[DESCRIPTION]

[TITLE OF INVENTION]

DELIVERY PLANNING SYSTEM, DELIVERY PLANNING METHOD, AND PROGRAM

[Technical Field]

[0001]

The present invention relates to a delivery planning system, a delivery planning method, and a program.

Priority is claimed on Japanese Patent Application No. 2016-213838, filed October 31, 2016, the content of which is incorporated herein by reference.

[Background Art]

[0002]

The need for car sharing has been increasing. Car sharing is, for example, a system in which members share a vehicle, pay a fee according to their boarding time or the like, and use the vehicle when they want to use it. As one form of car sharing, there is a use mode called a drop-off type (one-way type). In drop-off type car sharing, a user can use a common vehicle up to a predetermined parking lot near a destination and can drop off the vehicle at the parking lot as it is. In such a type of car sharing, it is necessary to deliver a vehicle used by a user to another parking lot where there is a new need for use.

[0003]

Even in the case of the so-called rounding salesman problem in which a service man performs rounds to customers in order to provide after-sales service for a product purchased by the customer, a similar situation occurs regarding the movement of the service person, parts necessary for the provision of a service, or the like. For example,

it is necessary to select a rounding route in a situation where a product which is a target for an after-sales service is installed for each of a plurality of customers, a service person supplies parts to be used for an after-sales service of the product at a certain place and brings the parts to the customer or a situation where a service person performing various types of after-sales service in one round moves from a certain customer to another customer who needs the same part to provide the service and returns the used part to its original place.

[0004]

With respect to such a problem, for example, Patent Document 1 discloses a technique for creating a transport plan for transporting loads from a plurality of delivery bases to a plurality of delivery destinations at designated dates using a plurality of transport vehicles. By using this technique, it is possible to create a transport plan in which a user loads a vehicle to be used onto a transportation vehicle such as a truck and transports the loaded vehicle to each parking lot, in a case of car sharing. Also, in an after-sales service round, it is possible to create a delivery plan for delivering parts to be used for service to a customer.

[0005]

However, in a case where a vehicle is delivered in car sharing, there is also a vehicle delivery method in which a delivery staff member boards a vehicle to be delivered and drives to a target parking lot. Such a method in which delivery is performed by boarding a delivery object itself is referred to as boarding transport. A technique for performing optimal delivery planning in delivery including boarding transport has not been provided.

Also in an after-sales service round, regarding a case where a service person moves with parts, a case where parts are delivered from a certain customer to another

customer, a case where a service person takes the remaining parts to the next customer, and the like, a technique for making an optimal round plan of a service person has not been provided, similar to a case of boarding transport.

Generally, a combination optimization problem of discrete values often uses a method called linear relaxation, that is, a method in which a problem is briefly solved by replacing the problem with a continuous value problem and an optimal solution is obtained from an obtained relaxation solution. However, when there are many complicated constraints like in a delivery problem, an excessive calculation time is required in this state, and thus it is necessary to devise a solution in a practical amount of time.

[Citation List]

[Patent Literature]

[0006]

[Patent Literature 1]

Japanese Unexamined Patent Application, First Publication No. 2013-136421

[Summary of Invention]

[Technical Problem]

[0007]

Incidentally, the applicant of the present application has already filed an application regarding a delivery plan system capable of solving the above-described problem in which a delivery plan is performed in delivery including boarding transport (Japanese Patent Application No. 2016-051550). When the delivery plan system is used, it is possible to obtain an optimum delivery plan for a delivery problem including boarding transport in a practical amount of time.

With regard to the delivery plan system, it is desirable to further reduce a

calculation time so as to obtain an optimum delivery plan in a practical amount of time even when the scale of a problem is increased due to an increase in the number of vehicles to be delivered and delivery destinations.

[0008]

Consequently, an object of the present invention is to provide a delivery planning system, a delivery planning method, and a program which are capable of solving the above-described problem.

[Solution to Problem]

[0009]

According to a first aspect of the present invention, a delivery plan system includes a division unit that divides a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand, and a delivery plan generation unit that generates a delivery plan for the delivery problems obtained by the division performed by the division unit.

It is possible to generate a delivery plan in a practical amount of time by dividing a large-scale delivery problem into small-scale delivery problems and calculating a delivery plan in units of a small delivery problem.

