Solving Distributed Delivery Problems with Agent-Based Technologies and Constraint Satisfaction Techniques

Position Statement

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Abstract

A considerable amount of research has been concerned with the domain of automatic planning and scheduling, but many real world scheduling problems such as The *Pick up and Delivery Problem With Time Windows (PDPTW)* are still not easily tackled. The PDPTW problem demands solving the schedule for each vehicle of a transportation fleet where pick up and delivery of customer orders are distributed among various locations, while satisfying the constraints on the time windows when serving at client pickup and delivery locations. In this paper, we are stating that an agent-based system designed to solve the PDPTW problem using constraint satisfaction techniques is appropriate for practical applications.

Introduction

Our research concerns the *Pick up and Delivery Problem With Time Windows (PDPTW)* and is motivated by its application to the transport logistics domain. The PDPTW problem consists of computing the optimal set of routes for a fleet of vehicles in order to satisfy a collection of transportation orders while satisfying the time windows at client locations. The goal of the PDPTW is to provide feasible schedules, which satisfy the time window constraints, for each vehicle in order to deliver to a set of customers with known demands on minimum-cost vehicle routes.

While a significant amount of research exists in the domain of planning and scheduling, the problems of vehicle routing and order scheduling are far from adequately solved in practice. This is due to the fact that in research studies many parameters or customer requests are ignored. Moreover, although there exist efficient algorithms for solving static scheduling problems where all the data about the client orders is known in advance, in practice one has to deal with dynamic scheduling, where client orders or changes in already requested orders might arrive in the system at any time. Distributed aspects of planning and scheduling problems are hard to define in a generic manner since they often depend on the application domain.

We have been developing a commercial system for computing the truck schedules in transportation logistic applications (Dorer & Calisti 2004). We are using multi-agent technologies as the platform underlying our system and we are experimenting with various techniques for schedule solving, ranging from operations research to constraint programming. Our production system is now in use by several medium to large-sized transport logistics companies which has incurred a reduction of 4% to 6% in costs relative to the manual dispatchers solution (Dorer & Calisti 2005). This improvement is significant for shipping companies which have huge inputs and costs but small profit margins.

In this position paper we give a brief description of our observations gathered from experience in the domain of transport logistics and express our interest in discussions regarding distributed planning and scheduling management techniques for solving the PDPTW problem.

Multi-Agent Systems for the PDP Problem

Today, several industries including transportation logistics are faced with constantly spreading world-wide trading and goods flow. This global context requires distribution and high flexibility in the transportation scheduling system, as can be provided by multi-agent systems, as demonstrated by other approaches such as (Fischer, Müller, & Pischel 1995). The main specific needs of the transportation logistics problem computation have been identified to be as follows. When system capabilities are set apart into independent units/agents they may be intrinsically *distributed* over a large network of computers. Transportation applications are especially suitable for the application of techniques such as *task decomposition*, where the schedule for each vehicle is computed by a single agent. Computation and system control are distributed among the agents. Each agent can be designed to act autonomously, in a *decentralized* manner, by computing a part of the schedule without needing knowledge,or reasoning, about the global process of the whole system. In order to achieve a better global solution, the agents must *cooperate* by exchanging client orders between one other and adjusting their schedules accordingly with the goal of minimizing the overall cost.

Based on our practical experience with transportation scheduling in medium and large-size shipping companies, we can testify to the suitability of multi-agent techniques to real-world problems.

Constraint Satisfaction for Scheduling

Research work in the constraint satisfaction problems (CSPs) domain has brought about new ways of tackling combinatorial optimization problems, including scheduling. When dealing with scheduling problems with complex side constraints, CSPs techniques offer high flexibility and robustness through constraint propagation, an advantage over operations research methods such as mathematical programming, which lack the flexibility needed for solving problems with side constraints.

In practical applications many more parameters and side constraints, which characterize the client requests, occur than in theoretical studies. An example of such side constraints are the time constraints on the driver schedule in order to satisfy legislation, e.g. the driver must take a 45 minute break after 4 h 30 of continuous driving. This kind of constraint is hard to handle in integer programming based systems, whereas constraint programming can handle them in a natural way. This example illustrates the *flexibility* of the constraint programming framework. Moreover, variables, domain values and constraints can be adjusted to the specific problem conditions, without necessarily affecting problem solving procedures and algorithms. This allows easy customization of the system to new client requirements. Flexibility can be also increased by solution adaptation techniques based on constraint satisfaction problems properties (Neagu & Faltings 2005). Moreover, constraint programming based on *weighted* constraints, which can be violated at a certain cost, can be used in order to model costs (for the roads) and preferences (for the customers as well as for suppliers). Every way of violating a constraint carries with it the cost of that violation, and the cost of a solution is a combination of the costs of each constraint violation it implies. This enables a flexible approach to calculate costs for plan deviations in real-world scenarios.

The CSPs have been also studied in *dynamic* environments where the set of constraints changes during problem solving, e.g., constraints can be added or removed, variables and values can change. Because constraints change it may be necessary to abandon the current solution for a new one. We are seeking for adaptation techniques which allow for partial reuse of previously computed solutions which can be helpful during subsequent problem solving in order to minimize the need for re-computation.

Another advantage of CSPs is that they can be represented and solved also in *distributed* environments. A distributed CSP has the variables and constraints distributed among distinct autonomous agents. Each agent has one or multiple variables and tries to determine its/their value(s). In general, there exist intra- and inter-agent constraints which the value assignment must satisfy. In order to verify inter-agent constraints, i.e., constraints between variables controlled by distinct agents, some form of agent communication needs to be supported.

In our transportation logistics system we are using constraint satisfaction techniques for solving the schedules of each vehicle. From our experience, the number of orders to be scheduled in a vehicle tends to be quite small, up to 20 client orders, and for these cases it is possible to perform a complete search. In situations where the number of client orders increases, local search constraint satisfaction algorithms can be used.

Discussion

The PDPTW problem is hard to solve. For medium and large scale applications the global optimal solutions are hard to reach and thus good approximation and heuristic approaches are more feasible. In the real world large, constantly growing and distributed companies show a strong interest in automating and optimizing their dispatching process. Thus, finding solutions for distributed solving of the PDPTW problem is of major importance for large-scale practical applications. There are few open issues which are important for practical applications of the PDPTW problem.

Global solution: While localizing the computation of a route's schedules in individual agents, it is difficult to achieve high-quality global solutions. How can the computation of a global solution be improved without a centralized schedule?

Suitability to distribution: In very large transportation applications, the need for a distributed representation is mandatory. How should the multi-agent system be distributed for large applications? Which agents should be concerned with certain client orders? And which agents should collaborate?

Dynamic aspects: The problem is called dynamic, as opposed to static, if the transportation requests are not all known in advance. This means that new requests can be received and treated during the optimization process itself. Which techniques are most appropriate to handle these problems?

Conclusion

We believe that multi-agent systems as a support platform for the PDPTW problem, and constraint satisfaction techniques as the solver for scheduling aspects are suitable techniques for transportation logistics applications. We have a transportation logistics production system which can handle transportation scenarios consisting of thousands of client orders. We would like the aforementioned aspects, global solution, dynamic aspect and suitability to distribution, in the context of distributed plan and schedule management.

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