Continuous Delivery Scheduling and Execution with Multiagents

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Abstract: We report a cooperative multiagent system for solving the delivery scheduling problem where the environment changes dynamically. In the truck delivery problem, the environmental conditions such as the traffic condition of roads changes and additional delivery orders arrive dynamically during the execution of the delivery, then the reactive and adaptive measures are required to cope with such situations. Multiple agents for the delivery center and delivery trucks cooperate to cope with the rescheduling problem of additionally arriving orders after once the delivery has started according to the initial delivery plan. We show that the proposed method provides a flexible solution for the dynamic re-scheduling problem.

1. Introduction

Problems of truck delivery scheduling in logistic systems involve the generation of plans under a variety of constraints, which change continuously depending on numerous factors, and so at present solution of such problems rely on the efforts of human experts. There have been studies combining numerical methods and AI (heuristic) techniques to construct a system for vehicle routing problem with time window (VRPTW) [1], researches utilizing digital road network information [2,3], and researches employing domain models [4].

Algorithms for pickup and delivery problem with time windows (PDPTW) are studied as a generalization of vehicle routing problem [5]. The MARS system [6] models PDPTW within a society of shipping companies with multiple trucks as a cooperative multi-agent system.

However, several themes of research on delivery scheduling problems require further work, among them, (1) realization of adaptive systems conforming to actual problems and accommodation of multiple evaluation parameters, (2) creation of problem-solving models using knowledge of multiple levels, and (3) establishment of a method for deriving, within a practically useful length of time, approximate solutions within a permissible range which satisfy the imposed constraints. An effective framework for solving such problems is sought.

We have been conducting studies on the application of cooperative problem solving models to truck delivery scheduling [7]. Methods for cooperative problem solving are now being developed as a basic technology for use in scheduling, but at present there is insufficient application of such methods to delivery scheduling problems of the type addressed in this paper.

We discuss the multiagent functions of a decision-making support system in solving delivery problems, aiming at the realization of a highly responsive system. Delivery scheduling problems contain the separate problems of generating an initial static delivery plan and of dynamic re-scheduling to correspond to the real world changing at the time of actual plan execution (delivery execution). In particular, the latter coping with dynamic changes in the real world incorporates the notion of so-called continuous planning [8].

In this paper, we propose a cooperative multiagent system for solving the delivery scheduling problem with time window where the environment changes dynamically. In section 2 of this paper we describe delivery-scheduling problem. In section 3 we present the method used for solution of truck delivery re-scheduling problem proposed with application to sample problems, and in section 4 we evaluate the result and discuss remaining problems.

2. Truck delivery scheduling problem

2.1 Overview of the truck delivery scheduling

The problem we attempt to address is that of planning operations involving multiple trucks dispatched from a delivery center to deliver goods to numerous locations; the schedule includes personnel allocation, vehicle allocation, delivery route selection and other parameters, with consideration paid to delivery costs. Specifically, a delivery scheduling system has the following goals:

(1) Reduction of costs through efficient utilization of personnel and vehicles,
(2) Improvement of service by meeting deadlines for delivery to locations,
(3) Rapid generation of a delivery schedule without relying on human experts,
(4) Generation of large-scale delivery schedules within a practical time frame.

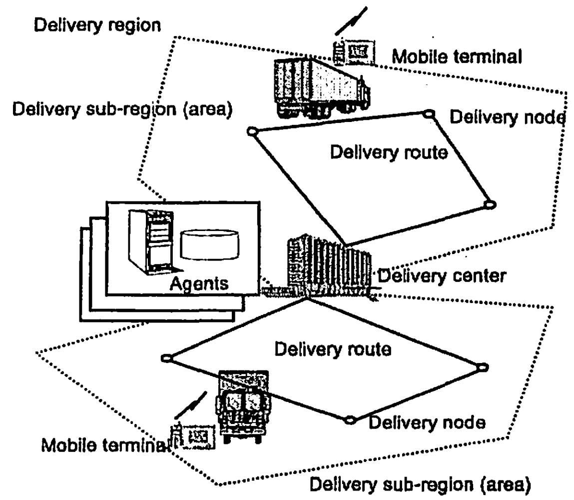

Fig. 1. Typical model of a truck delivery scheduling system

Fig. 1 shows a representative model of a truck delivery scheduling problem. Orders collected at one delivery center are divided among multiple trucks and are delivered to locations dispersed throughout a delivery region. The delivery region is partitioned into a number of delivery sub-regions. The delivery schedule implemented at the delivery center determines delivery routes, allocates personnel and trucks, and decides times for departure and arrival at the center and delivery locations. Examples of such vehicle routing applications include ;

- Services for delivery of merchandise to customers from a department store delivery center,
- Post office parcel delivery operations,
- Beverage delivery to bars and restaurants,
- Currency delivery and scheduling at ATM machines,
- Internet-based home grocery delivery,
- Wholesale distribution from warehouses to retailers.

