Digital Transformation Of Refining& Chemical Enterprises Under The Contemporary Situation From Digital To Smart

Qing Wu[1] Dawei Zhang[2]

(*1China National Offshore Oil Corp., 100010, Beijing, China;*
2 CNOOC Oil & Petrochemicals Co., Ltd., 100029, Beijing, China）
Corresponding Author: Qing Wu

--*ABSTRACT*---

At present, cloud computing, big data, internet of things, mobile applications, social media and other information technology are concerned by refinery around the world because they greatly improve the production and operation efficiency. Especially in China, they will become the key work of the development of information technology of refining and chemical enterprises. In this paper, an information strategy of smart refinery is proposed to cope with the new competitive situation faced by refining and chemical enterprises. The construction steps and blueprint of smart refinery are discussed in detail, as well as the functions and design of several important typical systems/applications, including molecular database of crude oil, smart supply chain, regional operations center(ROC), energy consumption system management and optimization, device performance optimization system and smart petrol station. The blueprint of smart refinery designed in this paper has been used in a large refining and chemical enterprise and provides technical support for the top design of the enterprise' digital transformation.

KEY WORDS *: Refining and chemical enterprises; digital transformation; digital refinery; intelligent refinery; smart refinery; smart supply chain*

I. INTRODUCTION

The refining and chemical is the central link of the oil enterprises to increase the value and the profit, and is an important field to improve the competitiveness of the oil enterprises[1]. Under the influence of geopolitics, resources, global climate change, new energy and new technologies[2]-[6], the refining and chemical industry is facing new challenges and opportunities. The Internet is changing the market pattern of petrochemical products and consumers' consumption behavior, making the market competition increasingly fierce, and the refining and chemical industry is facing a new trend of development.

To cope with the new trend, the refining and chemical enterprises are strengthening the integration[7]and large-scale development[8], and diversifying energy and resources. At the same time, we should pay more attention to the information technology in order to upgrade the refinery capability and the product sales model. Information technology such as cloud computing, big data, Internet of things, mobile applications, social media and other information technologies have changed the model of refining and chemical industry, and promoted the digital transformation of refining and chemical enterprises. The construction of digital refineries, intelligent refineries and smart refineries[9]-[13] has become the focus of the refining and chemical industry in order to improve the production and operation efficiency and office work efficiency.

By utilizing the new technologies include internet of things, big data, artificial intelligence, smart refinery is, on the one hand, torealize the optimization of the whole supply chain from crude oil production, transportation, storage, logistics and sales of oil products. On the other hand, smart refinery is to realize the planning optimization, scheduling optimization and overall online optimization. Finally, the agile optimization of resources, the collaborative optimization of the whole industry chain and the traceability of QHSE are realized.

1 The blueprint of smart refinery
Based on digital refinery and intelligent refinery, the objective of smart refinery is to maximize the value of industrial chain of refining and chemical enterprises, which is shown in figure 1.
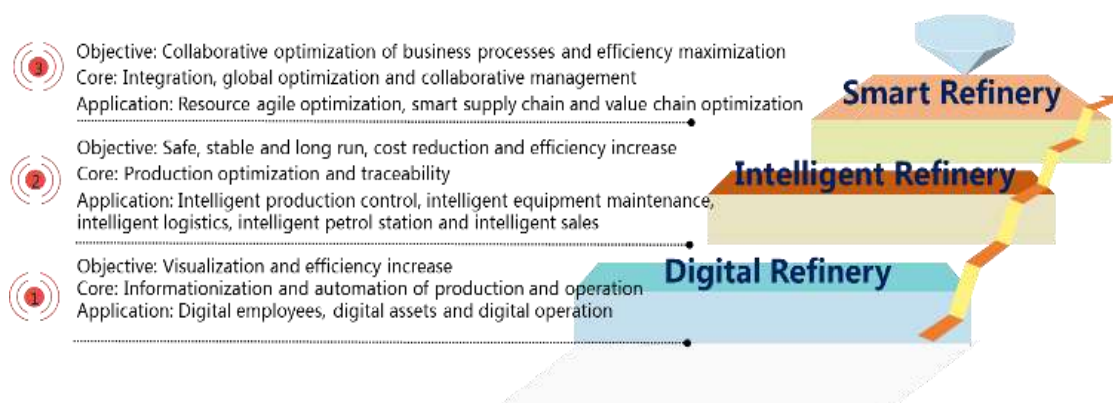
Figure 1 Construction Plan of Smart Refinery

Digital refinery is the foundation. The core application of digital refinery is the digitalization of human, equipment and operation, with process automation and management informatization. Through the digital refinery construction, the visualization of the factory operation will be realized, and the management efficiency of the production and sales will be improved.