[0010]

The division unit in a second aspect of the present invention may associate one demand point included in a delivery base group having a demand for the delivery object and one supply point included in a delivery base group serving as a supply source of the delivery object with each other so that a time of movement from the one demand point to the one supply point is minimized, may generate a set of combinations of the demand point and the supply point associated with each other, and may divide the delivery

problem indicated by the initial conditions into delivery problems from a demand point group to a supply point group which are included in the generated set.

It is possible to generate a delivery plan in a practical amount of time by dividing a delivery area into units of a delivery area for each set of delivery bases present within a short distance on the basis of information on a demand and a supply for each delivery base included in the initial conditions and calculating a delivery plan in units of a delivery area after division.

[0011]

The division unit in a third aspect of the present invention may calculate a delivery route from a supply point to a demand point in which a time of movement from one supply point to one demand point is set to be equal to or less than a predetermined value among correspondence relationships between a plurality of supply points and a plurality of demand points which are included in the generated set, and the delivery plan generation unit may generate a delivery plan for a small-scale delivery problem by using a delivery route in which a time of movement is set to be equal to or less than the predetermined threshold value among the delivery routes from the supply point group to the demand point group which are included in the generated set.

A delivery plan is generated using information on a delivery route between delivery bases in which a moving time is set to be equal to or less than a threshold value, and thus it is possible to reduce the amount of calculation required for the generation of the delivery plan.

[0012]

The division unit in a fourth aspect of the present invention may acquire a plurality of pieces of unit route information indicating a preset delivery route including departing from a departure base, performing delivery related to some delivery bases, and

returning to the departure base and costs when delivery is performed through the delivery route, calculate a combination in which the number of delivery bases included in a combination, among the combinations of the plurality of pieces of unit route information, is equal to or less than a predetermined number and the sum of costs is minimized, generate a set of a departure base and a delivery base which are included in the combination, and may divide the delivery problem indicated by the initial conditions into delivery problems from a demand point group to a supply point group which are included in the generated set of the departure base and the delivery base.

A combination of delivery routes for minimizing delivery costs while satisfying demands in a plurality of delivery bases equal to or smaller than a predetermined number is calculated on the basis of a certain departure base, and a set of the plurality of delivery bases and the departure base is set to be one delivery area. It is possible to generate a delivery plan in a practical amount of time by dividing a delivery area with respect to all of the delivery bases given under the initial conditions into delivery areas generated in this manner and calculating the delivery plan in units of a delivery area.

[0013]

The division unit in a fifth aspect of the present invention calculates a combination of the pieces of unit route information by a column generation technique.

It is possible to generate a delivery area at high speed by using the column generation technique.

[0014]

The division unit in a sixth aspect of the present invention may divide a delivery time limit of the delivery object into a plurality of times to divide the delivery problem indicated by the initial conditions into delivery problems for respective times obtained by the division, and the delivery plan generation unit may generate a delivery plan in which

the delivery object is delivered to a base having as many demands as possible within each time after the division from a delivery situation of the delivery object at a first time of the times after the division.

[0015]

With regard to a delivery problem related to a last time obtained by the division performed by the division unit, the delivery plan generation unit in a seventh aspect of the present invention may generate a delivery plan in which the delivery object is delivered to all delivery bases having a demand which is indicated by the initial conditions until the last time ends.

According to the sixth and seventh aspects, it is possible to generate a delivery plan in a practical amount of time by dividing a delivery time limit given under the initial conditions and calculating the delivery plan for delivery problems in the time unit after the division.

[0016]

The division unit in an eighth aspect of the present invention may divide the delivery problem indicated by the initial conditions into delivery problems in which a first delivery time limit shorter than a delivery time limit included in the initial conditions by a predetermined time is set as a new delivery time limit, and the delivery plan generation unit may generate a delivery plan in which the delivery object is delivered to a base having as many demands as possible within the first delivery time limit.

[0017]

The division unit in a ninth aspect of the present invention may set a time having a predetermined length and subsequent to the first delivery time limit as a second delivery time limit, and the delivery plan generation unit may generate a delivery plan in which the delivery object is delivered to a base having as many demands as possible

within the second delivery time limit.

[0018]

The delivery plan generation unit in a tenth aspect of the present invention may generate a delivery plan for terminating delivery of delivery objects of which delivery has not been completed as a result of execution of the delivery plan within a last time when a point in time of completion in a case where the generated delivery plan is executed is set as a start time and a time when the delivery time limit included in the initial conditions elapses from the start time of the first delivery time limit is set as a termination time.

