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Truck Delivery Scheduling System with a Mobile Communication Feature

Jun Sawamoto
Mitsubishi Electric Corporation
2-2-3 Marunouchi Chiyoda-ku, Tokyo, 100-8310 Japan
Jun.Sawamoto@hq.melco.co.jp

Abstract: In this paper, we propose a practical method for solving the delivery @scheduling problem and discuss its implementation. The method is based on the cooperative problem solving with multiple agents. In the truck delivery scheduling method, the covered region is partitioned into multiple sub-regions and each sub-region is assigned a sub-problem solving agent. For integrating those sub-problem solving agents, an integration-and-evaluation agent solves the total problem. We discuss the functions for building cooperative decision support system in a mobile environment in delivery scheduling domain. We consider a delivery center with function, i.e., generating and integrating delivery schedule, acquiring and managing the information shared commonly by all delivery persons, and dispatching the selected information to delivery persons, and the mobile terminal, which a delivery person uses for exchanging information with the center. By employing the cooperative problem-solving framework for the delivery-scheduling problem, we achieved an easy incorporation of various evaluation parameters in the process of scheduling, efficient use and management of scheduling knowledge of various levels, and reduction of computer processing by division of the problem into sub-problems.

Key Words: Delivery Scheduling System, Agent System, Mobile Communication

1. Introduction

A problem of truck delivery scheduling in the logistic system involves the generation of plans under a variety of constraints, which change continuously depending on numerous factors, and at present, solutions of such problems rely on the efforts of seasoned experts. On the other hand, shortages of transportation personnel, rises in personnel costs, worsening traffic conditions in urban areas and other problems have lead to calls for delivery scheduling systems which can propose more efficient delivery schedules.

There have been studies combining numerical methods and AI (heuristic) techniques to construct a system on a practical scale [1], researches utilizing digital road network information [2,3], and researches employing domain knowledge/models [4].

As a more practical problem situation, [5] proposes a framework integrating an inventory management problem and the vehicle routing problem with time windows. Their algorithm optimizes inventory and backlogging costs subject to warehouse and retailers' capacity, and transportation cost subject to vehicle capacities and time windows. Algorithms for pickup and delivery problem with time windows (PDPTW) are studied as a generalization of vehicle routing problem [6]. It is shown that good solutions for a vehicle routing problem with time windows (VRPTW) do not imply good solutions for PDPTW. Although both papers propose new algorithms and benchmark results, they still need to be enhanced to apply to real world problems.

In addition, work is underway in the field of task scheduling on solutions based on distributive cooperative frameworks, as a method of solving large-scale scheduling problems while adapting them to an actual environment [7,8].

However, several themes of research on delivery scheduling problems require further work, among them, (1) realization of adaptive systems conforming to actual problems and able to accommodate 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 tolerance range of quality 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 [9]. 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. And it is being studied in the context of application to specific areas, so that the results obtained lack general validity, and the frameworks of existing studies are not in general easily applied to other fields.

We discuss the functions of a cooperative decision-making support system in solving delivery problems, making use of a mobile environment aiming at the realization of a highly responsive system suited to addressing practical problems. Delivery scheduling problems contain the separate problems of generating an initial static delivery plan and of dynamic re-planning to correspond to the real world changing at the time of actual plan execution (delivery execution). In particular, the latter coping with dynamic change in the real world incorporates the notion of so-called continuous planning [10,11], in a cooperative decision-support system, which can cope with changes in conditions at the time of plan execution.

In this paper, our method was implemented in a practical-scale proving system to evaluate its efficiency, and its usefulness was confirmed. In section 2 of this paper we describe delivery-scheduling problem. In section 3 we present the method used for solution of truck delivery scheduling problems proposed, and in section 4 we describe its application in a proving system for actual solution of delivery scheduling problems and its evaluation, together with analysis.

