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AN INTEGRATED FRAMEWORK FOR FLEXIBLE REFINED PRODUCTS SUPPLY CHAIN

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ABSTRACT

The paper outlines our ongoing efforts on building a framework for a flexible refined products supply chain. Current refined products supply chain faces the risks of supply and demand fluctuation, refineries and transport facilities (i.e. pipelines) disruption, and depots accidents. These risks will lead to the unmet demand of the sales market and affect social and economic developments. The framework integrates a basic mixed-integer linear programming model for current refined products supply chain simulation, a reliability assessment method, and an expanded model considering facilities expansion and multi-energy sources supplement. We introduce the concept and importance of refined products supply chain flexibility study, the conceptual framework and its integrated components. Finally, we summarize the current research challenges and give a conclusion.

Keywords: refined products, supply chain, flexibility, mixed-integer linear programming

NONMENCLATURE

Abbreviations	
RPSC	Refined products supply chain
MILP	Mixed-integer linear programming
CNG	Compressed natural gas

1. INTRODUCTION

The flexibility of supply chain arouses more attention in the fast-developing logistic industry. The concept of flexibility requires the supply chain can have a response to all conditions that have influences on it to make the unbalance in supply and demand especially the disruption, and through some measures to recover its stable operational state. As for the refined products supply chain (RPSC), it also faces the need to pay more attention to the flexibility.

Refined products consumption accounts for a relatively high proportion in the current energy structure in China [1], the scale of its logistics system is growing with the continuous expansion of China's energy demand. Reducing logistics cost and improving transportation efficiency are the key points in the development of refined products transport systems [2]. Due to the unevenly distributed of refineries and markets, long distance transportations are required to ensure the demand of downstream markets, which increase the need of developing a reliable RPSC [3]. The 13th Five-Year Plan of the China clearly points out that a modern energy storage and transportation network should be built and the construction of a modern energy storage and transportation network that is multi-energy complementary, open, smooth, safe and reliable should be accelerated. Also, on March 28, 2019, the Ministry of Transport of the People's Republic of China proposed some measures to improve the efficiency of comprehensive transportation network and reduce the cost of transportation logistics. As an important and complex supply chain that has multiple transport modes, RPSC should accelerate its process of constructing an efficient integrated transport system.

Fig.1 illustrates the conceptual RPSC. Refined products are transported from refineries to regional oil depots by pipelines, railways, highways and waterways, through the transfer between regional storage depots, and finally to provincial and municipal oil depots [4]. The system is complex in structure and large in scale. It also faces the threaten of fluctuation in supply and demand, refineries and transport facilities (i.e. pipelines) disruption, and depots accidents. Therefore, the flexibility of this supply chain has to be studied to find an optimal way to tackle these incidents. Also, considering the flexibility in the RPSC design and operation can help to reduce logistics costs, improve transport efficiency, ensure the demand satisfaction of downstream markets and reduce shortages.

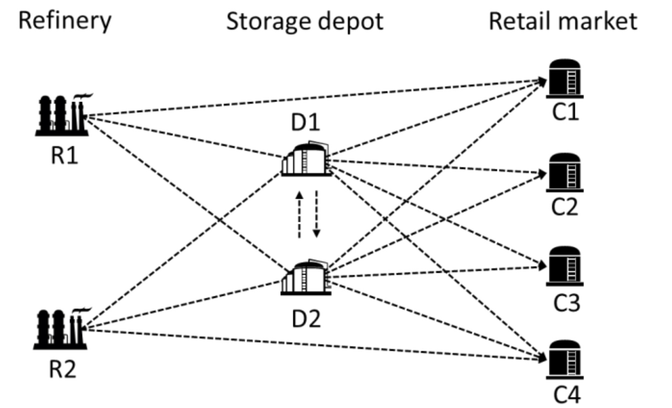

Fig 1 Schematic diagram of the RPSC

In the primary logistics system of refined products, to meet the demand of different refined products in the downstream market, it is necessary to formulate an optimal distribution plan. The various modes of transportation should be arranged and allocated rationally according to the production rate of upstream refineries, the stock of oil depots in various regions, and the market demand in downstream areas. At the same time, the maximum transportation capacity of each mode of transportation, the inventory of each depot, the ability of receiving and dispatching refined products, and the fluctuation of market demand all should be considered to determine a lower cost and higher satisfaction rate plan. In addition, primary distribution will also be affected by some sudden factors, such as upstream refinery shutdown, transportation facilities shutdown, downstream demand surge, etc. [5]. These factors all should be considered to meet the market demand for refined products to the greatest extent, to ensure the efficient and accurate allocation of refined products, and to reduce logistic cost.