Intelligent refinery is the core. Knowledge and optimization of production and operation are the main applications of intelligent refinery. Intelligent refinery emphasizes the construction of model system, including planning and scheduling optimization model of the production system, production operation optimization model, equipment predictive analysis model, warehousing logistics optimization model, customer clustering analysis model, etc.Molecular refining technology, big data analysis of production and sales are new technologies for the establishment of enterprise model, and is also the key point of the application of refining and chemical industry at present.

Based on the optimization model, the intelligent refinery will realize the optimal control of production planning, scheduling and operation, realize the whole lifecycle management and predictability maintenance, optimize the whole plant energy consumption system, realize the integrated optimization of sales and logistics, and establish intelligent petrol station.

Smart refinery is the goal. In order to optimize the total value of refinery enterprises, the smart supply chain needs to be established. Realize the visibility, coordination and optimization of each element of the whole industrial chain from crude oil procurement to market sales and realize the maximization of the value chain through the smart supply chain.For the production and sales, the cost optimization should be realized, including variable cost management and value maximization, inventory optimization and sales value maximization.

II. TYPICAL IMPORTANT SYSTEMS / APPLICATIONS

The smart refinery cannot be achieved overnight. It needs to be continuously improved in the process of information system construction. Unified planning and implementation are needed on the bases of the existing information system. The construction and implementation of the key information systems of smart refinery are described as follows.

1.1 Molecular database of crude oil

Petroleum molecular engineering is to study the relationship between the composition, performance and structure of petroleum and its reaction performance from the perspective of molecules, in order to achieve the maximization of molecular utilization and efficiency. Molecular management is based on petroleum molecular engineering, which has a reasonable cost to enable molecules to appear in the right place at a reasonable time, so as to optimize the refining management[14][15].

The molecular database of crude oil is the basis of petroleum molecular engineering and management[16]. With the advanced technologies of X ray method, spectroscopic method, chromatography, nuclear magnetic resonance method, the components of crude oil elements, hydrocarbon, hydrocarbon composition and structural composition and other information were determined, analyzed and characterized. Then taking a classification method that conforms to a particular rule and theencoding method of molecular skeleton structure (such as the guide vector method[17]), combined with the corresponding molecular physics and thermodynamics data, to form the molecular database of crude oil.

The molecular database of crude oil are widely used. The possibility of similar chemical properties of crude oil in the same reservoir or nearby reservoir is relatively large. Taking the crude oil from the same reservoir as a reference, then verifying andadjustingthe data according to certain methods or rules, such as laboratory data, so as to get the molecular information of the crude oil[18].The establishment of molecular database of crude oil is

helpful to the research of molecular transformation rule, and promote the establishment of molecular response rule library, and then promote the establishment of product reconciliation model, and provide guarantee for upgrading the petroleum product quality. According to the molecular information of crude oil in different regions and refining capacity of refineries, the allocation of crude oil resources can be optimized and the economic benefits of the crude oil can be maximized.

However, most of the related researches are still at the theoretical stage of qualitative analysis. Molecular refining technology and molecular analysis of heavy oil need further research.