2. Truck delivery scheduling problem

The problem which a delivery schedule attempts 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

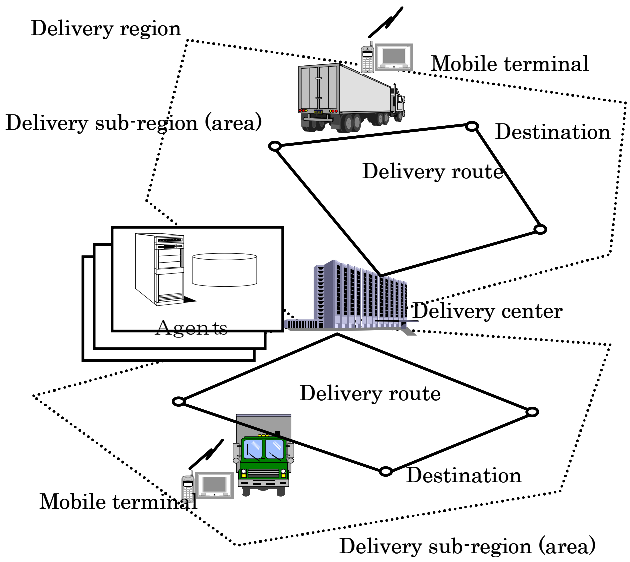

Fig. 1. Typical model of a truck delivery scheduling system

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 operations include services for delivery of merchandise to customers from a department store delivery center, and post office parcel delivery operations. 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 period specified for delivery to a given location
*Special conditions in effect along 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.

3. Solving truck delivery scheduling problem in a mobile environment

3.1 Basic approach to the 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 multi-agent systems used for cooperative problem solving with a mobile communication capability (Fig. 2). The structure of a mobile environment is extensive, and here it can be divided into communication, a center (server, etc), and terminal components (portable terminals, for instance). We describe the required functions of the components for each of these.

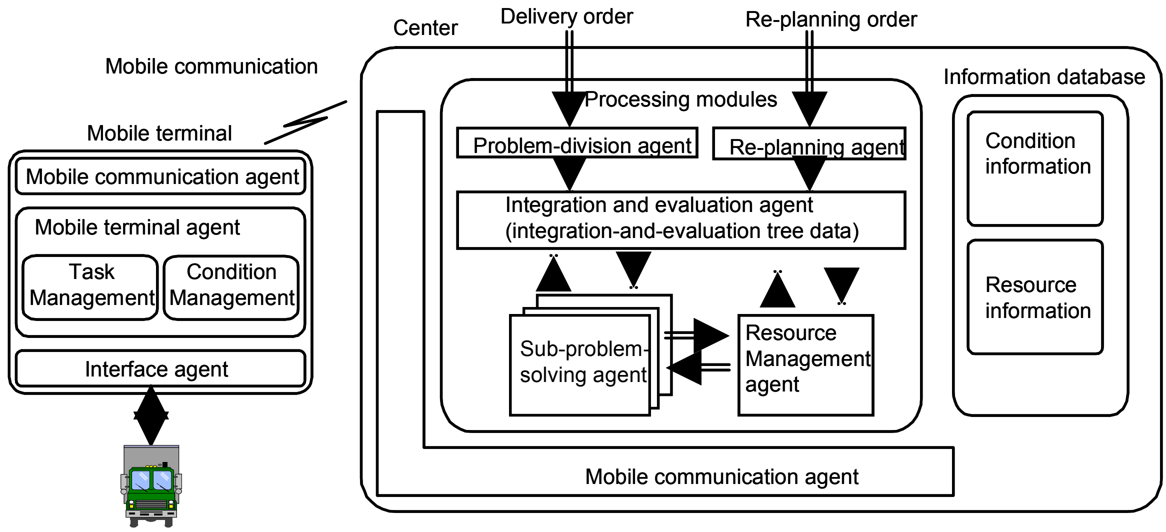

Fig. 2. Structure of multi-agents in problem solving

(1) Communication function
In a mobile environment, constraints are imposed on the volume of data communicated, and so some measures are needed to limit the amount of communication between the center and terminals insofar as possible. And because communication paths are unstable, it is necessary to consider use of a mobile communication agent such as the Java-based Mobile Agent [12], which can cope with unexpected breaks in a communication path.
(2) 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.
(3) Terminal function
Limitations on the processing power of portable terminals mean that emphasis is placed on data input, display and other user interface functions rather than on information processing. For instance, constraints on the display screen dictate that information be displayed selectively, and that data input and manipulation employ means as simple as possible (for instance, pen input) taking the operating environment into account.
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.

