CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871089

Chemical Fuel Supply Chain Integration and Optimization under the Influence of Uncertain Factors

Liu Liu

Chongqing City Management College,college of business administration,ChongQing 401331, China
441723230@qq.com

The petrochemical industry belongs to the dangerous chemical industry. The optimization of supply chain can significantly improve the overall profits of enterprises, reducing costs and risks. Based on the value-at-risk theory, this paper proposes an optimal dispatching model for chemical fuel supply chain, which is used to solve the uncertainty of market demand and capacity scale. The sample mean estimation method is used to calculate the optimal demand risk threshold and capacity risk threshold. The calculation results show that the higher the risk threshold is, the lower the supply chain cost will be. The impact of chemical fuel market demand risk threshold on the supply chain object function is greater than that of capacity risk threshold on the supply chain object function. Therefore, the supply chain optimal dispatching should take the market demand as a priority. According to calculation results, the optimal values of demand risk threshold and capacity risk threshold are set to 0.26 and 0.1, respectively. This research can provide theoretical reference for the large-scale supply chain optimal dispatching under the condition of uncertain factors.

1. Introduction

With the rapid development of economy, the demand for chemical fuels is increasing all over the world. A statistics show that, the oil consumption of the United States and China exceeded 19 billion barrels and 10 billion barrels respectively in 2017. The crude oil production and refining also grew significantly (Shah et al., 2011). Compared with refining crude oil, the management and control of the whole supply chain from purchasing chemical fuels to selling products have significantly improved, reducing the overall costs and risks (Göthe-Lundgren et al., 2002; Kim et al., 2008).
The supply chain of petrochemical industry is shown in Fig. 1, including the procurement, transportation, refining crude oil, product oil transportation, and sale (Sérgio and José, 2004; Dempster et al., 2000). The asset scale of petrochemical industry is large, and its supply chain optimization is very complex. Moreover, petroleum is a dangerous chemical. Potential risks such as explosion, leakage and combustion must be considered in the transportation. Therefore, its supply chain optimization is more uncertain than others (Goel and Grossmann, 2004; Alqahtani and Elkamel, 2008).

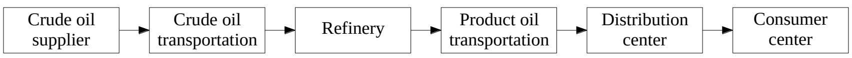


Figure 1: Petrochemical Industry Supply Chain

Uncertain factors of chemical fuel supply chain include raw material supply, original refining, product oil transportation and market demand, etc. (Tsiakis et al, 2001; Li et al., 2004). Uncertainty can be divided into supply uncertainty, production uncertainty and demand uncertainty according to the upstream and downstream relationship of fossil fuel industry, all of which can affect the optimal design of chemical fuel supply chain (Li and Ierapetritou, 2008; Tarhan et al., 2009; Haitham, 2004). Researchers have proposed a variety of methods to optimize the supply chain under uncertain conditions, such as the stochastic programming model, fuzzy optimization model, robust optimization model and risk management model, etc.

Please cite this article as: Liu L., 2018, Chemical fuel supply chain integration and optimization under the influence of uncertain factors, Chemical Engineering Transactions, 71, 529-534 DOI:10.3303/CET1871089

(Alqahtani and Elkamel, 2010; Yang and Barton, 2016; Wang and Rong, 2010). However, one-off optimization algorithms can hardly meet the dynamic attributes of large-scale supply chain dispatching (You et al., 2010).
For the above defects, this paper proposes an optimal dispatching model for chemical fuel supply chain based on the value-at-risk theory, which is used to solve the uncertainty of market demand and capacity scale. The sample mean estimation method is used to calculate the optimal demand risk threshold and capacity risk threshold. This research can provide theoretical reference for the large-scale supply chain optimal dispatching under the condition of uncertain factors.