1.2 Smart supply chain

In recent years, the academia and industry have paid more and more attention to the supply chain management[19]. The downstream supply chain in oil industry involves crude oil procurement, transportation, refining, storage, logistics, sales, which is shown in figure 2. Supply chain operation is mainly based on planning and scheduling. Business processes are usually coordinated by crude oil and raw material supply department, trade department, refinery plan and operation department, logistics department and sales department.
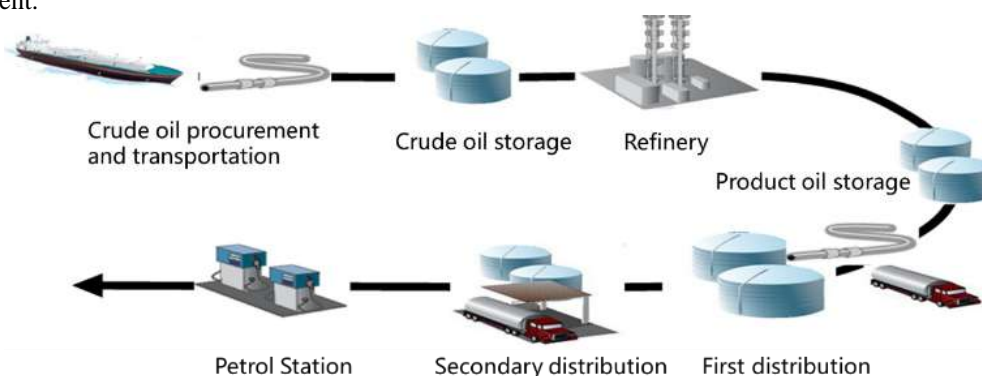
Figure 2 A sketch Map of the Downstream Supply Chain in Oil Industry

At present, some enterprises have begun to build smart supply chain, that is, the construction and application of production, supply, marketing and storage integration. For example, Brazil Petroleum (PetroBras) builtthe supply chain and logistics management system to achieve the cooperative management of planning and scheduling in the supply chain. ExxonMobil establishes the global oil product mobile system (GOM), forecasts the business conformance requirements and analyzes the balance of supply and demand in the supply chain. However, only part of the supply chain is optimized, and the global optimization of the supply chain has not been realized. Moreover, the business processes of the application systems in many petrochemical enterprises are incomplete, causing the departments in the supply chain to execute their respective processes separately, and the business processes and data are generally split up, which results in inefficient supply chain operation.

Smart supply chain emphasizes overall coordination and global optimization, which optimizes crude oil procurement, transportation, refining, logistics and sales. In the entire production, supply, marketing and various business areas, an integrated information system is to be established, which is called Integration platform for production, supply and marketing (IPPSM).

IPPSM has five major functions, namely, big data platform, collaborative scheduling, integrated optimization, index visualization and influencing factor association analysis. Each function provides support for different businesses.

The collection and processing of production, supply, sales and storage information are achieved through the big data platform. Based on the external market, petrol stations, wholesale, direct sales and refinery production data, a big data analysis model of production, supply, sales and storage integration is build, which provides support for optimizing the key links of the supply chain.

Through cooperative scheduling, the dynamic management of the execution process of production, supply, sales and storage is realized, and also the dynamic supervision of sales and operation is realized. The integration of production and sales is realized, so that each link in the whole supply chain is fully connected.

Based on large data platform, the integrated optimization is achieved, which accurately predict the changes of customer product demand and sales in various regions, and analyze the production and sales trends. The sales plan is dynamically coordinated and optimized. The production plan has realized closed loop management and continued optimization. At the same time, the key transport links are optimized through the schedule management system, which realizes shipment management and whole execution process management, in order to realize the coordination of crude oil transportation, loading/unloading, and the crude oil processing.

The display, analysis and deep mining of key indicators of production, supply, sales and storage are

realized through the index visualization, and the risk warning can be achieved.

The big data analysis technology is applied to the data accumulated on the big data platform of the production, supply, sales and storage, in order to analyze the related factors of production and sales in various regions. By analyzing the change of production, supply, sales and storage data of each region and the impact of the trend of changes on the performance, the decision support for improving the performance of each region is provided.

Through the implementation of the smart supply chain, the management and control capacity of the enterprise, the efficiency and cost of the supply chain will be improved. At the same time, how to realize the effective integration of data from the complex and different standards between different enterprises in the supply chain is also a problem that needs to be solved.

1.3 Regional operations center

Regional operations center (ROC) aims to establish a collaborative work environment, which integrate all the necessary resources for the implementation of the production management and operation optimization. ROC provides the data analysis and decision support tools, which can effectively cooperate with all majors, improve the efficiency of production system management, reduce production management cost and achieve excellent operation.

