Multi-Agent Distribution Planning

Luke Marsh, Slava Shekh, Tony Allard,
Hing-Wah Kwok, Don Gossink

Defence Science and Technology Organisation,
Edinburgh, South Australia, Australia

E-Mail: **Luke.Marsh@dsto.defence.gov.au**

Abstract

In this paper we outline an emerging research project which focuses on a multi-agent solution to the logistics distribution and movements planning problem. Logistics distribution and movements planning involves developing an efficient plan to move all of the supplies, equipment and personnel required to desired locations in a timely manner. A multi-agent solution based on an auction system is under development, where an auctioneer agent acting as a central controller coordinates the tasks to be completed. Agents representing the transports develop and submit bids for tasks to create the overall plan. The multi-agent system has been designed so that different transports with varying capabilities can be modelled and easily inserted into the solution without revealing their exact capabilities, thus potentially covering a coalition aspect to the solution. An initial simulation has been created, implementing the current multi-agent solution and will be used as a test bed to analyse the approach taken plus variations on a theme. Future work includes enhancing the multi-agent system to handle more complex distribution scenarios; the implementation of various optimisation criteria; the experimentation of different multi-agent architectures with varying devolutions of responsibilities amongst the agents; and the comparison of the quality of solutions developed with this multi-agent solution against other distribution planning solutions.

Introduction

The focus of this paper is on a multi-agent solution (Wooldridge, 2006) for logistics distribution and movements planning. Logistics distribution and movements planning involves developing an efficient plan to move all of the supplies, equipment and personnel required to desired locations in a timely manner (Perugini, 2006). The following sections give an overview of the distribution problem that the multi-agent solution has been designed to solve. The multi-agent architecture will be outlined, covering the auction system used (Bertsekas, 2001), agent sub-contracting, and the rationalisation of transport schedules. Finally a summary of the future work to be done in this research project will be discussed.

Overview of Distribution Problem

The distribution and movements planning domain incorporates many transport platforms covering land, sea, air and rail with a goal of delivering supplies to a destination from a source location. The supplies, equipment and people can be sourced from many locations, and similarly need to be transported to possibly many locations. Immediately it can be seen that the solution space can expand exponentially, as the number of transports, routes, base locations and requirements of supply increases. Additionally there are many business rules, constraints and complexities inherent in the distribution domain, which need to be satisfied when developing a plan. The following paragraphs outline the sets of features and constraints in the distribution problem which our multi-agent solution is oriented towards.

The set of features inherent to the distribution problem include: multiple source locations; multiple destination locations; multiple route types (land, sea, air, rail); directed routes; multiple routes to destination; intermediary locations to destination, known as “transshipment” (Rojas, 2007); multiple transport trips via ‘drop and swap[1]’; many types of transports; multiple supply types to be moved; transports can carry many types of supply at once; and many trips may be required to complete the distribution.

The set of constraints inherent in this distribution problem include: The minimum runway length required for aircraft; minimum runway classification required for aircraft, known as “pavement classification number”; transport speed; transport range; transport personnel capacity; transport cargo capacity; transport loading/unloading times; and transports being unavailable for certain times.

Multi-Agent Architecture

Auction System

The auction system used in the multi-agent solution is a first-price sealed-bid auction (Sandholm, 2000), where a customer agent announces a task to all of the supplier agents, the supplier agents then submit their bids to achieve the task, or refuse to submit a bid, and finally after a set time, the customer agent selects the best bid according to its criteria. In the multi-agent solution there is one customer agent

[1] One transport could carry a quantity of supplies part way, then another transport may pick up the supplies and carry them further.

known as the auctioneer agent, and there are potentially many supplier agents which represent the transports in the distribution scenario, known as transport agents. Figure 1 shows the communication flow and structure of the multi-agent solution.