2. An Optimal Dispatching Model for Chemical Fuel Supply Chain

This paper proposes an optimal dispatching model for chemical fuel large-scale supply chain. The object function is the minimum operating cost of supply chain, which can be expressed as equation (1):

$$\begin{aligned} \min \quad & \sum_{s\in S^{OS},s',i,t} price_i F_{s,s',i,t} + \sum_{<s,s',v>\in Link,t} fc_{s,s',v,t} F_{s,s',v,t} + \\ & \sum_{s,i,t} hc_{s,i} IV_{s,i,t} + \sum_{s,i,t} ip_{s,i} IV^{\Delta}_{s,i,t} + \sum_{c,i,t} dp_i D^{\Delta}_{c,i,t} + \sum_{m,t,k} ccCH_{m,t,k} \end{aligned} \tag{1}$$

, of which

$$F_{s,s',i,v,t} = \sum_{m,k} Q_{m,t,k} Y_{i,m} \qquad \forall s \in S^{outplant}, i, v, t \tag{2}$$

$$F_{s',s,i,v,t} = \sum_{m,k} Q_{m,t,k} X_{i,m} \qquad \forall s \in S^{inplant}, i, v, t \tag{3}$$

The first item of equation (1) represents the procurement cost of raw materials. $F_{s,s1,i,v,t}$ is the quantity of raw material i delivered from s to s^1. Equations (2) and (3) are the upstream and downstream materials balance conditions of chemical fuel refinery
Equations (4) to (10) are constraint conditions of object function. There are a total of m supply chain optimal dispatching schemes. $Z_{m,t,k}$ is the dispatching scheme m adopted at K cycle, and $CH_{m,t,k}$ is the scheme m switched from other schemes at K cycle. The relationship between $Z_{m,t,k}$ and $CH_{m,t,k}$ are expressed as equations (6) and (7). $ZA_{m,h}$ and $CHA_{m,h}$ are auxiliary variables of $Z_{m,t,k}$ and $CH_{m,t,k}$, respectively.

$$\sum_{m} Z_{m,t,k} = 1 \qquad \forall t, k \tag{4}$$

$$Q^L Z_{m,t,k} \le Q_{m,t,k} \le Q^U Z_{m,t,k} \qquad \forall m,t,k \tag{5}$$

$$CH_{m,t,k} \ge Z_{m,t,k} - Z_{m,t,k-1} \qquad \forall m,t,k \ge 2 \tag{6}$$

$$CH_{m,t,k} \ge Z_{m,t,k} - Z_{m,t-1,K} \qquad \forall m,t,k = 1 \tag{7}$$

$$ZA_{m,(t-1)N_k+k} = Z_{m,t,k} \qquad \forall m,t,k \tag{8}$$

$$CHA_{m,(t-1)N_k+k} = CH_{m,t,k} \qquad \forall m,t,k \tag{9}$$

$$CHA_{m,h} \le ZA_{m,h'} \qquad \forall h < h' \le h + tn, m \tag{10}$$

The constraint condition equation (11) represents the material balance of all cargo storage points, including the chemical fuel producing areas, product oil areas, and distribution points. Equation (12) indicates that the supply quantity of chemical fuel is not larger than the total sales volume of distribution points. Equation (13) shows that the object function will trigger penalty factors when materials reserved at any chemical fuel storage points are less than the safety inventory threshold. Equation (14) is the upper and lower limit of raw material supply.

$$IV_{s,i,t} = IV_{s,i,t-1} + \sum_{s',v} F_{s',s,i,v,t} - \sum_{s'',v} F_{s,s'',i,v,t} \qquad \forall s \in S^{IV}, i, t \tag{11}$$

$$\sum_{s,v} F_{s,c,i,v,t} \le D_{c,i,t} \qquad \forall c,i,t \tag{12}$$

$$IV^{\Delta}_{s,i,t} \ge IV^{L}_{s,i} - IV_{s,i,t} \qquad \forall s \in S^{IV}, i, t \tag{13}$$

$$O^{L}_{s,i} \le \sum_{s',v} F_{s,s',i,v,t} \le O^{U}_{s,i} \qquad \forall s \in S^{OS}, i \in I^{RM}, t \tag{14}$$

In the chemical fuel supply chain dispatching, the capacity and market demand of dangerous chemicals have the greatest uncertainty. This paper studies the capacity and demand uncertainty of chemical fuels based on the value-at-risk theory.

