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Pipeline and Vehicle Transportation Problems in the Petroleum Industry
石油行業的管道與車輛運輸問題

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Abstract

In the petroleum industry, petroleum product logistics can be divided into two phases: *first logistics*, which is mainly provided through pipeline transportation or railway, refers to distribution from refineries to oil depots; and *second logistics*, which is primarily supported by vehicles, pertains to distribution from oil depots to oil stations. This thesis studies three petroleum product transportation problems faced by transportation practitioners in the petroleum industry: one stems from *first logistics* and two from *second logistics*.

Oil product transportation costs currently account for a proportion of sales fees in the Chinese petroleum industry that is considerably higher than the average international level. Hence, reducing costs incurred from the transportation of oil products has become a highly important problem for the managers of Chinese oil companies. This thesis aims to provide a reference for oil companies for reducing both *first* and *second logistics* expenditures. The investigation of these problems was motivated by actual projects for China National Petroleum Corporation (CNPC).

For *first logistics*, a three-phase optimization model for the transportation of multiple petroleum products using pipelines is described. Through this

method, we aim to ensure that all depots are able to satisfy the demand for each petroleum product while minimizing costs. The first phase involves solving a mixed integer programming model to create resource allocation plans. This phase minimizes the number of products transported in each time period. The second phase uses the output from the first phase and integrates it into a quadratic mixed integer programming model to create a scheduling plan, which minimizes pumping costs by selecting the optimal pumping configuration and flow rate. We employ dynamic programming to increase the efficiency of the algorithm, which enables a commercial linear programming solver to address problem instances of a practical scope. Finally, the third phase post-processes the solution from the second phase to minimize mixture costs using dynamic programming. This research was conducted on behalf of CNPC in mainland China, with findings resulting in annual savings exceeding 1 million Yuan.

For *second logistics*, we discuss a new practical variant of the vehicle routing problem with time windows (VRPTW), which originated from the regional transportation planning for oil products at a China National Petroleum Corporation (CNPC) branch in a northwest province of mainland China. Tanker trucks are scheduled to serve each oil station in multiple periods according to a recurring and dynamic time window setting. Refilling at an oil depot is always required after visiting an oil station, so it is safe to assume that the vehicles are uncapacitated. The problem is formulated into a mixed-integer programming model and shown to be $\mathcal{NP}$-hard. We found that the mixed-integer programming model is only solvable for very small impractical cases using exact methods, e.g., branch and cut, which is employed by the state-of-the-art commercial solver ILOG CPLEX. Moreover, due to the floating time windows imposed on the nodes, traditional local search-based heuristics with

node interchange operators are not applicable. Thus, we adapt and propose an iterative time window partitioning heuristic that discretizes time windows into multiple time points with dynamic partition widths. Experiments show good quality solutions can be achieved for problem cases with practical sizes.

In times of uncertainty, transportation demand changes seasonally as the consumption of oil products fluctuates depending on season. CNPC owns a limited number of vehicles dedicated to transportation requirements during regular seasons. During peak seasons, they need to outsource some transportation jobs to third party logistics (3PL) providers because the demand for oil products (and correspondingly the transportation demand) at this time is considerably higher. Therefore, the solving of two problems of oil product transportation from oil depots to oil stations during peak seasons are necessary: first, determine which of the transportation requirements of oil stations should be outsourced to 3PL providers; second, devise the scheduling plan that determines which of the oil stations' transportation requirements will be handled by the vehicles of the petroleum company. This thesis integrates the combinatorial auction (CA) and vehicle routing problem with time windows (VRPTW) into a single problem. The problem is formulated into a mixed integer programming model and shown to be $\mathcal{NP}$-hard. We devise a heuristic to separate all the stations into two types (depending on whether it is outsourced to 3PL companies) according to distance. We then obtain an initial solution by separately solving the CA and VRPTW problems. To improve the initial solution, we design and test multiple heuristic operators to interactively solve the CA and VRPTW. Experiments show that good quality solutions are achieved for problem cases of practical scope.

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