In creating a delivery schedule, consideration must be paid simultaneously to numerous constraints:

- The upper limit to the number of available personnel,
- The experience and skill of personnel (vehicles they are able to operate, time required for inspection of goods, etc),
- The upper limit to the number of trucks available for use,
- Constraints on truck loads (volume, weight),
- Time window specified for delivery to a given delivery node,
- Special conditions in effect along the roads on the routes.

For actual real-scale problems, this becomes a problem of optimizing a large-scale combination, making reduction to a formula difficult and a rigorous solution impractical.

We have been conducting studies on the application of cooperative problem solving models to truck delivery scheduling [7].

2.2 Continuous re-scheduling and execution problem

Continuous re-scheduling is performed corresponding to dynamic changes in the real world during the plan execution (when deliveries are being executed). We have reported some of the results of the reactive scheduling method for the conditional changes during the execution of the delivery [7]. However, the case of dynamic arrival of additional orders still remains as an issue to be fully addressed in the course of efficient execution of a delivery operation.

The domain of truck delivery scheduling could be basically modeled as the vehicle routing problem with time window (VRPTW) [9].

(1) Input data
– Delivery center : The single delivery depot (denoted as *c*)
– Delivery nodes : Geographical location of customers (*node-i*)
– Routes : Geographical connection of delivery nodes (and the center) (*node-i, node-j*)
– Travel distance (time) : Distance between delivery nodes (*distance (node-i, node-j)*)
– Delivery order : Order for a node with time window (*order (node-i, volume, earliest time for delivery, deadline for delivery)*)
– Delivery truck : A truck has a limited capacity (*truck (maximum load volume, cost per time)*)
– Sub-region : Division of the delivery region into sub-regions (*sub-region A (node-i, node-j,...,node-n)*)

(2) Output data
– Delivery route : A path that starts/ends at the center and visits delivery nodes (*(c, node-i, node-j, ...,c)*)
– Trip timetable for each delivery route: Including

the vehicle/personnel used, table of departure and arrival time at each node, and table of items for delivery orders
– Loading table : Listing the quantities and order of items for loading

(3) Evaluation Criteria
Evaluation value (delivery cost) for a route is simply the route mileage of the vehicle

(4) Re-scheduling for additional orders
Using the initial delivery schedule, trucks loaded with the initial orders are on the road when a new order *o-i = order (node-i, vol-i, t-1, t-2)* arrives at time *t-i* at the center. We assume that additional orders are small in number (less than 10% of the total) and the initially assigned trucks could deliver the incoming orders. The problem is that the re-scheduling should find the new plan with the minimum cost increase within the reasonable timeframe, which allows the real-time delivery operation goes on.

3. Solving truck delivery scheduling problem with multiagents

3.1 Structure of multiagents in problem solving

Because practical-scale problems involve optimization of large-scale combinations, it is extremely difficult to formulate such problems or to find an exact solution. We consider cooperative problem solving with multiagents (Fig. 2).

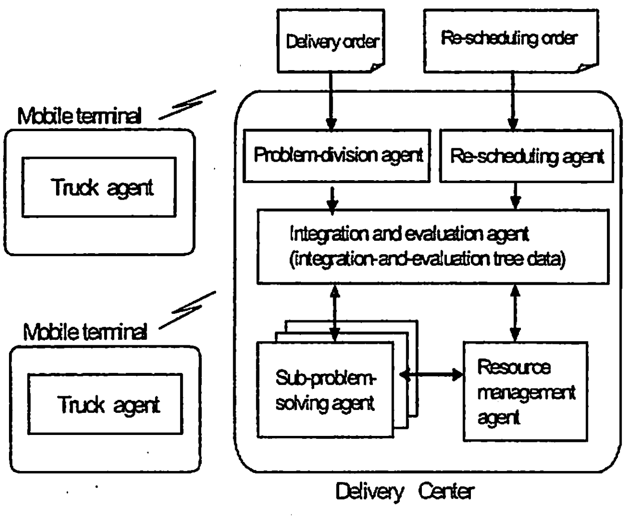

Fig. 2. Structure of multiagents in problem solving

We propose a framework for cooperation between agents at the delivery center and agents on the trucks' mobile terminals (truck agents). Some of the main agents composing the delivery scheduling system are as follows;