The oil supply chain demand is mostly estimated by historical data. The loss function of chemical fuel market demand can be expressed as:

$$f^{dem}_{c,i,t,sc} = \left(D_{c,i,t,sc} - \sum_{s,v} F_{s,c,i,v,t} \right) price_i \qquad \forall c,i,t,sc \tag{15}$$

Equation (15) represents the lost sales due to the unsupplied quantity failing to meet the market demand. Equation (16) shows the loss function value after adjusting equation (15). Equation (17) defines the risk value of predicted chemical fuel market demand.

$$\pi^{dem}_{c,i,t,sc} \ge f^{dem}_{c,i,t,sc} - \alpha^{dem}_{c,i,t} \qquad \forall c,i,t,sc \tag{16}$$

$$\alpha^{dem}_{c,i,t} + \left(1-\beta^{dem}\right)^{-1} \sum_{sc} p_{sc} \pi^{dem}_{c,i,t,sc} \le \theta^{dem} D_{c,i,t}\, price_i \qquad \forall c,i,t \tag{17}$$

The uncertainty of chemical fuel capacity is further analyzed. The loss function considering the uncertainty of capacity is:

$$f^{inv}_{s,i,t,sc} = IV^{L}_{s,i} - IV_{s,i,0} + \sum_{s'',t'\le t} F_{s,s'',c,i,v,t',sc} - \sum_{m,k,t'\le t} Q_{m,t',k} Y_{i,m,t',k,sc} \qquad \forall s \in S^{ptank}, i, t, sc \tag{18}$$

Equation (19) defines the predicted chemical fuel capacity risk value.

$$\alpha^{inv}_{s,i,t} + \left(1-\beta^{inv}\right)^{-1} \sum_{sc} p_{sc} \pi^{inv}_{s,i,t,sc} \le \theta^{inv} IV^{L}_{s,i} \qquad \forall s \in S^{ptank}, i, t, sc \tag{19}$$

According to equations (15) to (19), the established object function is adjusted:

$$\begin{aligned} f_s = & \sum_{s,i,t,(sc)} \left(p_{sc}\right) hc_{s,i} IV_{s,i,t,(sc)} + \sum_{s,i,t,(sc)} \left(p_{sc}\right) ip_{s,i} IV^{\Delta}_{s,i,t,(sc)} \\ & + \sum_{c,i,t,(sc)} \left(p_{sc}\right) dp_i D^{\Delta}_{c,i,t,(sc)} + \sum_{m,t,k} ccCH_{m,t,k} \end{aligned} \tag{20}$$

3. Verification and Analysis

An experiment is given to verify the feasibility of the optimal model for chemical fuel supply chain proposed in this paper. The chemical fuel supply chain is shown in Fig. 2. Crude oil processing plants obtain three kinds of crude oil and gasoline additives from raw material suppliers MS1—MS3 and MTVESR. RMS, PZ and OPS respectively represent chemical raw material storage area, crude oil processing area and product oil storage area. Crude oil processing plants produce 92# and 95# gasoline, diesel and fuel oil. The product oil is transported from OPS to distribution centers in batches, and then distribution centers deliver the product oil to each sales point.

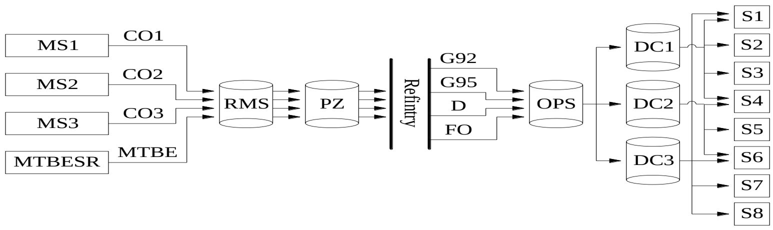
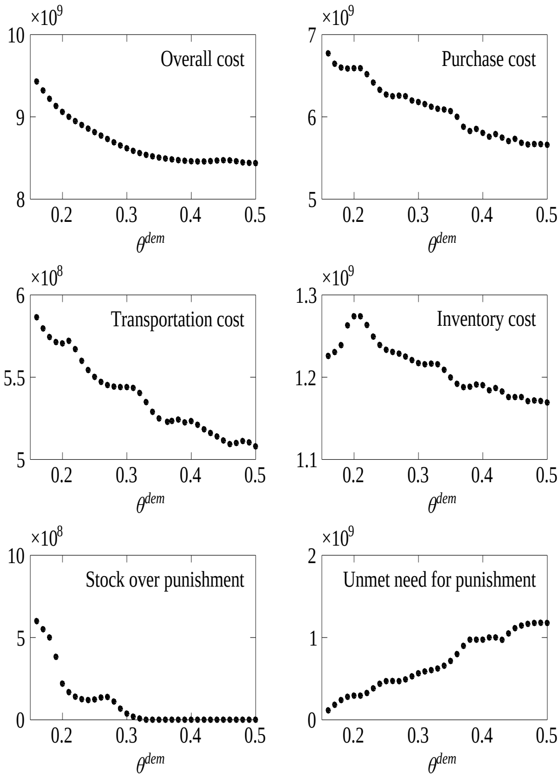


