PLANNING FOR THE CONVOY MOVEMENT PROBLEM

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Keywords: Convoy routing, Convoy movement problem, Logistics, Transport.

Abstract: Convoy movement problem has significant practical applications. The problem has been attempted in many styles with varying results. We address it as an AI Search and Planning and Scheduling problem. The work focuses on modeling the convoy movement problem using PDDL and attempting a solution using existing planning methods and planners. Initial results indicated problems of scalability. To address this we propose a two stage planning process.

1 INTRODUCTION

The convoy movement problem (CMP) is a logistical problem and addresses the issue of planning and scheduling a fleet of convoys between their sources and their respective destinations. Usually convoys are many vehicles long and take days to reach their destination.

Convoys are often employed when a large number of men and or large amounts of material have to be moved. In many situations movement by road is the only option. Planning convoys is of strategic importance and it is a time consuming job. This work presents a study on modeling the convoy movement problem from a planning and scheduling perspective. Toward the end present results from our experiments on moderately large problem instances using existing domain independent planners.

2 CONVOY MOVEMENT PROBLEM

The convoy movement problem has two parts to it. First is finding out the route the convoy is going to take to reach its destination and the second is fixing the time of the actions so that the resulting plan satisfies all relevant constraints. Route selection and scheduling of convoys can be seen as two interdependent activities. The route selected has to be scheduleable within the deadlines goals and vice-versa there should be a viable route that within bounds of the imposed deadlines. There are constraints in the problem that involve either or both of route selection and scheduling.

Routing Constraints. Certain roads may not support a convoy because the infrastructure may not be able to support say movement of heavy vehicles. Some roads may not allow bi-directional traffic flow. Constraints under this category are most often static.

Scheduling Constraints. These are usually deadline constraints. There are four common forms in which they are imposed. They are *"Earliest arrival time"*, *"Latest arrival time"*, *"Earliest departure time"* and *"Latest departure time"*.

Mixed Constraints. Cities most often impose constraints on when convoys can enter city traffic zones. Some roads along a route might become available for traffic only during certain time of day. Constraints of this type affects both route planning and scheduling.

3 RELATED WORK

The convoy movement problem has been tried in different forms. Most often it has been formulated as an optimization problem (Chardaire et al., 2005; Goldstein et al., 2010; Montana et al., 1999). Some of the earlier work consider convoys as point objects and do not model their length explicitly (Chardaire et al., 2005; Montana et al., 1999).

In (Goldstein et al., 2010) the problem they consider is most similar to the work discussed above.

Kumar A., Murugeswari I., Khemani D. and S. Narayanaswamy N..
PLANNING FOR THE CONVOY MOVEMENT PROBLEM.
DOI: 10.5220/0003739004950498
In *Proceedings of the 4th International Conference on Agents and Artificial Intelligence* (ICAART-2012), pages 495-498
ISBN: 978-989-8425-95-9

They consider convoys in the case of disaster recovery and management. Genetic algorithm is used for finding the solution. The initial state consists of the shortest path between the source and destination for each convoy. The cost function in this case considers a linear combination of penalties for vertex overlaps (no. of common vertexes between paths) and edge overlaps (no. of common edges between paths).

In (Chardaire et al., 2005) the cost function defined is focused on the time taken for the convoys to reach their destination over a given path. Length of the convoy is modeled indirectly as a guard time interval. We start from a set of simple paths between source and destination and optimize using integer programming.

In (Montana et al., 1999) genetic algorithms are used for route selection and convoy scheduling. In this work the convoy schedules are optimized for minimum cargo weight time and minimum civilian traffic disruption. These are objectives that the current work does not attempt to address.

4 PDDL MODEL

PDDL has chosen as the domain description language because this allows use of existing planners for study. The models were developed incrementally. The initial model is a single domain incorporating operators that together model all constraints listed in 4.1.