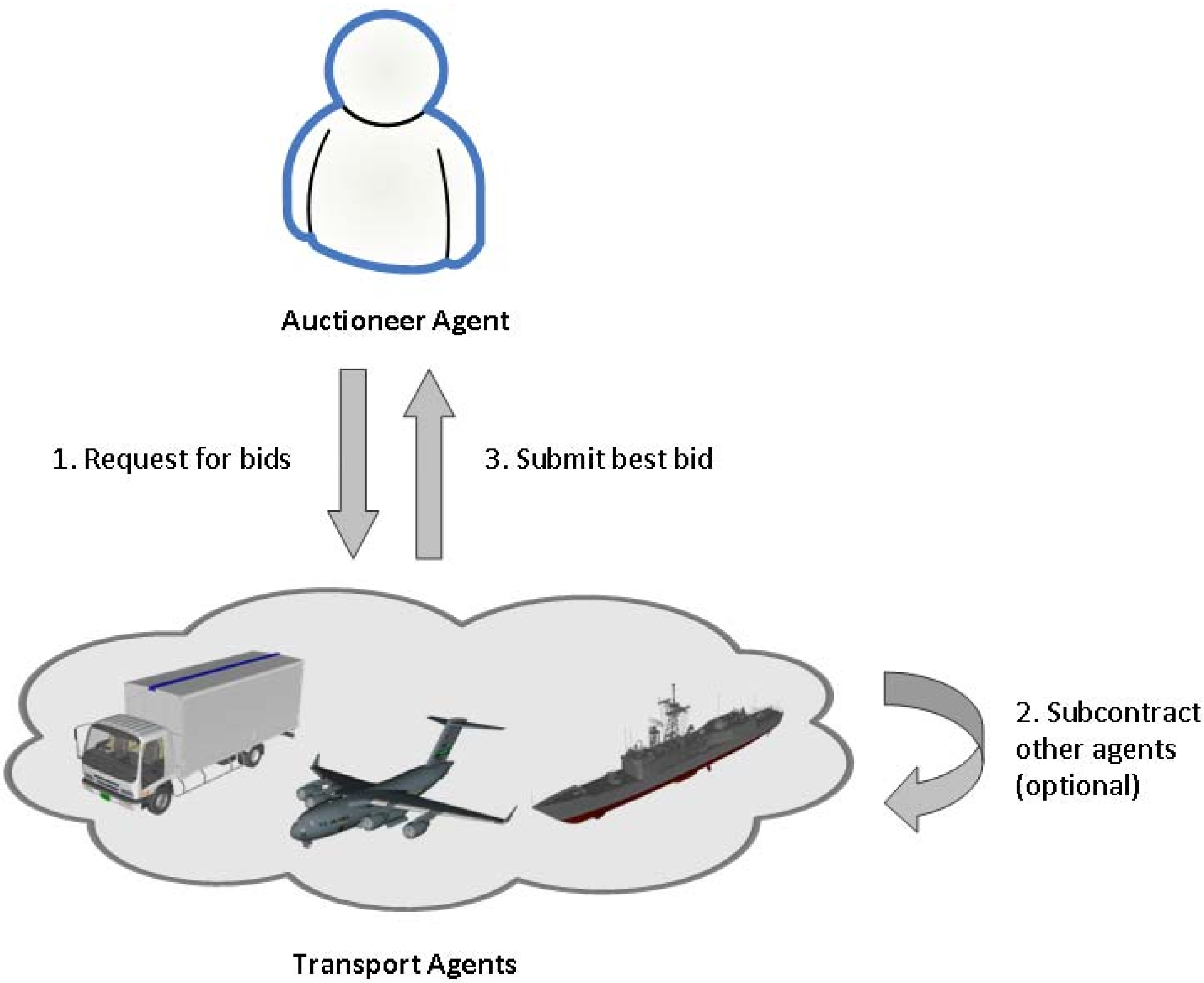

Figure 1: Multi-agent communication flow.

At the commencement of our multi-agent approach to the distribution problem, the auctioneer agent sorts the requirements of supply to be moved, based on a priority. It then iterates through each of these requirements one at a time announcing a call (request) for bids from the transport agents. The request includes the supply items, their locations, the destination of the delivery and preferred delivery time.

Upon receiving the request each transport agent will produce its best bid to achieve the request through the agent sub-contracting process. The sub-contracting process will be outlined in the next sub-section. When the transport agent has considered all valid sub-contracts, it will return the estimated delivery time of the best contract to the auctioneer agent as its bid for the task. If the transport agent cannot complete the movement it responds back to the auctioneer agent with an infinite delivery time.

After receiving bids from all of the transport agents, the auctioneer agent will choose the bid with the least estimated delivery time, and create a schedule for each transport involved in the movement for delivering that requirement. Given that for each requirement a complete schedule is created for its movement from its initial source location to its destination, and that the entire distribution plan is created before it is executed, the solution is essentially an offline algorithm (Russell and Norvig, 2010). This has the advantage that the distribution plan can be analysed and modified in order to introduce further optimisation or exploit the flexibility of the plan. However it does reduce the solutions' ability to handle dynamic changes to the scenario part way through and would require dynamic replanning to modify the distribution plan. In the final step the auctioneer agent attempts to rationalise the transports schedules by aligning drop and swap actions between agents and check efficiency of transport usage. This rationalisation step is outlined in the sub-section below. After this final step is completed, the auctioneer agent chooses the next highest priority requirement and the process outlined above is repeated, until movement schedules have been created for each requirement in the distribution scenario. If no valid schedule can be created for a requirement the scenario is deemed unachievable.