ROC provides applications for different roles shown in figure 3, including head of production in headquarter, head of production in branch plant, production scheduling personnel, optimizing control personnel, equipment maintenance personnel and cost analysis personnel.
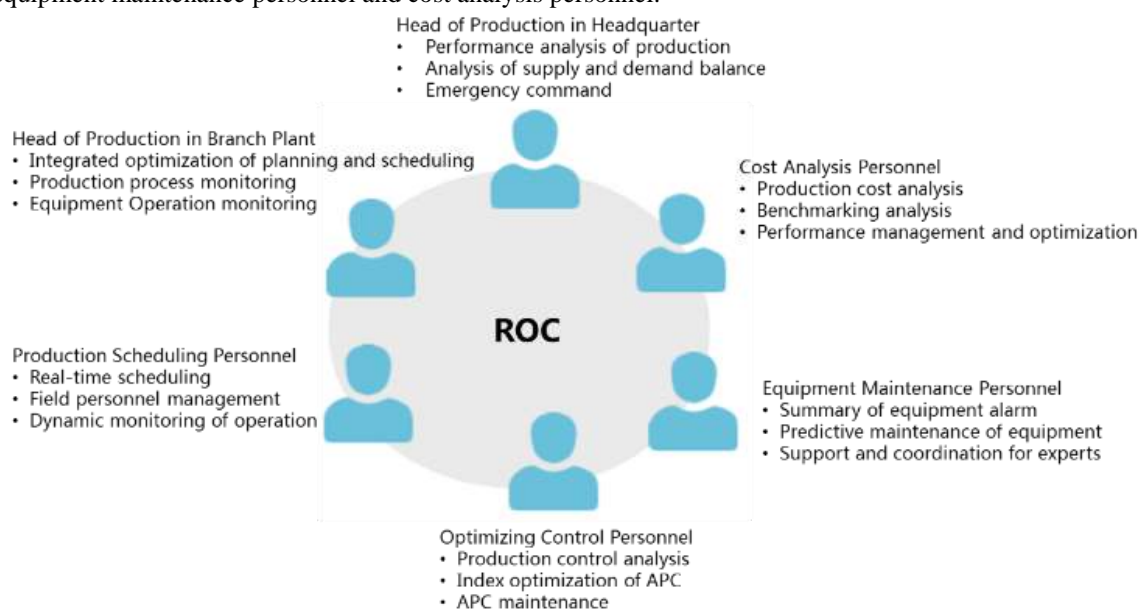
Figure 3 Different roles in ROC

ROC has four functions. The first one is the visualization of operations, which can timely obtain the relevant data of production operations, including crude oil input amount, product output amount, product inventory, equipment operations, energy consumption, safety and environmental protection, market trends, in order to ensure the safety and smooth production.

The second one is the result can be analyzed. The overall operations of the enterprise could be shown in a highly visual way, and the drill down analysis and benchmarking analysis could be realized. The third one is the risk can be predicted. That is to say, we can grasp the operation status, maintenance status, stock status, and get the abnormal production conditions in time, providing support for emergency command. The fourth is the operation can be optimized, which is to integrate with the procurement and sales system in order to realize the visualization of supply chain and provide support for the overall optimization of supply chain.

1.4 Equipment operating performance optimization system

The availability and reliability of equipment assets is the key link in the production management of refining and chemical enterprises. The non-planned shutdown of equipment will bring great impact on the enterprise. At present, the operation and preventive maintenance of the equipment, especially the key equipment (key production units and large units), is still an urgent problem to be solved.

The equipment operation performance optimization system is designed to realize the intelligent management of equipment assets. With the establishment of a big data platform for equipment assets, the

equipment operating performance optimization system is build, which has the following five functions.

(1) The comprehensive monitoring function of the equipment realizes data acquisition from the bottom system, including the point inspection system, the on-line monitoring system of the large unit and so on.

(2) The basic data management function of equipment assets has realized the management of basic data related to the equipment asset performance, providing support for failure analysis and maintenance strategy optimization, including maintenance risk definition, equipment grading management and experiencemanagement.

(3) Malfunction analysis function, based on big data analysis and knowledge base, realizes the fault diagnosis and life prediction of the key unit, malfunction cost analysis, reliability analysis, and spare parts optimization analysis.

(4) Equipment asset maintenance function achieves the balance between equipment reliability, performance and cost. According to the prediction data and the historical maintenance plan, this function can assist the management to formulate the maintenance strategy and avoid under maintenance or over maintenance. The function includes maintenance strategy optimization, maintenance strategy formulation, approval and implementation.

(5) The strategy evaluation function realizes the risk assessment based on the fault. The function formulatesthe key KPI index, and realizes the root cause analysis, production loss analysis and so on.