The basic approach proposed in this paper for solving truck delivery scheduling problem is as follows:
(1) Perform a hierarchical division of functions of the schedule development, assign those functions to different agents, and generate solutions while conducting communications between agents.
(2) The center system is provided with one agent to coordinate overall scheduling solution candidates (Integration and evaluation agent) and one agent to manage resources (Resource management agent).
(3) The system is based on delivery area division at the global level using existing routes

and route improvement at the sub-problem level. The method of delivery area partitioning using existing routes cannot easily cope with delivery time constraints in light of order information which changes daily; but 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 cooperation between agents is possible at the sub-problem level, and the result is a more flexible problem-solving framework which addresses problems with delivery region division using existing routes.

(4) Dynamic re-planning is performed corresponding to dynamic changes in the real world during the plan execution (when deliveries are being made). The environmental conditions such as the traffic condition of roads, new arrival of additional orders, etc. change during the execution of the delivery, and the reactive and adaptive measures are required to cope with such situations. Communication function between the center and the mobile terminals on the delivering trucks is crucial for the timely exchange of various information and the execution instructions from the center to achieve the successful plan execution.

3.2 A truck delivery planning support system using multi-agents

Below are described the function composition and algorithm used to realize a delivery scheduling system employing the basic approach to problem-solving described in 3.1 above. Agents are of the following six kinds:

(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) Mobile terminal agents: Mobile terminals allocated to personnel during deliveries.
(6) Re-planning agents: Manages interfaces with dynamic changes of the environmental conditions in the real world during delivery execution.

All agents except the mobile terminal agents exist as processing modules in the delivery center. Fig. 2 shows the multi-agent configuration of the system.

3.3 Function composition and system-level algorithm

3.3.1 Generation of an initial delivery plan

Fig. 3 shows functions comprising the initial problem-solving system at the center. We here describe the processing of each agent in generating the initial delivery plan.

<Overall Algorithm>

(1) The problem-division agent receives the input delivery orders and divides the delivery region into sub-regions. In actuality, this division into delivery sub-regions relies on the knowledge of experienced persons (employing fixed routes and other past experience). The integration and evaluation agent is notified of the delivery sub-regions and of division of shipments (orders) among sub-regions.
(2) The integration and evaluation agent notifies the resource management agent of the delivery sub-region divisions. In addition, sub-problem agents are generated for each delivery sub-region, and the latter are provided with shipment information for their respective sub-regions.
(3) The resource management agent uses the delivery sub-region division information obtained from the integration and evaluation agent to allocate necessary resources (vehicles, personnel) for each delivery sub-region, and notifies the sub-problem agents accordingly.

(4) Each sub-problem agent uses the initially supplied resources to generate an initial plan combining possible routes. In the initial plan, delivery deadlines and other constraints on delivery orders are given priority, and constraints on resources (vehicles, personnel) are relaxed to some degree. Each sub-problem agent notifies the integration and evaluation agent of the combination of routes it has generated in its delivery sub-region.

(5) The integration and evaluation agent uses the combination of routes within delivery sub-regions provided by the sub-problem agents to generate a data set, called an integration-and-evaluation tree, which consistently manages the route combinations for all delivery sub-regions. Evaluation values for this integration-and-evaluation tree are used to select the route combination thought to be optimal (including user-selected routes). This information is then passed to each sub-problem agent.

(6) Each sub-problem agent uses the route combination specified by the integration and evaluation agent to combine closed routes in its delivery sub-region, and notifies the resource management agent of the resources used. However, if necessary closed routes within a delivery sub-region can be modified.

(7) The resource management agent receives adjusted requests from each of the sub-problem agents, makes necessary resource adjustments, and returns the results.