According to the eighth to tenth aspects, a time shorter than the delivery time limit given under the initial conditions is set as a delivery time limit, and a delivery plan is generated while extending the delivery time limit. It is possible to generate a delivery plan in a practical amount of time by dividing a delivery problem indicated by the initial conditions into small-scale delivery problems for each set or extended delivery time limit.

[0019]

According to an eleventh aspect of the present invention, in generating a delivery plan in which the delivery object is delivered to a base having as many demands as possible, the delivery plan generation unit may generate a delivery plan on a condition that a delivery staff member and delivery means required for execution of the delivery plan are not left in the delivery base as a result of the execution of the delivery plan.

It is possible to generate a delivery plan capable of not only delivering as many delivery objects as possible but also preventing the remaining delivery staff members and delivery means, which are not used for a later time among times after division, from being left in the delivery base.

[0020]

The delivery plan generation unit in a twelfth aspect of the present invention may solve an integer programming problem based on a time space network model constituted by point information and branch information to generate at least one set of pieces of branch information related to the delivery in the delivery problem after the division performed by the division unit, the point information having a set of a delivery subject delivering the delivery object, a departure base and the delivery base indicating an initial position of delivery means moving the delivery object or the delivery subject, and times based the start time of delivery, and the branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to the delivery between two pieces of point information related to the delivery of the delivery object among the pieces of point information.

It is possible to generate a delivery plan for a delivery problem including boarding transport by modeling the delivery problem using a time space network model.

[0021]

According to a thirteenth aspect of the present invention, the delivery plan generation unit may be configured to generate point information regarding an entrance having a set of an entrance and a time of the delivery base, point information regarding an exit having a set of an exit and a time of the delivery base, and point information regarding a place for the delivery object having a set of a time and each delivery object related to the delivery base with respect to one delivery base in the time space network model, and set values of flow rates of the delivery subject and the delivery object between the point information regarding the entrance and the point information regarding the delivery object and between the point information regarding the exit and the point information regarding the delivery object to 0 or 1.

Since the inside of the delivery base is handled by performing division into an entrance, an exit, and a place for each of delivery objects, situations in respective places can be represented by 0 and 1, and thus it is possible to handle the inside of the delivery base as a 0-1 integer programming problem and to speed up calculation processing.

[0022]

A fourteenth aspect of the present invention relates to a delivery plan method including causing a delivery plan system to divide a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand, and to generate a delivery plan for the delivery problems obtained by the division.

[0023]

A fifteenth aspect of the present invention relates to a program causing a computer of a delivery plan system to function as means for dividing a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand, and means for generating a delivery plan for the delivery problems obtained by the division.

[Advantageous Effects of Invention]

[0024]

According to the above-described delivery planning system, delivery planning method, and program, it is possible to make a delivery plan for minimizing costs and a moving time for a large-scale delivery problem in a practical amount of time.

[Brief Description of Drawings]

[0025]

Fig. 1 is a functional block diagram showing an example of a delivery planning system in a first embodiment of the present invention.

Fig. 2 is a diagram showing an example of a delivery plan in the first embodiment of the present invention.

Fig. 3 is a diagram showing a first time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 4 is a first diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 5 is a second diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 6 is a third diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 7 is a fourth diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 8 is a fifth diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 9 is a diagram showing an example of a delivery problem in the first embodiment of the present invention.

Fig. 10 is a diagram showing an example of a delivery plan generated for a delivery problem.

Fig. 11 is a first diagram showing a first area division process in the first embodiment of the present invention.

Fig. 12 is a second diagram showing the first area division process in the first embodiment of the present invention.

Fig. 13 is a flowchart showing an example of a delivery plan generation process in the first embodiment of the present invention.

Fig. 14 is a functional block diagram showing an example of a delivery plan

system in a second embodiment of the present invention.

Fig. 15 is a first diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

Fig. 16 is a second diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

Fig. 17 is a third diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

Fig. 18 is a flowchart showing an example of a delivery plan generation process in the second embodiment of the present invention.

Fig. 19 is a functional block diagram showing an example of a delivery plan system in a third embodiment of the present invention.

Fig. 20 is a first diagram showing a time division process of a delivery problem in the third embodiment of the present invention.