This paper aims to outline our ongoing efforts on building a framework for a flexible RPSC. The remainder of this paper is organized as follows: Section 2 introduces the framework we developed to achieve the flexibility of a RPSC. Section 3 introduces the challenges in the future study. Then, the conclusion of this article is emerged in Section 4.

2. FRAMEWORK DESCRIPTION

The research on supply chain flexibility has aroused widely attention these years. The RPSC is a complex network, studying its flexibility has necessity considering the importance of refined products to the development of the economy and human's life.

In order to study the flexibility of RPSC, the definition has to be given. Wang et al. [6] summarized several definitions of supply chain networks: (1) Flexibility is the ability to maintain feasible steady-state operation for all parameter values within a specified range. (2) Two aspects were coupled in supply chain flexibility: process flexibility, and logistics flexibility. Process flexibility refers to the number of products that can be manufactured at each pro-duction site, while logistics flexibility indicates different logistics strategies that can be adopted.

There is still a lack of research on evaluation and analysis of RPSC flexibility, design and operation optimization of RPSC considering flexibility. In addition, with the development of new energy sources, the collaborative planning of multi-energy supply chains is the trend in the future.

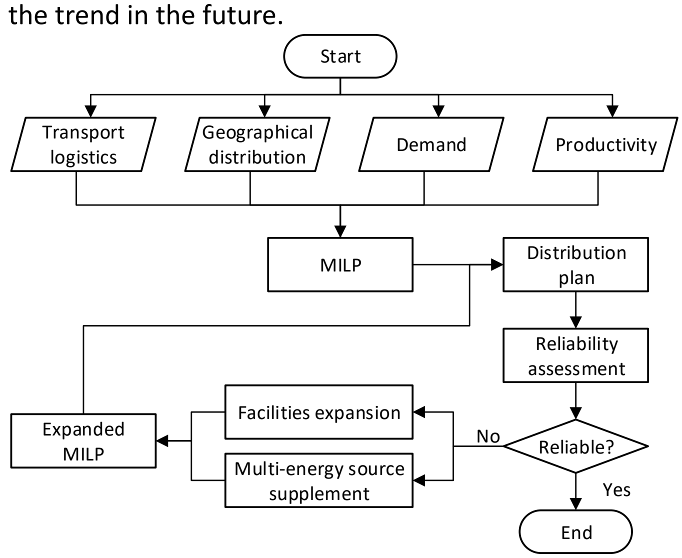

Fig 2 Flowchart of the designed framework for flexible RPSC research

To fill this literature gap, a flexible RPSC optimization framework is designed (shown in Fig. 2). This framework integrates a basic mixed-integer linear programming (MILP) model for current RPSC simulation, a reliability assessment method, and an expanded MILP model considering facilities expansion and multi-energy sources supplement for a flexible RPSC design. First, the data of transport logistics, geographical distribution, demand of retail markets and productivity of refineries are inputted.

A MILP model is applied to solve the distribution plan of the current RPSC. Then a reliability assessment method is used to examine whether the current RPSC is reliable or not. If it is not reliable, then we couple the facilities expansion and multi-energy sources supplement into the current MILP model to develop an expanded MILP model. Finally, it is supposed to use this expanded model to get a more flexible RPSC design scheme.

2.1 Driving force of Flexibility: Reliability

Risks in supply chain is the main driving force for flexibility research. The risks come from decrease in supply capability, discrepancy between forecast and actual demand, etc. If a supply chain is enough reliable, then that means it is also flexible enough to resist risks.

The primary logistics system of refined products in China has the problems of unreasonable transportation structure, and insufficient stable transportation capacity against fluctuation and risk. To carry out flexibility research, we need to quantify the reliability of existing supply chains first.

Although the supply reliability of other supply chains is studied, but there still lacks research on RPSC. The causes that lead to unreliable situations are different from other supply chains. The production of refineries and the demand of depots are not stable and may cause imbalance between these objects [7]. Also, refineries may suffer from fully or partly disruption [8], and the transportation process may be fully blocked by natural disasters or other man-made accidents [9]. The probabilities of these unnormal situations are different from other supply chains, and we cannot migrate the results and data from other supply chains directly. Thus, it is important to develop a method for the quantitative evaluation of the reliability of RPSCs.