4.1 Constraints Modeled

The set of constraints that we have currently modeled are

- Edges have direction and may not allow two way traffic.
- Nodes that allow halting have a specified capacity.
- Convoys have size which is proportional to their length.
- Each convoy has its own length.
- Each convoy has its own speed.
- Each convoy has to maintain a minimum distance from the convoy ahead of it.

4.2 Model Details

Roads in the networks are modeled as directed edges in a graph. This allows traffic directions to be modeled. To impose this constraint, it is assumed that convoys always move from left to right along an edge. This allows us to make the move operators require the convoys to move from the left end node, marked by asserting *(left-vertex ?v - vertex ?e - edge)*, to the right end node, marked by asserting *(right-vertex ?v - vertex ?e - edge)*. Nodes where convoys can halt are marked as halting grounds using the predicate *(halting-ground ?v - vertex)*. Convoys have heads and tails. The tail follows the head taking the same path. This is achieved by asserting the *(head-edge ?c - convoy ?v - vertex ?e - edge)* predicate whenever the head enters a new edge and is de-asserted after the tail passes through. Fluents are used to model the size *(convoy-size ?c - convoy)*, speed *(convoy-speed ?c - convoy)* and capacity *(free-space ?v - vertex)* parameters. The minimum inter-convoy distance that is to observed is a constant so we can model this constraint by increasing each convoys length appropriately.

4.2.1 Operators

There are four classes of operators in this model. These operators are *enter*, *exit*, *unwind* and *move*. As we are handling convoy length in the model, a single move, enter, exit or unwind operator does not suffice. The operators *enter*, *exit* and *unwind* each have three cases and the *move* operator has nine cases. Thus the model in total has 18 operators. The operators are discussed in detail below.

4.3 Observations

State space planners using planning graph heuristic perform poorly because they spend most of the time grounding actions. The domain has 18 operators in PDDL and each of these have at least 3 parameters. The parameters are of type convoy, vertex and edge respectively. Now assume a 8x8 grid domain. This has 81 vertexes with 89 edges. Suppose we have 8 convoys this amounts to $81x89x8$ variations of one operator. So we have a total of $81x89x8x18 = 1038096$ ground actions. This exponential blow up severely affects scaling. Plan space planners also performed poorly in our experiments. This can be attributed to poor heuristics and the high branching factors involved in the domain.

5 TWO STAGE PLANNING

5.1 Two Stage Process

To overcome the scaling issue introduced by section 4.3, we introduce a two staged planning method. The first stage is broadly concerned with finding convoy routes and the second stage deals with the addi-

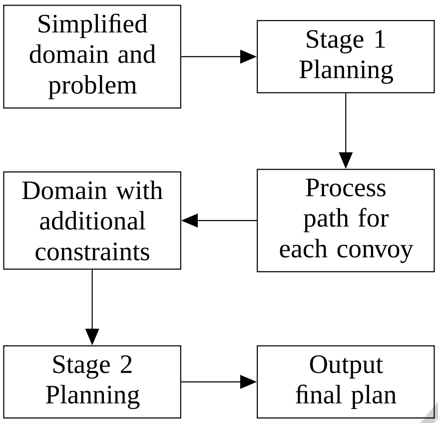

Figure 1: Two stage planning.

tional constraints that arise due to length of the convoys. The first stage uses a simplified domain model as compared to the one detailed in section 4. This model models point convoys and edge exclusivity for convoys.

The second stage deals with all the constraints dealt with in the monolithic model, in fact the same PDDL model is augmented and used again. We alter this model by removing the generic *move* operator with ground actions for each convoy. As noted in section 4.2.1 the move operator has 9 variants and contributes significantly against scaling. This leads to faster planning times. Figure 1 depicts the whole process.

5.1.1 PDDL Details

The first stage of the two stage model uses a simplified domain model. This model is geared toward finding routes for all the convoys while making sure that more than one convoy does not enter an edge simultaneously. It does not model convoy lengths. It has three operators in all. They are *enter*, *exit* and *move*.