Fig. 21 is a second diagram showing a time division process of a delivery problem in the third embodiment of the present invention.

Fig. 22 is a flowchart showing an example of a delivery plan generation process in the third embodiment of the present invention.

[Description of Embodiments]

[0026]

<First Embodiment>

Hereinafter, a delivery planning system according to an embodiment of the present invention will be described with reference to Figs. 1 to 13.

Fig. 1 is a functional block diagram showing an example of a delivery planning system in a first embodiment of the present invention. In the present embodiment, the delivery planning system is constituted by a computer device such as one PC or a server

device. The computer device is configured to include other hardware such as a computational unit such as a Central Processing Unit (CPU), storage units such as a Read Only Memory (ROM), a Random Access Memory (RAM), and a Hard Disk Drive (HDD), and a network interface.

[0027]

A delivery plan device 10 in Fig. 1 is an example of a delivery planning system. The delivery plan device 10 is a device that calculates delivery means, a delivery route, and the like for minimizing costs with respect to a delivery plan including boarding transport. In the present embodiment, a method of making an optimal delivery plan for realizing delivery in a situation where a vehicle to be shared by users is delivered to a place where a user starts using the vehicle in drop-off type car sharing is taken as an example. In a case where a delivery object is delivered, it is required that, for example, delivery means and a delivery route for minimizing costs be selected. Regarding making a delivery plan for minimizing costs, various methods have been provided. However, the delivery of a vehicle in car sharing is different from a case where loads are delivered by, for example, a home delivery service or the like. The difference is that, in a case where a vehicle is delivered, the vehicle can be moved in a state where a person is onboard the vehicle. For example, a state where there is a remaining vehicle or a state where there is a shortage of vehicles is assumed in each of bases A, B, C, D, and E. In such a state, for example, the following methods are considered in order to move a vehicle from a base where there is a remaining vehicle to a base where there is a shortage of vehicles and to respond a user's need. (1) One delivery staff member turns around each base with a truck on which a vehicle can be carried, loads a remaining vehicle on the truck, and delivers the vehicle to a base where there is a shortage of vehicles. (2) A plurality of delivery staff members board a delivery vehicle and move to each base.

When the delivery staff members arrive at the base where there is a remaining vehicle, some of the delivery staff members boarding the delivery vehicle transfer to the remaining vehicle and deliver the vehicle by driving the vehicle to the base where there is a shortage of vehicles (boarding transport). In such a case, it is not easy to ascertain which delivery means may be used for delivery and what route may be used for delivery to minimize costs. The delivery plan device 10 of the present embodiment provides a method of rapidly and efficiently generating a delivery plan, for example, for minimizing costs by introducing a mathematical model and constraints according to mathematical knowledge with respect to a delivery plan in a case where boarding transport can be performed. The delivery plan device 10 of the present embodiment divides the entire delivery problem indicated by initial conditions into small-scale partial delivery problems on the basis of a demand quantity (a shortage quantity) of delivery objects and a supply quantity of delivery objects (the number of remaining delivery objects) for each delivery base which are given as initial conditions of the delivery, in generating a delivery plan for delivering delivery objects to a delivery base. Thereby, it is possible to make a delivery plan in a practical amount of time (for example, 10 minutes) even when the number of vehicles to be delivered and the number of bases are large.

[0028]

As shown in Fig. 1, the delivery plan device 10 includes an initial conditions setting unit 11, a delivery plan generation unit 12, an input and output unit 13, and a first area division unit 14, and a storage unit 15.

The initial conditions setting unit 11 sets information such as a delivery object (for example, a vehicle used by a user) which is movable by a delivery subject (for example, a delivery staff member) onboard the delivery object, the delivery subject, a demand quantity and a supply quantity of delivery objects for each delivery base which is

a place where any delivery means (for example, a delivery vehicle such as a truck) moving a delivery object or a delivery subject is staying, information regarding one or a plurality of departure bases indicating the initial positions of a delivery subject and delivery means (for example, an operation base of a company providing a car sharing service), information regarding delivery means and a delivery subject which are usable in a departure base, and information regarding a delivery deadline, as initial conditions in generating a delivery plan. These parameters will be described later in detail.