(8) Each sub-problem agent receives notification of changes in resources from the resource management agent, and uses the resources to generate a combination of closed routes within its delivery sub-region as an adjusted delivery plan. Then, steps (6) to (8)are repeated until plans free of inconsistencies are obtained for all delivery sub-regions. The results (success or failure) of adjustments for all delivery sub-regions are passed on to the integration and evaluation agent.

(9) If the adjustments result in success, the integration and evaluation agent outputs the plan results. If the adjustment results in failure, the next-best route combination is chosen from the integration-and-evaluation tree, and steps (6) through (9) are repeated.

3.3.2 Processing performed by each agent

(1) Division into sub-problems

The problem-division agent generates sub-problems from the delivery scheduling problem. In order to divide the delivery scheduling problem into sub-problems, it divides the delivery region in question into delivery sub-regions. A sub-problem then consists of generation of a partial delivery schedule within a delivery sub-region which is itself part of the entire delivery region. Rather than simply dividing the delivery region as in previous approaches, however, mutual interaction and adjustment between the partial problems are introduced, so that overlap between delivery sub-regions results. This is illustrated in Fig. 4. For instance, the delivery sub-regions A and B overlap at destinations g, h. By this means, the destinations in overlapping areas are considered in both delivery sub-regions, and the adjustment can be made when coordinating the overall delivery schedule.

A delivery route, which assumes a single day’s orders, is called "a priori route", and is set based on the past experience. The delivery region is divided into overlapping sub-regions at the global level, utilizing a priori routes. By introducing complete linkage clustering method [13] to construct sub-regions from a priori routes using the traveling time as the distance between destinations, sub-regions could be formed tight and spherical resembling formulations of procedures actually in use by experts.

