Original Research Article

Research progress of crude oil storage and transportation scheduling modeling in refineries

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Abstract: Production scheduling in refining enterprises serves as a crucial link connecting planning and operation. Current research mainly focuses on small-scale crude oil scheduling problems with a scheduling cycle of 7 - 10 days and 3 or 4 scheduling links. However, there is a relative scarcity of research on large-scale scheduling problems involving more than 5 storage and transportation links and a long cycle (≥30 days). Aiming at the difficulties in global modeling under the trend of refining-chemical integration, this paper points out the rationality of modeling complex processes from a spatial segmentation perspective. It also analyzes the characteristics of modeling methods such as mathematical programming, constraint programming, genetic algorithm, and reinforcement learning, clarifying the application advantages of mathematical programming in maturity, constraint programming in logical processing, genetic algorithm in multi-objective optimization, and reinforcement learning in potential. The importance of spatial segmentation modeling and the integration of multiple methods in constructing a suitable-scale scheduling model is revealed. The research results provide assistance for schedulers in selecting appropriate methods and constructing scheduling models that conform to actual working conditions.

Keywords: Crude oil scheduling; Segmentation modeling; Modeling methods; Business scenarios

In the production system of refining enterprises, the scheduling link, as the core hub connecting plan formulation and on-site operation, directly affects the economic benefits and production stability of the enterprises [1-3]. Current research mostly focuses on small-scale crude oil scheduling with a short period of 7-10 days and 3-4 storage and transportation links, while paying less attention to large-scale scheduling with a long period of over 30 days and 5 or more storage and transportation links. With the development of refining and chemical integration, the scale of scheduling problems has increased dramatically, and it is a reasonable solution to simplify the crude oil storage and transportation process from the perspective of spatial segmentation. Among the existing research methods, mathematical programming is mature and widely used, constraint programming is good at handling complex logic, genetic algorithm is suitable for multi-objective modeling, and reinforcement learning has significant potential. Starting from the research scope and methods, this paper explains the rationality of spatial segmentation modeling, analyzes the characteristics of each method, and aims to provide guidance for schedulers to construct appropriate crude oil scheduling models.

1. Research scope of crude oil scheduling in refineries

1.1. Refining production planning and crude oil scheduling

The refining industry belongs to the continuous process industry, with a large production volume and high continuity requirements. Refining production planning is divided into long-term (more than 1 month) and short-term (7-10 days). The former can achieve profit maximization through linear programming, while the latter mostly relies on manual work. Due to the limitation of the model scale, the research on crude oil scheduling mostly focuses on the short cycle of 7-10 days.

1.2. Common business scenarios of crude oil

Scheduling in Refineries Past scholars often classify and study the business scenarios of crude oil scheduling according to the location distribution of production devices or the number of storage and transportation process links. According to the location, it can be divided into inland refining enterprises[4] and coastal refining enterprises[5]. Coastal enterprises are close to ports, and after the crude oil is unloaded, it can be directly supplied from the port area oil tanks to the distillation tower. The crude oil processing devices of inland enterprises are far from the port, and they need multiple links such as oil tankers and long-distance pipelines for transportation, and can also be subdivided according to the number of docks and pipelines. According to the number of storage and transportation links, the 3-level structure includes oil tankers, terminal tanks, and production devices; the 4-level structure adds the plant tank; the structure of level 5 and above is complex, involving long-distance pipelines, and there is a problem of "pipeline delay transportation". Scholars have carried out modeling for different structures. For example, Zhang Wanting[6] and Li Yaping[7] studied the 3-level structure, Haokun Yang[8] explored the 4-level structure, and Zhou Xiang and Zhou Zhiju optimized and modeled the 5-level structure.

