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Solving External Resource Constrained Vehicle Routing Problem by the Constraint Programming -based Routing and Scheduling Approach

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1 Introduction

In today's competitive marketplace, customers expect quick, timely delivery of products and services. Stiffer competition has placed a greater emphasis on after-sale service. Too often, companies carefully plan all of the steps leading to order fulfillment but can't manage final delivery in the way they'd like. Efficient routing and dispatching can reduce costs and improve customer service by optimizing vehicle routes - arming transportation firms with a competitive advantage. To maintain customer loyalty while preserving profitability, companies need their field service to respond rapidly, accurately and efficiently. Thus, vehicle routing and dispatching system are needed to determine how to deliver their products to warehouses, sales points or directly to end users by a wide range of companies in the manufacturing, food and trade industries. It becomes ever important to optimize the dispatching and scheduling of customer visits, ensuring the right people and equipments are sent to do the job at the specified time. However, the dispatching and scheduling of customer visits and allocating equipment by hand is a cumbersome task at best, and the risk of error grows as the number of service calls increases. An efficient dispatching and scheduling system will be able to shorten the planning and scheduling process while ensuring the best solution is found, enabling fast and reliable service to be delivered.

As a special case of Vehicle Routing Problem (VRP), External Resource Constrained Vehicle Routing and Scheduling Problem (ERC-VRP) has been studied and discussed in this paper. A Constraint Programming (CP)-based (or short as Constraint-based) routing and scheduling approach is introduced to solve it and a case study is used to show it in detail.

2 External Resource Constrained Vehicle Routing and Scheduling Problem

A VRP consists of a set of locations to be visited at the lowest possible cost. It is a practical problem that has been studied and is usually expressed as follows: given a set of customers requiring a visit, and a fleet of vehicles based at a depot that can perform the visits, construct a set of routes for the vehicles that minimizes the costs of operation. The objective function is typically expressed as costs related to the number of vehicles and to distance traveled. Constraints include various capacity constraints on weight, volume, length, etc., time constraints on when the customer will accept a visit, and the total length of routes.

In practical problems there may be different kinds of additional constraints including legislative restrictions, established work practices and customer preferences, and a complex objective function reflecting complicated pay provisions. Routing problems can differ greatly depending on the time windows and work-hour regulations available for visits, vehicle characteristics, and pickup-and-delivery routes. Thus, complexity of routing problems may vary greatly. For example, VRP with time window (VRP-TW) is also one of the constrained VRPs, in which predefined time windows should be considered as constraints for the depot or customer's sites.

Except core and side constraints of VRPs themselves, a VRP may also include different kinds of specific constraints that depend on the business area of the application, such as vehicles and their drivers may occasionally need resources that can be considered "external" to the delivery process itself. For example, there may be handling resources such as people, cranes, or docking bays at a depot that are necessary to load the trucks, or there may be trailers (shared between vehicles) that are used for the deliveries. Thus, constraints may be required to allow the use of resources in a depot or customer's sites within a limited capacity. This kind of problem can be typical considered as External Resource Constrained Vehicle Routing and Problem (ERC-VRP). Different from VRP-TW, ERC-VRP has predefined resource limitation for the depot or customer's sites, which may varies with the time and may subject to breaks for the resources that represents a break for the people loading the trucks. Thus, an ERC-VRP is a combination of both a Vehicle Routing Problem and External Resource Constrained Scheduling Problem, in which the resources need to be handled during the routing. In such problems, usually, the resource constraints should be treated as hard constraints, thus it is not easy to be solving by just checking the solution and make some repairs.

3 Solution Approaches for ERC-VRP

3.1 Various Existing Solution Approaches

There are many real-world, industrial problems where the possible solutions are so numerous that it is not practical to consider all of them in a search for an optimal feasible solution. These problems are sometimes referred to as combinatorial optimization problems, emphasizing the idea that the number of possible solutions grows combinatorially as the number of decision variables increases. The VRP is one of these types of problems. For routing problems of practical size, complete search methods cannot produce solutions in a short and reliable time period. By contrast, iterative improvement methods have proved very successful in this regard. Iterative improvement methods operate by changing small parts of the solution, for instance moving a visit from one route to another, in hopes of effecting a global improvement. This type of operation involves retracting previous decisions and making new ones. Such iterative improvement methods includes Local search, which operates by considering a set of possible moves. In order to escape a local minimum, it is required to have a controlled method of accepting a cost-degrading move, which may increase the total cost with the objective of finding a new neighborhood to explore. This is usually implemented by meta-heuristics, which provide the framework for accepting such moves. Meta-heuristics, such as SA (Simulated Annealing), GA (Generic Algorithm), Tabu search and guided local search, have been extensively applied to VRPs with good results.