In our reliability assessment method, we introduce the uncertainties and risks from refineries, transport facilities, retail markets, and storage depots. The detail of the uncertainties and risks of these facilities are shown in Table 1.

Table 1 Uncertainties and risks in RPSCs

Facilities and components	Uncertainties and Risks
Refinery	Uncertain productivity
	Fully disruption
	Partly disruption
	Production decrease
Transport facility	Pipeline interruption
Retail market	Uncertain demand
	Abnormal demand
Storage depot	Uncertain inventory

2.2 Method: mathematical programming

To study the flexibility of RPSC, one of the commonly used method is mathematical programming. It can be used to simulate distribution plans and could serve as the fundament for the follow-up analysis. The facilities in the RPSC can be regarded as sets in the model, and the transport feasibility, material balance and sending capacity in the RPCS can be modelled as constraints. The supplements of other energy sources can also be coupled in the model and optimize the system as an integration.

Researchers have done some relevant studies on the design and planning of the petroleum supply chain. The mathematical model developed in their studies were used as an efficient tool to determine the distribution plans. Methods such as stochastic programming, fuzzy programming, robust programming are widely used to tackle uncertainty [10]. These methods can be the references to develop the mathematical model that can optimize the distribution plan of the RPSC.

2.3 Flexibility improvement

Two methods are introduced in the framework for the flexible RPSC research: facilities expansion and multi-energy sources supplement.

<u>2.3.1 Facilities expansion</u>

The construction of new facilities and the expansion of transport capacity can (1) enhance the current supply chain by operating under multiple transport modes, and (2) increase buffer capacity of depots.

<u>2.3.2 Multi-energy sources supplement</u>

Other energy sources such as biofuel, compressed natural gas (CNG), and electricity could be a supplement for the refined products market. Ethanol could to be directly mixed with gasoline at final depots, cars that consume CNG and electricity could rely less on refined products when the supply is insufficient. These energies could release the imbalance between the supply and demand of refined products.

3. CHALLENGES IN THE FUTURE RESEARCH

For the research of supply chain flexibility, there are still some challenges that researchers should focus on in the future.

(1) According to our observations, most of existing literature that studied the RPSC focused on the design and planning, while a few of them coupled the reliability in the planning process. However, whether a RPSC can meet the demand of retail markets, how is the probability of potential shortage, which component is

the vulnerable part in the RPSC, how to improve the reliability of the RPSC still need to be studied.

(2) Besides the evaluation of the reliability of RPSC, how to couple these uncertainties and risks in the design of a flexible RPSC still need to be further explored. In China, the size of RPSC is already quite large, if these factors are considered, the problem will become more complex. This means more efficient solving method should be developed to meet the requirement of optimizing a flexible RPSC.

(3) Another challenge in the future study is how to model the cooperation of multi-energy sources. as far as the authors are aware, few researches study the energy cooperation of refined products and other energy sources. How to model the complementary relationship of different energy sources, and how to convert the demand of unmet refined products to the demand of other energy sources still should be studied. It can also be a guide to the future research on energy structure transformation.

(4) Meanwhile, both the expansion of facility capacities and introduction if new energy sources can contribute to a more flexible RPSC. But how these two measures influence the flexibility of a RPSC respectively? Comparing with the economic and environmental potential as well as the social development stage, when should these measures be applied, now or in the future? To which extent should these measures be introduced in the current RPSC, which facility should be expanded first, and which energy source should be introduced preferentially? To answer these questions, a rich research field should be explored.

According to the above discussion, lots of work should be done to explore the flexibility of the current operating RPSC by dealing with uncertainties and risks, and how it will cooperate with new energy sources in the future to achieve a more sustainable supply chain.

4. CONCLUSION

This paper outlines our ongoing work of developing a framework for the design of a flexible RPSC. Lot of efforts should be focused on (1) reliability assessment, (2) flexible RPSC model design and (3) multi-sources energy supply chain plan. To test our framework, practical case study based on real data will be done in the future research. Considering refined products consumption still occupy the main percentage in the current energy structure in China, this work has its potential to serve as a reference of future policy making on strategy level and flexible RPSC design on tactical level.

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