The delivery plan generation unit 12 calculates pieces of point information having sets of a delivery base, a departure base, and a time according to the start of delivery and branch information indicating flow rates of delivery objects, delivery subjects, and delivery means according to delivery between two pieces of point information according to delivery among the pieces of point information, and generates at least one set of pieces of branch information in a case where delivery objects satisfying a demand quantity within a delivery deadline are delivered to a delivery base where the demand quantity is set. The departure base and the delivery base will be collectively called bases.

The input and output unit 13 receives a user's input operations. The input and output unit 13 outputs information regarding a delivery plan and the like according to the set of pieces of branch information generated by the delivery plan generation unit 12 to a display or the like.

The first area division unit 14 associates one demand point included in a delivery base group having a demand for a delivery object and one supply point included in a delivery base group serving as a supply source of a delivery object with each other so that a moving time from the demand point to the supply point is minimized, and generates a set of combinations of the demand point and the supply point associated with

each other. That is, the first area division unit 14 divides all of the delivery problems for all of the delivery base groups having a demand for a delivery object based on initial conditions into delivery problems in units of a delivery area indicated by the generated set (problems of delivery from a demand point group to a supply point group which are included in the set). In addition, the delivery plan generation unit 12 generates a set of pieces of branch information for each of the small-scale delivery problems after division.

The storage unit 15 stores various pieces of information necessary for generation of a delivery plan.

The initial conditions setting unit 11, the delivery plan generation unit 12, and the first area division unit 14 are realized, for example, by reading out and executing a program from the storage unit 15 using a Central Processing Unit (CPU) included in the delivery plan device 10.

[0029]

The delivery plan device 10 generates a delivery plan using a time space network model for a given delivery problem. First, the time space network model and a delivery plan generation method using the time space network model will be described, and a delivery problem division method in a case where the scale of a problem is increased thereafter will be described.

[0030]

Fig. 2 is a diagram showing an example of a delivery plan in the first embodiment of the present invention.

An example of delivery of a delivery object (vehicle) in drop-off type car sharing will be described with reference to Fig. 2. A center in Fig. 2 is a base where there is a delivery staff member for a delivery object and the delivery of the delivery object is started (departure base). A parking lot A, a parking lot B, and a parking lot C

are bases (delivery bases) serving as a delivery source or a delivery destination of the delivery object. A user of the delivery object reserves the delivery object using a predetermined reservation system or the like. The user inputs information such as the number of delivery objects to be used, a place where the use of the delivery object is started (for example, the parking lot B) from the reservation system. In a case where the user desires to use the delivery object from the parking lot B, the user can use the delivery object when the delivery object is already present in the parking lot B. However, in a case where the delivery object is not present in the parking lot B, the delivery staff member needs to move the delivery object from another parking lot to the parking lot B. In the drop-off type car sharing, for example, the user drops off the delivery object at the parking lot A when the delivery object is used from the parking lot B to the parking lot A. Then, for example, a situation where delivery objects are unevenly distributed in the parking lot A used by many users may occur. The delivery staff member at the center delivers the unevenly distributed delivery objects to the parking lot A to the parking lot C where there is demand In a case of the example of Fig. 2, there are two remaining delivery objects at the parking lot A, and there is a shortage of one delivery object in each of the parking lot B and the parking lot C. The delivery staff member at the center delivers each of the two remaining delivery objects at the parking lot A to the parking lot B and the parking lot C, so that the users can use the delivery objects as desired. Fig. 2 shows an example of the realization of delivery satisfying this condition.

[0031]

First, two delivery staff members (k, l) from the center board one delivery vehicle 1 (delivery means) and move to the parking lot A (1). In the parking lot A, the delivery staff member k boards one delivery object out of the two remaining delivery

objects and moves to the parking lot B. The other delivery staff member l also boards the delivery vehicle 1 in this state and moves to the parking lot B (2). In the parking lot B, the delivery staff member k parks the delivery object at the parking lot B and boards the delivery vehicle 1 driven by the delivery staff member l. The delivery staff members k and l return to the parking lot A from the parking lot B (3). When the delivery staff members return to the parking lot A, the delivery staff member k boards one remaining delivery object and moves to the parking lot C. The delivery staff member l boards the delivery vehicle 1 in this state and moves to the parking lot C (4). In the parking lot C, the delivery staff member k parks the delivery object at the parking lot C and boards the delivery vehicle 1 driven by the delivery staff member l. The delivery staff members k and l return to the center from the parking lot B (5). When delivery is performed by such a procedure, the user's request can be satisfied. In the present embodiment, a method of delivering a delivery object in such a situation is formulated as a minimum cost flow problem of a time space network model, and a method for minimizing costs is obtained among executable delivery methods.