3.2 The Problem and Difficulty of the Various Existing Solution Approaches

There are many different existing solution approaches proposed to solve VRPs can be also used for solving ERC-VRP. However, most of the above approaches have difficulty to handling complicated hard constraints. For satisfying the constraints, constraint checker is the usual way used in most approaches. However, constraint checker can only be executed after a solution is generated. In complicated hard constraints or over-constrained problems, the constraint checker may reject most of the solutions generated, and thus it is not an efficient approach for highly constrained problems. ERC-VRP, especially, is a very highly constrained problem, and most of the existing solution approaches have difficulty to handle resource constraints as hard constraints. Also, most of the existing approaches have difficulty to solve constrained scheduling problem at the same time.

3.3 Constraint Programming -based Approach for ERC-VRP

On the other hand, constraint programming is a relatively new technique that has been proved particularly powerful when used to solve VRPs with complicated hard constraints. With the help of the constraint programming, only solutions that meet all the hard constraints can be generated, thus it is more efficient than the approaches with meta-heuristics alone. The approach suggested and introduced by this paper is the CP-based vehicle routing and the CP-based scheduling approach, which can combine with various meta-heuristics to solve complex constrained vehicle routing and scheduling problems, like ERC-VRP.

4 Case Study

An example is used here as a case study to show how to solve such kinds of ERC-VRP problems by CP-based approach. It demonstrates the use of external resources by starting with a standard Pickup and Delivery Problem (PDP) and adding the requirement to use one of a limited number of depot docking bays to load the vehicles.

4.1 Description of the example problem

The problem considers deliveries to customers with several vehicles, and each of them must be loaded at a limited number of docking bays at a depot. A visit may take certain unit of time to be performed at the depot. This means that the maximum number of visits at the depot must be less or equal to the capacity of the depot for all visits at any time. This capacity can also be considered as maximum capacity of some limited resource, which is related to the depot, such as maximum number of available parking slots, loading bays or forklifts, etc. There is a break on the docking bay resource that represents a break for the people loading the vehicles. Other constraints may exist such as pickups and deliveries with time window constraints. The objective is to minimize the cost of all the delivery. Because vehicle routing should be subject to limited resource usage and the sequence of using the resource should also be defined, the vehicle routing problem for this case becomes an ERC-VRP.

4.2 Steps of problem modeling

1) The problem can modeled as two subproblems, one as a vehicle routing subproblem and the other as a resource constrained scheduling subproblem.

2) Then the shared external resources docking bays in the problem can be simply modeled as discrete resources in scheduling subproblem which have a capacity that can vary over time. The visits in the vehicle routing subproblem are as activities that uses these resources.

3) All the routing related constraints are handled in vehical routing subproblem.

4) The two subproblems can be linked through constraints between start variables of visits in the vehicle routing subproblem and the start variables of activities in the scheduler subproblem.

4.3 Problem solving processes

- Activity placement is handled through a schedulering search goal.
- Visit placement is handled through a routing search goal.
- The schedulering search goal is passed as a subgoal to routing subproblem's search goal to first solution method.
- The schedulering search goal is also passed as a subgoal to routing subproblem's search goal to improving solution
- The solution is largely computed, improved, with method like local search.

4.4 Results

As a sample data set, limited number of docking bays are used to load up to many vehicles. The result shows a feasible and improved solution. (Final results will be provided during the presentation).

4.5 Benefits

- The two models for two subproblems are active at the same time.
- All the constraints can be treated as hard constraints, and only the feasible solutions are generated during the solution search processing.
- By incorporating scheduling with dispatching programs, some solutions can be pruned out by scheduleing or routing propagation and the search.
- The scheduling model is very versatile.
- It has all the wealth of constraint-based scheduleing's modeling features, and constraint-based routing's modeling features.

In this case study, ILOG Dispatcher, a CP-based routing generator, is used to build routes, and ILOG Scheduler, a CP-based scheduling library, is used to schedule.

5 Remarks

This paper promotes and suggests a flexible, powerful generic constraint programming -based routing and scheduleing approach to solve complex resource constrained vehicle routing and scheduling problems more efficiently. With the CP-based technology, it can obtain high performance and solving power for most difficulty routing applications. It can be also seen that this approach can easily model complex constrained routing problems. Most of the above technologies and methodologies are available in ILOG Scheduler and ILOG Dispatcher. They come as a framework that sits atop ILOG Solver, which is ILOG's core constraint-programming optimization engine. With the usage of both ILOG Scheduler and ILOG Dispatcher, both complex resource constrained scheduling problems and VRPs can be solved efficiently.

6 Reference

[1] ILOG Optimization Technology White Paper, ILOG, Inc. 2001. (http://www.ilog.co.jp/)

[2] ILOG, ILOG Dispatcher, User Manual, version 4.0, 2003.

[3] ILOG, ILOG Scheduler, User's Manual, version 6.0, 2003.