(1) Problem-division agent: Divides the problem into sub-problems. Specifically, divides tasks into delivery sub-regions according to the delivery order,
(2) Integration and evaluation agent: Coordinates sub-problem solutions, and generates an overall schedule free of inconsistencies,
(3) Sub-problem solving agents: Generate delivery schedules for sub-problems, and calculate evaluation parameters. One such agent is generated for each delivery sub-region,
(4) Resource management agent: Manages overall resources (personnel, vehicles), performs resource allocation,
(5) Re-scheduling agent: Manages interfaces with dynamic changes of the environmental conditions in the real world during delivery execution,
(6) Truck agents: Communicate with the center and control information to/from the delivery personnel and know the current status of the delivery operation.

We describe the required functions of the components for each of these.

(1) Center function
At the center, cooperative problem solving is conducted by making adjustments among the requests from multiple terminals. In a delivery problem, the status of execution and other information from terminals is included for tracking vehicle activity, adjustments are made by the center, and new execution instructions are dispatched. Functions (multicast/broadcast functions, etc.) are also necessary for sharing information, which changes with time (road conditions, for instance) with all terminals as necessary.

(2) Terminal function
The terminal function includes the following items;
(a) allows the driver to report the current status and activity, e.g. on-site, in-service, out-of-service with time stamping,
(b) provides GPS (geographical positioning system) function, and the geographical co-ordinates of the vehicle can be transmitted to the center,
(c) receives geographical information (route map, road condition information, etc.) with updated delivery instructions from the center,
(d) provides auxiliary peripherals, e.g. bar code scanner, external keyboard or a mobile printer as needed.

3.2 Basic approach to problem-solving using distributed cooperation

The basic approach we have proposed for solving truck delivery scheduling problem is as follows. Readers may refer [7] for more detailed discussion.

(1) Division into sub-problems and its problem solving
The system is based on delivery region division at the global level using existing routes called "a

priori route" and route improvement at the sub-problem level. The division of the delivery region is regarded as division of the problem into sub-problems, and delivery sub-regions are partitioned so as to overlap. By this means, interactions and adjustments between agents are introduced, and the result is a more flexible problem-solving framework. By dividing the delivery region into sub-regions and integrating partial solutions in the sub-regions into the solution of the whole delivery region, the quality of the solution reduces because the generation of the route combination is restricted.

(2) Coordination and evaluation by the integration and evaluation agent

When destination overlap is allowed in dividing the delivery region into sub-regions, the route combinations within each delivery sub-region by a sub-problem agent interfere with each other. The integration and evaluation agent takes this into consideration in generating a data set, called an integration-and-evaluation tree, for use in managing the route combinations without inconsistencies. The evaluation values associated with this integration-and-evaluation tree can be used to choose a route combination.

(3) Re-scheduling

Re-scheduling is performed corresponding to the changes in the real world during the delivery execution. Communication functions between the center and the mobile terminals on the delivering trucks are crucial for the timely exchange of various information and the execution instructions from the center to achieve the successful plan execution.

3.3 Dynamic re-scheduling for continuous delivery execution

An important feature of the system is that trucks actually start executing the delivery schedule when time is up. Additional orders, which arrive after the start of the delivery, have to be picked up at the center and delivered to the customers (delivery nodes) within the time windows. Trucks are important resources and limited in number. We assume that the dispatch of a new truck for the additional orders is not realistic and the trucks (truck agents) in operation try to re-schedule the initial plan to cover additional orders with the minimum cost increase in cooperation with the re-scheduling agent at the center.

3.3.1 Contract net protocol (CNP)

We introduce Contract Net protocol (CNP) for the negotiation process by truck agents and the re-scheduling agent to identify the cost (truck travel mileage) minimum assignment of the additional order. Sub-regions of the delivery region are considered here also as discussed in our previous report [7].

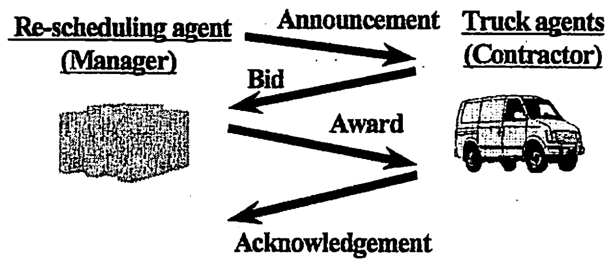

Fig. 3. Contract net protocol

CNP is shown in Fig. 3 and the process is described as follows.