[0032]

<First time space network model>

Fig. 3 is a diagram showing a first time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 3 is a diagram obtained by modeling an example of the delivery described in Fig. 2 in a time space network.

The vertical axis in Fig. 3 represents the elapse of time, and the horizontal axis represents the location of each base. In the drawing, a point in time and space represents each base at each time. In the drawing, an arrow connecting two points represents the movement of each of a delivery object, a delivery vehicle (delivery

means), and a delivery staff member (person) in time and space. Each arrow represents a movement source base, a movement destination base, and a period of time required for movement. A solid arrow represents movement between bases, and a double line arrow represents a delivery object, a delivery vehicle, and a delivery staff member staying in the same base (movement between times). Each element of a matrix displayed together with an arrow represents each of the number of delivery objects, the number of delivery vehicles, and the number of delivery staff members having moved according to delivery indicated by an arrow, and represents the number of moved delivery objects, the number of moved delivery vehicles, and the number of moved delivery staff members in order from above. For example, in a case of a solid arrow 31, it is indicated that there are no delivery objects, one delivery vehicle, and two delivery staff members having moved from the center to the parking lot A between times t=0 and t=1. A double line arrow 32 indicates that there are two delivery objects, no delivery vehicles, and no delivery staff members having stayed in the parking lot A between times t=0 and t=1. In a case of a solid arrow 33, it is indicated that there are one delivery object, one delivery vehicle, and two delivery staff members having moved from the parking lot A to the parking lot B between times t=1 and t=2. A double line arrow 34 indicates that there are one delivery object, no delivery vehicles, and no delivery staff members having stayed in the parking lot A between times t=1 and t=2. The number of delivery objects at the parking lot A has changed from two to one because the delivery staff member has boarded one delivery object out of the two delivery objects and has moved to the parking lot B. The same is true of the other arrows. One arrow will be called a branch. A set of the branches in Fig. 3 corresponds to the delivery plan described in Fig. 2. A case where a delivery object is delivered may be accompanied by a time-related action such as meeting a delivery staff member or delivery means at a parking lot. In the existing mathematical

model related to a delivery plan, modeling is often performed by setting a base as a point and the movement of a delivery vehicle between bases as a branch. In the present embodiment, modeling is performed in a two-dimensional time space network. Thereby, it is possible to represent not only spatial movement between bases but also the movement of a vehicle or a person in an intervening time.

[0033]

<Delivery plan generation method based on first time space network model>

In the present embodiment, a delivery plan for minimizing costs required for the delivery of delivery objects planned to be delivered so as to satisfy a demand within the time limit described in Figs. 2 and 3 is obtained. This problem can be formulated as the following integer programming problem.

[Objective Function]

Minimization of sum of costs of delivery objects, delivery means, and delivery staff members which are required for delivery

[Constraint conditions]

(1) The flow rate in each base satisfies the flow rate conservation law.

(2) The number of vehicles present in a parking lot does not exceed a parking space of a parking lot.

(3) A delivery staff member necessarily boards delivery means in places other than a departure base.

(4) A delivery staff member necessarily boards a delivery object or delivery means during movement, and the number of persons during movement is equal to or less than the sum of the number of persons capable of boarding a delivery object and delivery means.

[0034]

In order to solve the above-described integer programming problem, the delivery plan generation unit 12 generates two-dimensional time space information as shown in Fig. 3 on the basis of information regarding the initial conditions received by the initial conditions setting unit 11, generates a branch between points according to delivery, and generates a plurality of sets of branch information indicating that delivery objects can be delivered to a base where a demand quantity is set so as to satisfy demand quantities of respective bases within a delivery deadline. The delivery plan generation unit 12 selects a set of pieces of branch information for minimizing costs from among sets of a plurality of pieces of branch information.