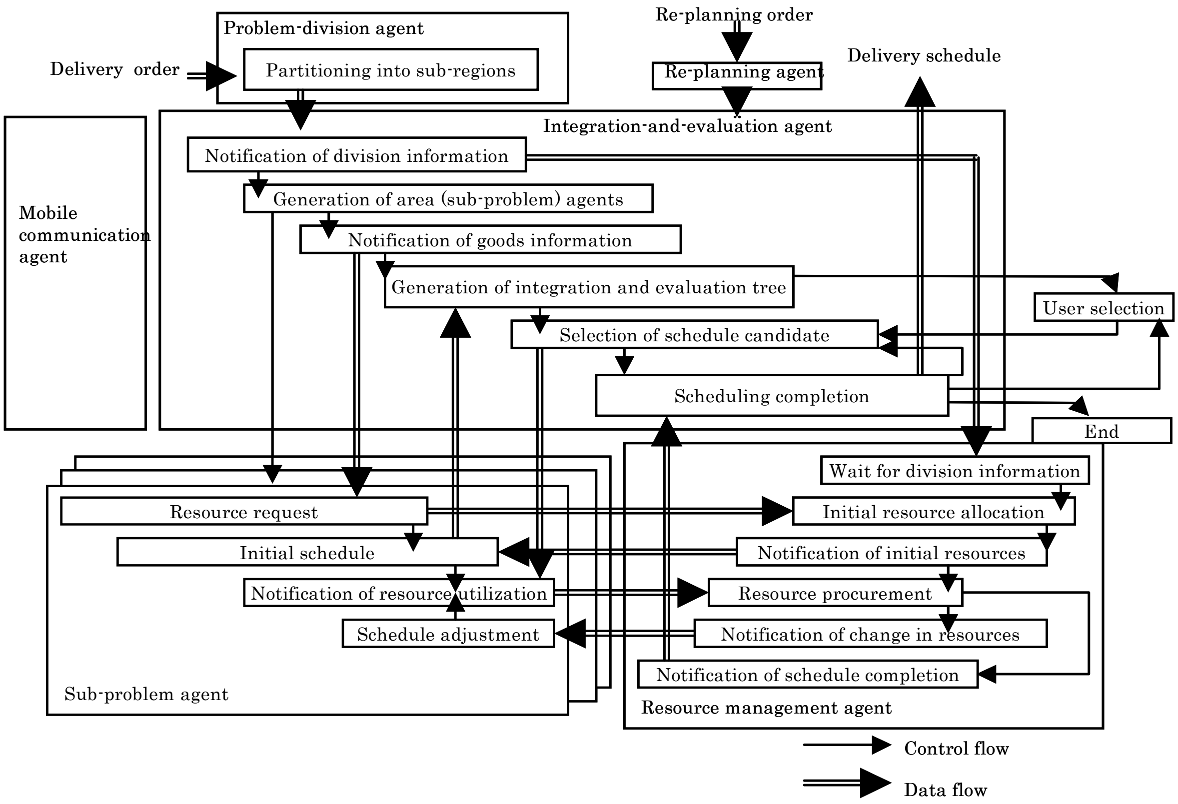

Fig. 3. Functions comprising the initial problem-solving system

We discuss the quality of the solution (integrated evaluation values) in our method, in terms of the deviation from the optimal solution in case the whole delivery region is solved as one region without dividing it. 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. The tolerance range (in deviation) of the solution can be calculated as follows.

{(the quality of the solution by our method - the optimal solution as one delivery region)/the optimal solution as one delivery region }x100

Some of our evaluation of our method shows that our method could achieve a solution within the tolerance range of 20%, which is generally considered reasonable in the scheduling field.

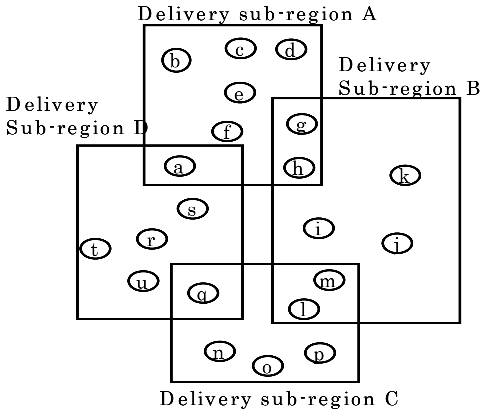

Fig. 4. Partition of the delivery region

(2) Functions for 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 structure of this integration-and-evaluation tree appears in Fig. 5. The tree structure of Fig. 5 corresponds to the delivery region partitioning of Fig. 4. The left most branch of Fig.5 corresponds to the delivery route combination shown in Fig. 6. For example, route {b, c} and route {d, e, f} are selected in the delivery sub-region A, where route {d, e, f} represents a route, delivery center -> node d -> node e -> node f -> delivery center. In the same way, route candidates are selected from delivery sub-regions B, C, D and the left most branch of Fig. 5 represents one of the route combination candidates in the whole delivery region that is shown in Fig. 6.

The evaluation values associated with this integration-and-evaluation tree can be used to choose a route combination. Evaluation values include personnel and vehicle costs, uniformity of the tasks assigned to personnel, and margins with respect to delivery deadlines.

Here a simple summation of each of these evaluation values for sub-regions forms the integrated evaluation value for a route combination in the delivery region. Three types of evaluation value calculated for a delivery route combination are presented to the user and the user selects a route combination according to his/her priority of the evaluation values. For example, a cost sensitive user may select a route combination with the lowest personnel and vehicle costs. Or the system may be given a certain priority of the evaluation values and selects a optimal delivery route combination by the given criteria.

Evaluation values for each sub-region:

($\sum_{route}$ Personnel and vehicle costs, $\sum_{route}$ Uniformity of the tasks assigned to personnel, $\sum_{route}$ Margins with respect to delivery deadlines)

Personnel and vehicle costs:

Work hours of personnel x *cost per hour + mileage of vehicle* x *cost per mile*

Uniformity of the tasks assigned to personnel:

(Work hours of personnel - Average work hour)^2

Margins with respect to delivery deadlines:

$\sum_{destination\ on\ route}$ *(Deadline for delivery - Delivery time)/(Deadline for delivery - Earliest time for delivery)*