1.3. Solving complex storage and transportation

Processes from the Perspective of Spatial Segmentation Modeling The integration of refining and chemical industry has increased the scale of scheduling, making global modeling difficult. Cutting the crude oil storage and transportation process into upstream and downstream sub-problems from a spatial perspective can simplify the complexity and speed up the solution. However, past research often ignores the constraints of upstream resource quantities, resulting in insufficient feasibility of downstream scheduling schemes. Therefore, when constructing downstream scheduling schemes, it is necessary to fully consider the constraint rules of upstream resources such as the oil carrying capacity of oil tankers.

2. Common methods for modeling crude oil storage and transportation

Scheduling in Refineries Common methods for modeling crude oil storage and transportation scheduling include mathematical programming, constraint programming, reinforcement learning, and genetic algorithms. Schedulers can select methods according to working conditions to formulate optimization schemes.

2.1. Mathematical programming method

Mathematical programming is a traditional and mature modeling method, and the model is composed of variables, constraints, and objective functions. It is widely applied in the field of production scheduling. In refining enterprises, Mixed Integer Linear Programming (MILP) and Mixed Integer Nonlinear Programming (MINLP) are commonly used. Many scholars use this method to construct models. For example, Symonds uses linear programming to optimize long-term refining plans, and Lee transforms the model with bilinear constraints into MILP for solution.

2.2. Genetic algorithm

The genetic algorithm is often used to study crude oil storage and transportation problems and can optimize multi-objective functions. For example, Huang Kanghuan uses a dual-population co-evolution algorithm to optimize objectives such as the cost of oil supply tanks. However, this method mostly deals with 3-4 level storage and transportation processes, has less research on problems of level 5 and above, and requires a long solution time, usually ranging from hundreds to thousands of seconds.

2.3. Reinforcement learning method

Reinforcement learning optimizes strategies through interaction with the environment and is widely applied to scheduling problems in the manufacturing industry. Compared with traditional methods, it has high universality and strong real-time performance, and is suitable for handling complex constraints and multi-objective optimization. Nan Ma and others use a deep reinforcement learning framework to compress the state space, and Ma Nan combines the SAC algorithm to achieve dynamic scheduling of crude oil storage and transportation.

2.4. Constraint programming method

The constraint programming model can only contain variables and constraints and is solved through three stages: value domain initialization reduction, constraint propagation, and backtracking verification. Its advantage lies in handling logical problems and avoiding the increase of model complexity, but its optimization-seeking ability is weak. Zhou Xiang uses composite modeling of constraint programming and mathematical programming to realize the simulation of long-distance pipelines.

2.5. Other methods

Some scholars use heuristic rules [9-11], Petri nets [12-14], etc. to solve crude oil scheduling problems. The heuristic method is suitable for small-scale scenarios and is prone to failure in the face of complex constraints; the Petri net can describe characteristics such as system synchronization and conflicts, but it is mostly used for analysis in specific situations.

3. Conclusions and prospects

(1) The business scenarios of refineries can be classified according to the location distribution of production devices or the number of storage and transportation process links for common business scenarios of crude oil scheduling. When dealing with complex large-scale crude oil scheduling business scenarios, it is advisable to consider segmenting the model from a spatial perspective.

(2) The mathematical programming method is relatively mature in application. However, when facing the global optimization of complex crude oil scheduling, its ability to handle integer variables and nonlinear constraints is somewhat insufficient. (3) The constraint programming method is convenient for modeling and suitable for dealing with feasibility issues in crude oil scheduling. However, it has certain deficiencies in optimization seeking.

(3) The genetic algorithm performs remarkably well in handling multi-objective problems. However, the scale of models it can handle is usually small, often involving 3 or 4 levels of storage and transportation processes, and the solution time is relatively long.

(5) As an emerging method, reinforcement learning performs outstandingly in handling the real-time nature of crude oil scheduling and in the calculation speed of solving models based on cases. However, similar to the genetic algorithm, there are currently no cases of solving large-scale and complex crude oil scheduling problems. (6) In the future modeling process, considering the business scenarios of crude oil scheduling, schedulers can consider applying appropriate modeling methods to solve crude oil scheduling problems. Of course, the approach of combined modeling can also be considered, using multiple methods to complement each other's advantages and handle problems better.

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