The second stage uses the monolithic model discussed in section 4 with the move operators replaced by appropriately grounded actions for each convoy as discussed in section 5.1

5.2 Experiment Results

The trial runs were conducted on two sets of problems with the same object count. One is a set of random graphs and the other a grid graph. All the graphs are directed. All experiment runs were done using LPG-td (Gerevini et al., 2006) as the planner for both stages of planning. Results from the experiments conducted are given in Tables 1 and 2. The planning process has an overall timeout of 20 minutes. The experiments were conducted on a machine with Q9550 processor and 4 GB of ram.

Table 1: Result on random graph.

Nodes, Edges	Convoys	Stage 1 (s)	Stage 2 (s)
25 , 80	10	0.1	0.02
	20	0.09	0.02
	30	0.09	0.02
100, 360	10	1.1	0.07
	20	1.15	0.12
	30	1.15	0.16
225, 840	10	5.4	0.38
	20	5.37	0.13
	30	5.42	0.13
400,1520	10	15.0	0.61
	20	15.0	0.3
	30	15.0	0.3

Table 2: Result on grid graph.

Nodes, Edges	Convoys	Stage 1	Stage 2
25, 80	10	0.11	0.45
	20	0.09	0.08
	30	0.1	0.07
100, 360	10	1.32	9.96
	20	1.38	0.86
	30	1.38	16.0
225, 840	10	7.62	4.65
	20	8.29	50.0
	30	8.26	474.0
400, 1520	10	-	-
	20	-	-
	30	-	-

From the above tables we can see that the new process has given results on domain which are much bigger than the domains we were able to deal with in the single stage planning process. Another interesting result that we can observe from the above tables is that the topology of the graph plays an important role in the time consumed for the planning process. More experiments have to be made for making strong claims in this regard. At present we are speculating that tight topologies like the grid lead to very few actions being pruned, weakening of the heuristic used or both.

6 FUTURE WORK

6.1 Case for Local Search

In the real world convoys are used in logistics planning and execution. This translates to a decision support system in many cases. One characteristic of this system that is of interest is that we might want to be able to plan around hazards when execution fails.

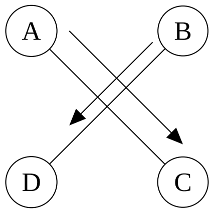

Figure 2: Convoy crossover.

This would also mean preservation of as much of the existing plan as possible. Another characteristic of interest is that of convoy interaction. This can lead to unsatisfied deadlines and/or other constraints which in turn leads to backtracking and a ripple effect. Both these characteristics suggest the use of local search.

6.2 Case for a Knowledgeable Heuristic

In figure 2 if the small but faster convoy is arriving a little later than the larger and slower convoy then we would like to have the larger convoy wait for the smaller convoy to crossover. We would like to consider a heuristic that considers the convoy length, speed and the time constraints associated with each convoy. We would like to investigate whether a heuristic can be formed for a dynamic scenario like this which can take into point temporal constraints.

6.3 Complete Search in Split Planning

When dealing with goals that have deadlines, which are common in this domain, the split planning approaching discussed in section 5 can fail to find a suitable plan. This is because the second stage is already committed to certain routes, and a solution may not exist for those routes. An interesting development would be a backtracking feedback based planner. The feedback can result in the plan from previous stage begin altered according to the reason for failure.

7 CONCLUSIONS

In this paper we have looked at some of the problems that arise when we look at path finding and scheduling of convoys when their length is significant and modeled explicitly. We have experimented with Sapa (Do and Kambhampati, 2003), Crikey (Coles et al., 2009), LPG (Gerevini and Serina, 2002) and LPG-td (Gerevini et al., 2006), an extension of LPG, at various stages of model development. LPG-td performed better than the other planners overall. By splitting the problem into two stages and planning separately we were able to improve scale and reduce planning time. We plan to improve the system by attempting to make it complete and also explore if this methodology of split planning can be generalized over multiple stages.

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