Finally, through the optimization of equipment performance, the monitoring and analysis of the health factors of equipment in the whole process is achieved. Fault diagnosis and life prediction of the key units based on big data analysis and expert knowledge base is realized. The maintenance strategy is optimized and the management of equipment maintenance and reliability is improved.

1.5 Energy management system

Traditional energy management is facing challenges in the industrial production, such as rising energy prices and operating costs, increasingly fierce international competition, more stringent environmental protection and regulatory constraints. The refining and chemical industry, as an industry with greater energy consumption, is facing a more severe situation. Therefore, domestic and foreign refining and chemical enterprises are looking for new methods to improve existing energy management methods and optimize energy utilization. For example, the Houston refinery of Valero, the largest refinery in the US, adopts Aspen Utilities Planner & Optimizer to build the utilities online optimization system. After operation, it reduces steam emissions by 7%, improves the boiler thermal efficiency by 0.6%, and the annual benefit is about $ 2.7 million.

The objectives of energy management system are: First, to realize the whole process management of energy planning, operation, statistical analysis, evaluation and energy optimization; Second, to achieve real-time data acquisition and monitoring of energy consuming equipment and utilities (steam, fuel and power system), and analyze energy efficiency, cost and energy balance; Third, to establish the optimization model of steam, fuel and power system to realize the management and optimization of the whole process of energy production, transportation, transfer, storage, consumption and sales. The energy management system has the functions of energy plan management, energy network balance, energy statistics analysis, energy operation and monitoring, energy consumption analysis and optimization, energy data collection and so on.

Through energy planning management, the generation and decomposition of energy consumption plan are realized, and the comparison and analysis of energy consumption plan and actual energy consumption are realized. The daily balance and monthly balance are realized by the built-in algorithm based on the collected data. The analysis of energy use can be analyzed by means of report and graph. The energy consumption is monitored through the energy flow chart, including energy use, energy operation monitoring, open and shutdown consumption management, etc. The core technology of energy consumption prediction, energy pipeline network simulation and multi-period dynamic optimization of energy scheduling is applied to establish energy generation/consumption prediction model, energy pipeline network simulation model and optimal scheduling model of energy systems. Through the system, the optimal dispatching and distribution plan of various energy medium can be automatically given, so as to achieve optimal scheduling and operation of energy systems (fuel gas, hydrogen, steam, power, water system, etc.).

1.6 Smart petrol station

Petrol station is the core of product oil sales, which is the sales channel to achieve maximum profit margin. How to make full use of the space of petrol stations and provide customers with fast and convenient services is an urgent problem for petrol stations.

Based on customer needs, with the help of advanced technology, smart petrol station monitors and collects all the key information in the operation process, and applies big data technology to filter, clean, sort and excavate information in time, in order to achieve the intelligent response and decision to the relevant personnel and processes, such as customers, managers, oil products, non-oil products, equipment, sales channels, marketing,

environmental protection, etc.The essence of the smart petrol station is to proceed from the need of customers, realize smart management and service of petrol stations, improve operational efficiency and customer satisfaction, and ultimately achieve maximum profit[20].

Based on the operation ideas of "people, vehicle, service", drawing on the internet thinking, relying on the integration of supply chain and logistics, automotive services, payment and finance, e-commerce and petrol station service, we build the ecosphere of smart petrol station, and realize the comprehensive transformation and upgrading of petrol station business, which is shown in figure 4.

Figure 4 Ecosphere of Smart Petrol Station

III. CONCLUSION

(1) Refining and chemical industry is facing new competitive situation, including changeable market, domestic and foreign refining and chemical enterprises, energy substitutes, pressure of product quality upgrading and application of new technologies. Therefore, it is the key for enterprises to strive for internal strength and forge ahead. It is an important means for the refining and chemical enterprises to deal with the new situation by realizing the smart refinery and the comprehensive digital transformation and upgrading of the refining and chemical enterprises.

(2) The academia and industry put forward some suggestions on the construction of "smart refinery". The infrastructure should be well prepared to ensure the efficiency and accuracy of data acquisition and transmission. A unified data standard is needed to ensure the accuracy and uniqueness of data. The combination of technology and management is needed, with strict requirements, high requirements, and process control from the source of data to the end.

(3) Smart refinery involves many aspects, such as engineering, research, crude oil procurement and transportation, refining and production, warehousing and logistics, sales and so on. The construction of smart refinery should be based on digital refinery. Intelligent refinery is the core and smart refinery is the goal. The construction of smart refinery should make full use of the existing information system, integrate all kinds of information resources, maximize the value of information resources, and enhance the comprehensive competitiveness of refining and chemical enterprises through information technology.