Integrated evaluation value:

($\sum_{sub\text{-}region}$ Personnel and vehicle costs,

∑ sub-region Uniformity of the tasks assigned to personnel, ∑ sub-region Margins with respect to delivery deadlines)

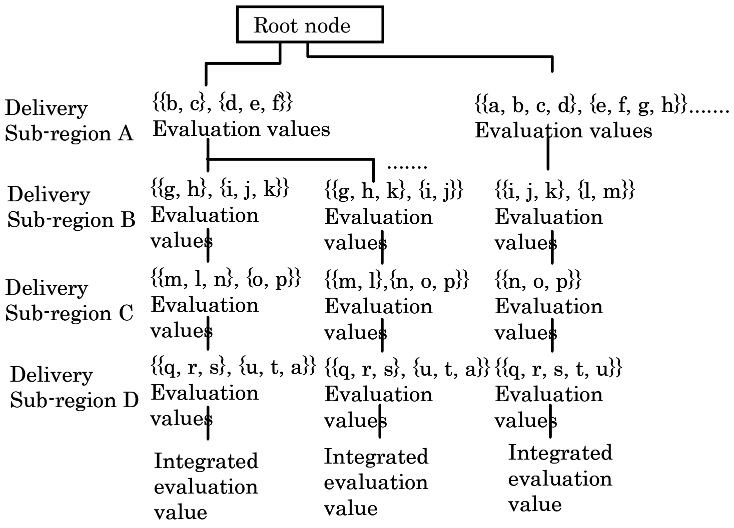

Fig. 5. Part of an integration-and-evaluation tree

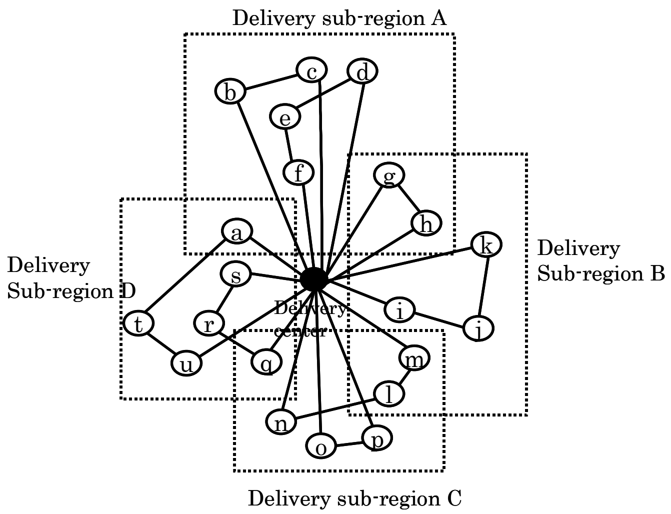

Fig. 6. An example of delivery route

3.4 Dynamic re-planning at the time of plan execution

We consider actual onsite execution of the delivery plan generated by the system. Broadly speaking, there are two kinds of functions, those at the delivery center and the mobile terminals onboard the vehicles making deliveries. The delivery center exercises such functions as transmission of information according to updates (on roads, the state of progress of deliveries, occurrence of additional orders, etc), regeneration of plans, and instructions for task modification. The mobile terminals onboard the vehicles have functions for conveying newly obtained information to the center, receiving update

information, and receiving instructions from the center to modify tasks.
Dynamic re-planning problems corresponding to dynamic changes in the real world must be addressed at the time of plan execution (when deliveries are being made). Re-planning proceeds by applying steps (4) and later in the algorithm (section 3.3.1) for drafting a plan at the center; however, the following should be noted.

(1) Re-planning is performed at the time of occurrence of such events as changes in conditions and failures in executing the existing plan such as the traffic condition of roads, availability of the delivering vehicles and drivers, etc. Relaxation of constraints (for instance, relaxation of delivery deadlines) must be included. First, the re-planning agent receives real time information such as the traffic condition of roads, status of the delivery execution, new arrival of additional orders, etc., then notifies the necessary information for re-planning to the sub-problem agents and the resource management agent through the integration and evaluation agent. The integration and evaluation agent updates the integration-and-evaluation tree to keep its consistency corresponding to dynamic changes in the environment using updated combination of routes from each sub-region. By each sub-problem agent, initially generated combination of routes is preserved selectively and is utilized when updating the route combination corresponding to the environmental changes. By employing the hypothetical reasoning method, we achieved efficient consistency maintenance for the route combination.

