market to buy at low prices and reduce the cost of gas purchases, so as to increase revenue. If necessary, we can also go out and participate in international cooperation projects on natural gas upstream, and establish a natural gas liquefaction plant in overseas so as to obtain a stable supply of resources. At the same time, consideration should continue to be given to accelerate the establishment of large-scale LNG reserves in the country. On the one hand, it can ensure the system continuity to ensure gas supply when air supply is blocked or a failure occurs. On the other hand, it can also absorb the futures and stocks that appear on the market in a timely manner.

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