Figure 2: Chemical Fuel Supply Chain



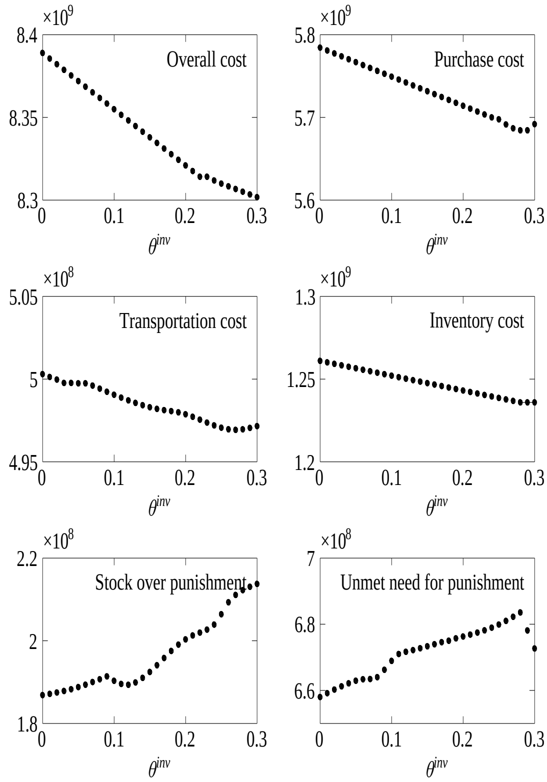


Figure 3: Relationship between Risk Threshold and Supply Chain Cost under Uncertain Market Demand

Figure 4: Relationship between Risk Threshold and Supply Chain Cost under Uncertain Production Capacity

The established supply chain model is divided into 10 planning cycles. Each planning cycle contains 3 optimal dispatching subcycles. A total of 4 processing schemes (m1-m4) are set. The conversion of different processing schemes is limited to adjacent dispatching cycles. The capacity lower limit of each dispatching subcycles is 1,600 barrels and the upper limit is 2,600 barrels. The maximum supply quantity of crude oil and gasoline additives are respectively 10,000 barrels and 5,000 barrels. The penalty for each adjustment is 28,000 dollars. In these four schemes, the original CO1, CO2, CO3 and MTBE materials mixing ratios are m_1=0.6:0.35:0:0.05, m_2=0.35:0.45:0:0.1, m_3=0.2:0.3:0.5:0, and m_4=0.2:0.25:0.55:0, respectively.

Fig. 3 shows the relationship between risk threshold and established supply chain cost under uncertain market demand, in which the range of risk threshold is $0.16<\theta<0.5$. It can be seen that the overall cost, procurement cost, transportation cost and inventory cost of chemical fuel supply chain all show a trend of gradual decrease with the increase of the demand risk threshold. When the risk threshold exceeds 0.32, the chemical fuel inventory penalty drops to 0. It indicates when the supply chain risk threshold is high, that is decision makers accept the economic loss caused by the market demand failing to meet the expectation, all storage points of supply chain can meet the requirements of safety inventory.