(2) Road conditions and other information to be shared by all personnel require multicast/broadcast communications with mobile terminals. Further, when mobile terminal agents cannot easily display all road map or other information, they must have functions for selectively displaying only the information necessary.
GIS/GPS capability allows the terminal to display geographical information selectively only the neighboring portion at a time.

4. Experiments, evaluations and analysis

4.1 Details of the proving system

In order to evaluate the procedure proposed in this paper, we applied the method to the following delivery scheduling.
(1) Scale-related conditions
The delivery scheduling problem considered is that of creating a schedule for the delivery of ordered items from a single delivery center to approx. 120 delivery destinations. The delivery region was partitioned into four delivery sub-regions; there were 15 trucks available and between 10 and 15 delivery staff available. The system is to set delivery routes, allocate personnel and vehicles, and determine times of departure and arrival at the center and at delivery destinations.

(2) Physical constraints
The main constraints considered by the proving system were as follows.
*Delivery center: One delivery center
*Destinations: Limits imposed by the sizes of the trucks available
*Trucks: Limits to the number of trucks available (this constraint can be relaxed in part), maximum loaded weight, maximum loaded volume
*Delivery personnel: Limits to the number of persons available (this constraint can be relaxed in part), vehicle operation license, driving skills, inspection skills, familiarity with delivery sub-regions
*Orders: Earliest time for delivery, deadline for delivery
*Products: Type, volume, weight, time for inspection
Evaluation parameters to be used are the personnel and vehicle costs, uniformity of the tasks assigned to personnel, and the margin for meeting delivery deadlines.

4.2 Evaluations and discussion

We evaluate and analyze the results of application to a proving system of the method for delivery scheduling problem solving. In the proving system, attribute information and various constraints pertaining to delivery orders, personnel, vehicles, roads and the like were considered, and it was possible to develop schedules for application to an actual problem. Fig.7 shows, a trip timetable for a delivery route including the vehicle used, personnel, order of destinations, table of departure and arrival times, and table of items for delivery, and the route map for the driver.

On the scale of this proving system, combinatorial explosion did not occur; this was attributed to the effects of dividing the problem into sub-problems, and to avoiding global backtracking. Below we evaluate and analyze the delivery scheduling method proposed in this paper and consider problems remaining to be solved.

(1) Highly adaptable systems able to accommodate multiple evaluation parameters
Here three evaluation parameters were adopted: the costs of vehicles and personnel, the uniformity or balance of the workloads of personnel, and margins for meeting delivery deadlines. The user was provided with a means for selecting three evaluation criteria for application between the stage of initial schedules and the stage of the final adjusted schedule, so that a scheduling solution suited to the problem at hand could be derived.
(2) Clarification of problem-solving models using knowledge on multiple levels
In the problem-solving model proposed, the knowledge required for problem solving could be more easily organized according to the role played by each agent. And because the processing for schedule generation is more nearly like the procedure used by human experts, the system should be easier to use. By introducing a method for partitioning the region into delivery sub-regions, which allows overlapping, adjustments between neighboring sub-regions in the course of route allocation by sub-problem agents more nearly resemble formulations of procedures actually in use. Quantitative results sufficient to indicate the optimal degree of overlap between sub-regions were not obtained. In addition, further study of the generalization of this delivery scheduling problem-solving model will be necessary.