A perceived benefit of adopting a multi-agent approach to the distribution problem is that it can facilitate coalition planning and scheduling. Given that the only information exchanged by the agents is for the auction and consists of the cargo dimensions, destinations, completion times, etc., for the movement, the capabilities of the transports that the agents represent, the types of cargo being moved, and the underlying reason for needing the movement by the auctioneer agent can remain private. By exposing the interfaces and protocols of our multi-agent system, agents can be independently developed and inserted into the running system (Perugini et al., 2003). However there remain some issues relating to such an approach, these are often tackled under the area of mechanism design (Rosenschein and Zlotkin, 1994). Assuming that the goals of the coalition are aligned, an example of such an issue is inserting an early desired delivery time other than really required; in effect escalation of a false priority to ensure service. Such behaviours could be exploited by auctioneer and/or transport agents to maximise the benefit to one of the coalition partners. Research into robust mechanism design is required to minimise or eliminate the potential benefits of deceitful behaviour.

Agent Sub-Contracting

Upon receiving the request for a bid, each transport agent will attempt to complete the initial movement to the supply location. If the transport agent cannot reach the supply location it will respond back to the auctioneer agent with an infinite delivery time. Otherwise, this initial movement forms the beginning of a contract. The transport agent then sub-contracts the next portion[2] of the movement to all transports agents including itself. However a transport agent is only sub-contracted as long as the transport it is representing is capable of completing the next portion of the movement, and this movement does not conflict with the transports current schedule. Emulating a depth first search the current transport agent passes control to each sub-contracted agent in turn, and the subcontracting process is repeated for the next portion of the movement. If at any stage, the partial movement reaches the destination, the contract is complete. The agent that initiated the contract process will maintain a record of the best overall contract based on the minimal delivery time. Once the transport agent has completed the sub-contracting process, it will submit its best bid to the auctioneer agent. The auctioneer agent will examine all submitted bids and select the best bid. Finally, the contract associated with this bid is added to the schedules of the corresponding transport agents.

[2] A portion of a movement could be between two locations or between multiple locations.

Schedule Rationalisation

Once the schedules for transport agents have been formed, the auctioneer agent can perform schedule rationalisation. In this process, the auctioneer agent reviews schedules for each transport developed so far, looking for movements with similar characteristics which will improve the overall efficiency of the schedule. For example, consider the scenario where a transport is currently scheduled to move some supply, and is then tasked to move more supply along the same route at a later time. If this transport has spare capacity, and it is more efficient for the transport to wait for the later supply, these two movements will be merged into a single trip. The auctioneer agent will not merge a movement if it makes the estimated delivery time for that movement later than the preferred time.

Future Work

The multi-agent architecture will be further developed to handle more distribution scenarios containing more complicated constraints such as the limit on the number of aircraft able to be stationed at an airfield at any one time (Saraf and Slater, 2008); and allowing locations or routes to be unavailable at certain times. Further schedule rationalisations could also be implemented to improve schedule efficiency.

To improve performance of the solution, a possibility is to change the multi-agent architecture to model domain agents which will represent a number of transport agents. For example when all things are equal and there are ten transports with identical capabilities in the same location, only one computation is required for the ten transports, which could be done by the domain agent. Exploiting these symmetries in the problem space has the effect of reducing redundancy and saving computation time (Ravindran and Barto, 2001). In the case of the transports not being equal, the domain agents can undertake local search and submit locally optimal bids, trading global optimisation for speed in determining a solution.

Varying optimisation criteria can be explored such as: minimising the time to satisfy all requirements; delivering prioritised supplies first; delivering supplies exactly when they are required; maximising the number of requirements satisfied; minimising the transports travel time; minimisation of the total number of transport trips, utilisation of scarce/high-value transport resources effectively. Utilising our multi-agent test bed, experiments will be conducted to analyse and compare the various distribution solutions for the different criteria.

Utilising and developing an agent architecture will support experimentation of different devolutions of responsibilities amongst the agents. Further, policies relating to mechanism design can be explored. Finally, the comparison of the quality of solutions developed with this multi-agent solution against other distribution planning solutions can be tested, resulting in an understanding of heuristic tradeoffs and design decisions.

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