Fig. 4 shows the relationship between risk threshold and established supply chain cost under uncertain production capacity, in which the range of risk threshold is $0<\theta<0.3$. It can be seen that with the increase of production capacity risk threshold, the overall cost, procurement cost, transportation cost and inventory cost of chemical fuel supply chain also show a gradually decreasing trend on the whole. Compared with Fig. 3, the variation range of cost within the supply chain is relatively small when the chemical fuel production capacity is uncertain.

From the above analysis, it found that the impact of chemical fuel market demand risk threshold on the supply chain object function is greater than that of capacity risk threshold on the supply chain object function. Therefore, the supply chain optimal dispatching should take the market demand as a priority.

To further determine the optimal demand risk threshold and capacity risk threshold, Fig. 5 shows the supply chain mean estimation under uncertain market demand. It presents that the average demand constraint violation ratio of the simulation model decreases firstly and then increases when the demand risk threshold gradually drops. While the maximum violation rate shows a trend of decreasing first and then remaining unchanged. When the demand risk threshold reduces, the overall dispatching scheme of supply chain tends to be more conservative, so the calculation results will violate fewer constraints. Taking factors such as overall costs and risks into consideration, the demand risk threshold of 0.26 is selected as the optimal value.

Fig. 6 shows the supply chain mean estimation under uncertain production capacity. The variation trends of each parameter are roughly similar to that in Fig. 5, indicating that some profits are needed to ensure the safe lower limit of storage quantity when the risk threshold is small. Considering overall costs, risks and other factors, the production capacity risk threshold of 0.1 is selected as the optimal value.

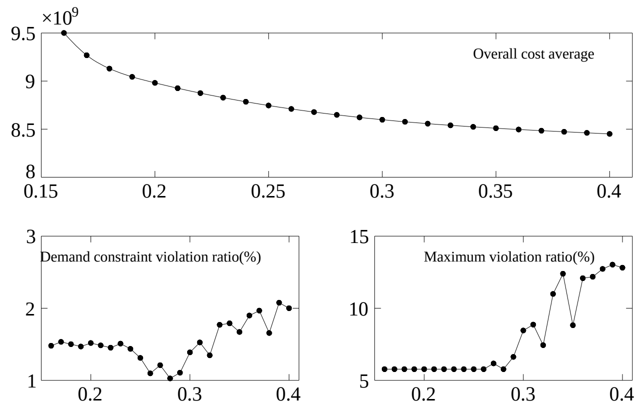


Figure 5: Supply Chain Mean Estimation under Uncertain Market Demand

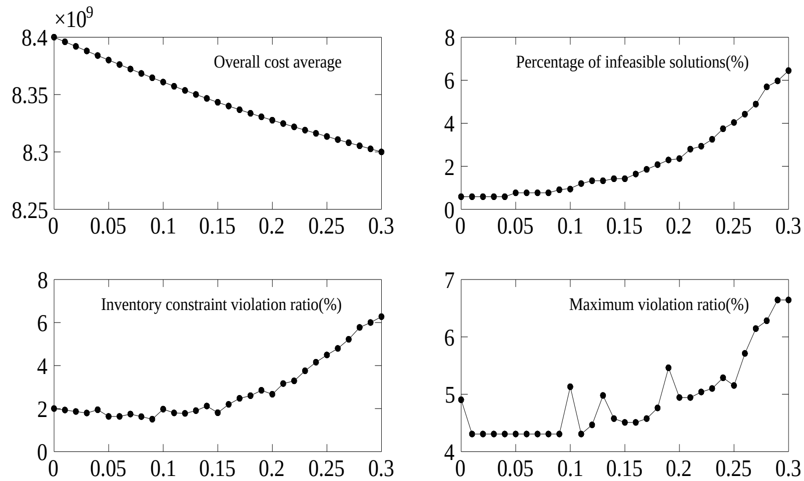


Figure 6: Supply Chain Mean Estimation under Uncertain Production Capacity

4. Conclusion

Based on the value-at-risk theory, this paper proposes an optimal dispatching model for chemical fuel supply chain, which is used to solve the uncertainty of market demand and capacity scale. The sample mean estimation method is used to calculate the optimal demand risk threshold and capacity risk threshold. The calculation results show that the higher the risk threshold is, the lower the supply chain cost will be. The impact of chemical fuel market demand risk threshold on the supply chain object function is greater than that of capacity risk threshold on the supply chain object function. Therefore, the supply chain optimal dispatching should take the market demand as a priority. According to calculation results, the optimal values of demand risk threshold and capacity risk threshold are set to 0.26 and 0.1, respectively. This research can provide theoretical reference for the large-scale supply chain optimal dispatching under the condition of uncertain factors.