(4) There is no unified mode of smart refinery construction. The construction of smart refinery should be based on the enterprise's informationization level. The top level design should be completed first, and the typical system construction should be highlighted. The economic benefit is the core and the short-term speed win should be achieved. The construction of smart refinery should take economic benefit as the core to achieve a quick win.

REFERENCES

[1].   ZUO S H. Vigorously Promote the Refining and Chemical Integration to Enhance China's Oil Refining Business Profitability[J]. Journal of Beijing Petroleum Managers Training Institute, 2011, 18 (1): 4-7.
[2].   TAN W Z. Intelligent Process Manufacturing—an Efficient Way to Upgrade Traditional Refineries[J]. Petroleum & Petrochemical Today, 2016, 24 (6): 1-4.
[3].   WANG J M. Development Status of Refining & Chemical Industry and Its Development Trends[J]. Petroleum & Petrochemical Today, 2014, (6): 1-7.

[4].   James G. Speight. The Refinery of the Future. Gulf Professional Publishing. First edition 2011: preface ⅷ.
[5].   Rana MS, Sámano V, Ancheyta J, et al. A Review of Recent Advances on Process Technologies for Upgrading of Heavy Oils and Residua. Fuel, 2007, 86: 1216–1231.
[6].   Shanying Hu, G. Towler, (Frank) X. X. Zhu. Combine Molecular Modeling with Optimization to Stretch Refinery Operation. Ind. Eng. Chem. Res. 2002, 41, 825-841.
[7].   LI Z Q. Integration of Oil Refining and Chemical Industry-Development Trend of Future Petrochemical Industry[J]. Petroleum & Petrochemical Today, 2005, 13 (5): 8-11.
[8].   LIANG L H. Probing Development Trends of CNOOC Refining and Petrochemical Industry[J]. Petroleum & Petrochemical Today, 2015, 23 (8): 29-33.
[9].   LI H T, ZHAO X P. Application of 3D Digital Factory Technology in PetroChina Refining and Chemical Enterprises [J]. Information China, 2012, (225): 44-47.
[10].   MA D Q, XU D S, LI H Y, et al. Construction and Application of Digital Factory in Refining and Chemical Enterprises[J]. China Management Informationization, 2015, 18 (19): 86-88.
[11].   LIU L L, FU G L, HAN L L. Application Research and Discussion on Digital Refinery Technology[J]. China Management Informationization, 2014, 17 (20): 36-38.
[12].   YANG J H, QIU M X, HAO H N. Intelligentization - the Development Trend of Oil and Gas Industry [J]. Oil Forum, 2016 (6): 36-42.
[13].   WANG H, WANG Y, LIU J, et al. Planning Objectives and Important Directions of Refinery informationization [J]. Petroleum Planning & Engineering, 2017, 28 (1): 51-55.
[14].   Aye, M. S., Zhang, N. A Novel Methodology in Transformation Bulk Properties of Refining Streams into Molecular Information. Chem. Eng. Sci., 60, pp6702-6717, 2005.
[15].   Yongwen Wu. Molecular Management For Refining Operations. A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Engineering and Physical Sciences. 2010.
[16].   WU Q. [J]. Research on Molecular Engineering ＆ Molecular Management for Petroleum and its Applications (Part I)[J]. Petroleum Refinery Engineering, 2017, 47 (1): 1-7.
[17].   ZHU R, SHEN B X. Constructing Catalytic Cracking Kinetic Model Based on Structure Oriented Lumping New Method and Study on its Application[D]. Shanghai: East China University of Science and Technology, 2013.
[18].   WU Q. Research on Molecular Engineering ＆ Molecular Management for Petroleum and its Applications (Part Ⅱ)[J]. Petroleum Refinery Engineering, 2017, 47 (2): 1-14.
[19].   Stefan Seuringa, Martin Müllerb. From A Literature Review To A Conceptual Framework For Sustainable Supply Chain Management. Journal of Cleaner Production, 2008, 16 (15): 1699–1710.
[20].   WANG H L, WAN H, DAI J Q. Analysis of Smart Petrol Station[J]. International Petroleum Economics, 2016, 24 (3): 90-94.