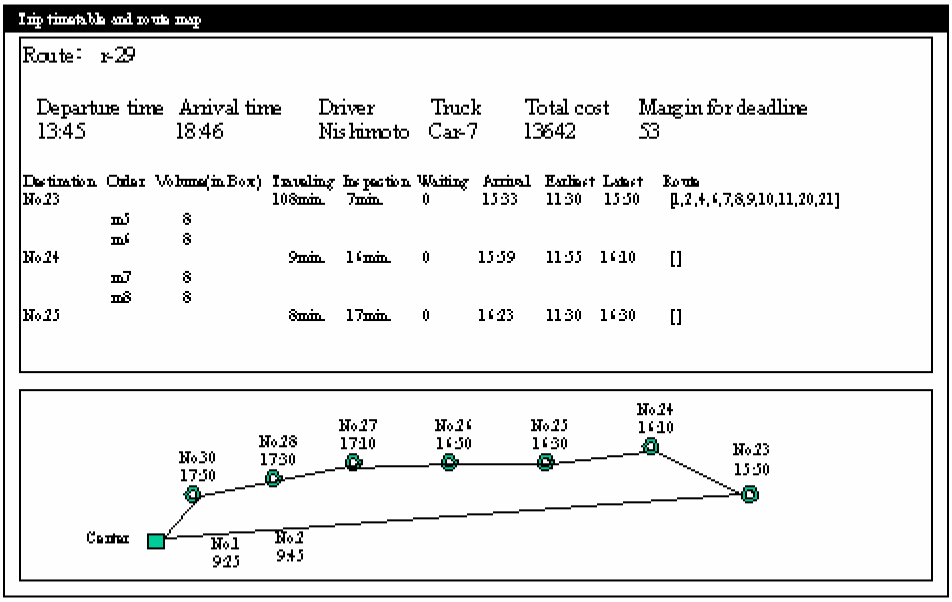

Fig. 7 A trip timetable for a delivery route

(3) Derivation of approximate solutions within a practical time frame
The solution obtained was not necessarily optimal with respect to the three evaluation parameters adopted, but it was confirmed to lie within the range of tolerance. Where the computation load required for schedule generation was concerned, an approach was adopted in which scheduling was divided into initial schedule and adjusted schedule generation, in order to avoid global backtracking. Computation time is exponential to the number of destinations in the worst case. However, in our experiment, following data is obtained.

(A small example)
Condition: Destinations 20, Personnel 6, Trucks 5
Result: Computation time 46 seconds (CPU time)
(A large example)
Condition: Destination 90, Personnel 14, Trucks 15
Result: Computation time 210 seconds (CPU time)

Computation time is only 4.6 times where the number of destinations is 4.5 times larger. This indicates the division of the region into sub-regions has reduced the most time-consuming process of sub-problem agents to a constant size of approximately 20 destinations.

(4) Quality of solution in the re-planning
In the truck delivery scheduling, the occurrence of event, which requires the execution of re-planning such as traffic closing on one of the scheduled routes, is moderate and the real time event-driven approach as proposed in this paper is feasible. On the other hand, information gathering and re-planning 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.
By preserving the initially generated combination of routs by each sub-problem agent and searching for the next available solution in the updated integration-and-evaluation tree, the proposed re-planning method guarantees to obtain next feasible overall optimal solution.

5. Conclusion

In this paper we have proposed a method for truck delivery schedule problem solving. By constructing and evaluating a proving system based on this method, we have confirmed its usefulness. We have pointed out that, broadly, the problem of delivery scheduling involves three objectives: ensuring adaptability to various evaluation parameters, modeling of the use of various kinds of information, and derivation within a practical time frame of a solution within tolerance limits of quality. In order to achieve each of these, we have proposed a problem-solving method based on a cooperation system consisting of problem-solving agents for each delivery sub-region and agents for integration/evaluation and for resource management, utilizing the fact that delivery scheduling problems are in practice addressed by dividing the delivery region into a number of sub-regions for individual processing. We also have proposed a system for delivery planning and execution support using multi-agents. This multi-agent system consists of a delivery center with functions for cooperatively generating and integrating delivery plans and for accumulating, managing and selectively distributing information to be shared by all personnel, and mobile terminals used by delivery personnel.

This method can be expected to advance the practical application of delivery scheduling support systems.

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