References

Alqahtani K., Elkamel A., 2008, Multisite facility network integration design and coordination: an application to the refining industry, Computers Chemical Engineering, 32(10), 2189-2202, DOI:10.1016/j.compchemeng.2007.10.017

Alqahtani K., Elkamel A., 2010, Robust planning of multisite refinery networks: optimization under uncertainty, Computers Chemical Engineering, 34(6), 985-995, DOI:10.1016/j.compchemeng.2010.02.032

Dempster M.A.H., Hicks Pedrón N., Medova E.A., Sembos J.E.S., 2000, Planning logistics operations in the oil industry, The Journal of the Operational Research Society, 51(11), 1271-1288.

Goel V., Grossmann I.E., 2004, A stochastic programming approach to planning of offshore gas field developments under uncertainty in reserves, Computers Chemical Engineering, 28(8), 1409-1429, DOI:10.1016/j.compchemeng.2003.10.005

Göthe-Lundgren M., Lundgren J.T., Persson J.A., 2002, An optimization model for refinery production scheduling, International Journal of Production Economics, 78(3), 255-270, DOI: 10.1016/s0925-5273(00)00162-6

Haitham M.S., Lababidi, Mohamed A. Ahmed, Imad M. Alatiqi, Adel F. AlEnzi., 2004, Optimizing the supply chain of a petrochemical company under uncertain operating and economic conditions, Industrial Engineering Chemistry Research, 43(1), 63-73, DOI:10.1021/ie030555d

Kim Y., Yun C., Park S.B., Park S., Fan L.T., 2008, An integrated model of supply network and production planning for multiple fuel products of multi-site refineries, Computers Chemical Engineering, 32(11), 2529-2535, DOI:10.1016/j.compchemeng.2007.07.013

Li W., Hui C.W., Li P., Li A.X., 2004, Refinery planning under uncertainty, Industrial Engineering Chemistry Research, 43(21), 196-208, DOI: 10.1021/ie049737d

Li Z., Ierapetritou M., 2008, Process scheduling under uncertainty: review and challenges, Computers Chemical Engineering, 32(4), 715-727, DOI: 10.1016/j.compchemeng.2007.03.001

Sérgio M.S., Neiro José M.P., 2004, A general modeling framework for the operational planning of petroleum supply chains, Computers Chemical Engineering, 28(6), 871-896, DOI: 10.1016/j.compchemeng.2003.09.018

Shah N.K., Li Z., Ierapetritou M.G., 2011, Petroleum refining operations: key issues, advances, and opportunities, Industrial engineering chemistry research, 50(3), 1161-1170, DOI: 10.1021/ie1010004

Tarhan B., Grossmann I.E., Goel V., 2009, A multistage stochastic programming approach for the planning of offshore oil or gas field infrastructure under decision dependent uncertainty, Industrial Engineering Chemistry Research,48(6), 3078-3097, DOI:10.1021/ie8013549

Tsiakis P., Shah N., Pantelides C.C., 2001, Design of multi-echelon supply chain networks under demand uncertainty, Ind.eng.chem.res, 40(16), 3585-3604, DOI:10.1021/ie0100030

Wang J.S., Rong G., 2010, Robust optimization model for crude oil scheduling under uncertainty, Industrial Engineering Chemistry Research, 49(4), 1737-1748, DOI:10.1021/ie900358z

Yang Y., Barton P.I., 2016, Integrated crude selection and refinery optimization under uncertainty, Aiche Journal, 62(4), 1038-1053, DOI:10.1002/aic.15075

You F.Q., Wassick J.M., Grossmann I.E., 2010, Risk management for a global supply chain planning under uncertainty: models and algorithms, Aiche Journal, 55(4), 931-946, DOI:10.1002/aic.11721