(a) A new order *o = order (node-i, vol-i, t-1, t-2)* arrives at time *t-0* at the center. The new order is to deliver goods of volume *vol-i* to destination *node-i* from the delivery center within the time window (*earliest time for delivery t-1, deadline for delivery t-2*). The order is immediately announced to truck agents that belong to the sub-region(s) where the delivery node *node-i* exists.

(b) Each truck agent that has received the announcement, checks the possibility to accept the new order considering the current status of its delivery operation and constraints such as time windows at the delivery nodes, capacity limit of the trucks. Then, if acceptable, *TruckAgent-k* ($1 \leqq k \leqq N$ *where N is the number of trucks*) computes a bid *(TruckAgent-k, o, c)* where *c* is the additional cost for inserting the new order to the current delivery route.

(c) *TruckAgent-k* sends its bid *(TruckAgent-k, o, c)* to the re-scheduling agent at the center.

(d) Re-scheduling agent selects the optimal bid and sends the award message to a truck agent as the successful contractor and sends reject messages to other truck agents.

(e) The contractor sends an acknowledgement of the award.

If the contract is not successful with any truck agent, the center may report to the customer and try to negotiate about possible solutions such as to shift the order to the next day's delivery or to dispatch an emergency truck with higher cost.

3.3.2 Extension of contract net protocol

(1) Hierarchical organization

The contract net protocol could be organized hierarchically as shown in Fig.4. This organization has the advantage of simplifying the each protocol between Re-scheduling agent and Sub-problem solving agents, and Sub-problem solving agents and Truck agents. And also Sub-problem solving agents could have a chance to consider other factors such as the skill level of drivers, the idle level of trucks etc. in addition to the cost to award the bid.

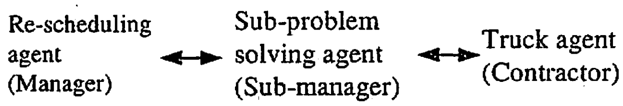

Fig. 4 Hierarchical organization

(2) Time-bound protocol
The negotiation process has to be executed during the actual delivery operation by trucks. Because of the real-time nature of the problem domain, the duration allowed for the negotiation process is very restricted. The extension of the CNP to consider the commitment duration of messages (announcement, bid, and award) is reasonable.

Firstly, the announcement message is sent with a certain time duration saying that bids have to be returned from truck agents within the time duration.

Secondly, when a truck agent returns a bid, it can only guarantee its bid until the insertion point of the announced new order. In that case, the bid message has to be attached with commitment duration to show that the bid is time-bound.

3.3.3 Experiment with examples

In order to evaluate the procedure proposed in this paper for re-scheduling, we pick up Solomon test-set [10] of the vehicle routing problem with time window. This test-set is a problem set for initial vehicle routing. We assume that at certain time during delivery operation a new delivery order arrives at random node. The delivery cost is the mileage needed by the trucks for the route. Trucks have the equivalent load capacity in a problem. It is assumed that there is a direct path connecting two nodes and *travel time between two modes = distance between two node* x *1(unit amount)*.

Fig.5 shows an initial solution of the delivery routes for problem R203 of 25 nodes from the test-set and routes are *Truckagent-1= (c, 6, 5, 8, 17, 16, 14, 13, c)*, *Truckagent-2= (c, 2, 15, 23, 22, 21, 4, 25, 24, 3, 12, c)*, *and Truckagent-3= (c, 18, 7, 19, 11, 20, 9, 10, 1, c)*. A new order at node No.26 is given as *order(No.26, 17, 0, 500)* at time 170. Although Solomon test-set does not have the concept of sub-region, we assume division into sub-regions, *area-1*, *area-2*, *area-3* as shown in Fig.5.

Fig.6 shows a local optimal solution inside *area-2*, that is the new order is announced only to *Truckagent-2* in *area-2* where the new customer No.26 is located.

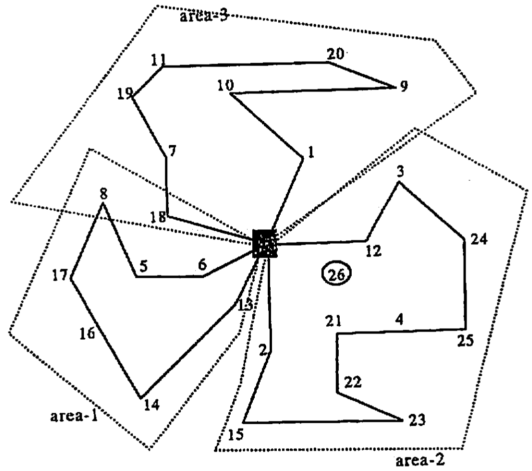

Fig. 5 Problem example of 25 nodes

The local optimal solution is *Truckagent-2= (c, 2, 15, 23, 22, 21, c, 26, 4, 25, 24, 3, 12, c)*, and the cost increase is 33.3 in increase of the distance the truck has to travel to pick up the order at the center and deliver it to node 26 then return to node 4.

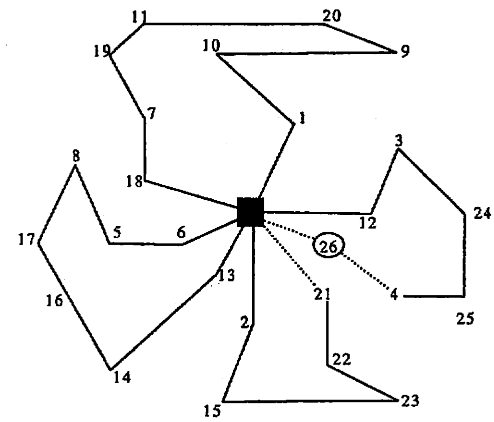

Fig. 6 The local optimal solution inside *area-2* for new order at node 26

If we consider the case where the new order is announced to all the truck agents. Then the optimal solution is *Truckagent-1= (c, 26, 6, 5, 8, 17, 16, 14, 13, c)*, and the cost increase is 20.0.

This result indicates that the computational complexity increases in the CNP process by announcing all the truck agents; there is a good chance of getting better solution than restricting the announcement inside the relevant sub-regions. We consider that by creating the sub-regions under certain criteria, there is a trade-off point between the computational cost and the delivery cost.

In our implementation, multiagent process of the system including CNP is implemented in TAF [11] as shown in Fig. 7.

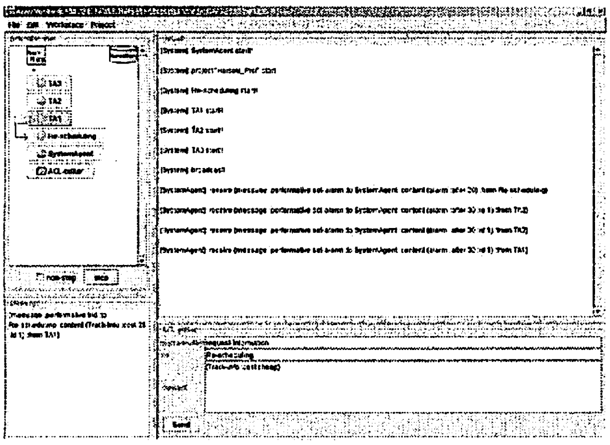

Fig. 7 Multiagent implementation by TAF

4. Discussion

We evaluate and analyze the delivery re-scheduling method proposed in this paper and consider problems remaining to be solved.

(1) Efficient negotiation process

Here time-bound negotiation process among multiagents is considered for the negotiation. We expect that the process could be used for automated negotiation framework. We need to investigate the strategy and to experiment more to identify the best system architecture for this particular domain of the delivery re-scheduling.

(2) Division of the region into sub-regions

By dividing the region into delivery sub-regions, and allowing overlapping between neighboring sub-regions, we have discussed the trade-off of computational cost and the optimal delivery cost. Further study of the optimal degree of overlap between sub-regions will be necessary.

Computation time for inserting a new order into the initial delivery route is roughly $O(n^2)$. And this is the most time consuming process of re-scheduling.

(4) Event driven approach in the re-scheduling

In the truck delivery scheduling, we consider the occurrence of event, which requires the execution of re-scheduling is moderate and the real time event-driven approach as proposed in this paper is feasible.

On the other hand, information gathering and re-scheduling with a certain time interval increases the cost of operation but could produce more optimal result of delivery by adjusting the delivery operation against gradual deviation from the original schedule.

5. Conclusion

In this paper we have proposed a cooperative multiagent system and applied to the Solomon test-set of the vehicle routing problem with time window. Additional delivery orders, which arrive dynamically during the execution of the delivery according to the initial delivery plan, are considered. Multiagents for the delivery center and delivery trucks cooperate to cope with the re-scheduling problem. We show that the proposed extended CNP method provides a flexible solution for the dynamic scheduling problem where various evaluation parameters in the process of re-scheduling should be considered.

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