[0035]

Mathematical models and programs of delivery plans that have been provided are limited to a case where mathematical models and programs of delivery plans that have existed and are limited to a case where delivery objects are delivered in a state of being loaded on a transport means such as trucks or railroads. Regarding a case where boarding transport is included like the delivery of a vehicle, there is a likelihood that a solution can also be obtained by adding constraint conditions using the existing technique, but it is considered that this would not be practical because the number of combinations of transport means and routes increases exponentially, in addition to the complexity of constraint conditions. According to the present embodiment, formulation as a minimum cost flow problem of a time space network model is performed in calculating a delivery plan for a delivery object applicable to boarding transport, and thus it is possible to obtain a delivery plan for minimizing costs among executable delivery methods.

[0036]

<Second time space network model>

In a second time space network model, a graph (point information and branch information indicating the movement of delivery staff members, delivery objects, and delivery means) within a delivery base is further added to the first time space network model. Thereby, the inside of the delivery base is treated as a 0-1 integer programming problem. In a 0-1 integer programming problem, the range of variables is more limited than that of an integer programming problem, and thus a tight relaxation problem can be configured. Thereby, a valid inequality (cut) is easily input, and thus it is possible to achieve speeding up of a calculation process (a reduction in a calculation time).

[0037]

In a case where the delivery plan generation unit 12 generates a delivery plan using the second time space network model, the delivery plan generation unit generates point information having a set of an entrance and a time of one delivery base, point information having a set of an exit and a time of the delivery base, and point information having a set of times with respect to each of delivery objects according to the delivery base with respect to one delivery base, in addition to the time space information described in the case of the first time space network model. The delivery plan generation unit 12 sets the values of flow rates of delivery staff members and delivery objects between the point information regarding the entrance and the point information regarding the delivery object to 0 or 1, in addition to the function of the delivery plan generation unit 12. The delivery plan generation unit 12 sets the values of flow rates of delivery staff members and delivery objects between the point information regarding the exit and the point information regarding the delivery object to 0 or 1.

[0038]

Here, parameters to be input to the delivery plan device 10 by a person making a delivery plan will be described. The input parameters include the following items.

That is, the items include a set of departure bases (Depot), a set of delivery bases (W), a delivery deadline (dl), time of one section (h), a set of types of delivery objects (P), a set of types of delivery means (D), an amount of loading on delivery means (cp), the cost of a delivery object cx (yen/minute), the cost of delivery means cy (yen/minute), the cost of a delivery staff member cz (yen/minute), a moving time matrix M (for example, a moving time from a delivery base w1 to a delivery base w2 using delivery means d is set to be m[d][w1][w2]), a supply quantity in each base "supply" (for example, a supply quantity of d in a delivery base w is set to be supply[w, d]), a demand quantity in each delivery base "demand" (for example, a demand quantity of d in the delivery base w is set to be demand[w, d]). An initial conditions setting unit 11 acquires these parameters and sets the parameters as initial conditions of a delivery plan.

[0039]

The delivery plan generation unit 12 outputs a flow rate x ((v,s), (w,t)) of delivery objects flowing through a time space network in an optimized delivery plan, a flow rate y ((v,s), (w,t)) of delivery means, and a flow rate z ((v,s), (w,t)) of delivery staff members to an input and output unit 13, as output items. A branch departing a delivery base v at time s and arriving at the delivery base w at time t is expressed by ((v,s), (w,t)). The output items also include costs required for delivery, and the like.

[0040]

Fig. 4 is a first diagram showing a second time space network model according to a delivery plan in the first embodiment of the present invention.

The second time space network will be described with reference to Fig. 4. Hereinafter, a place set will be set to be N, a time set will be set to be T, and a graph G of the time space network will be set to be (V, E). Here, V represents a point set, and E represents a branch set. The point set V is defined as follows.

$V=\{(w,d,p,t)|w\in W,d\in\{0\}\cup P,p\in S_{wd},t\in T\}$

Here, $S_{wd}=\{0,1\}(d=0)$, $S_{wd}=\{0,1,...,m\}$ $(d\neq0)$. In addition, d=0 indicates the road at an entrance and an exit of a delivery base. When d=0, S_{wd} has a value of 0 or 1, but $S_{wd}=0$ and $S_{wd}=1$ indicate the entrance and the exit, respectively. In a case of $d\neq0$, d indicates the type of delivery object, and S_{wd} has values of 0 to m. In addition, m is a supply quantity-1 or a demand quantity-1 with respect to the delivery object d in the delivery base w. For example, in a case where three delivery objects are left in the delivery base w (supply quantity=3), S_{wd} has values of 0, 1, and 2. For example, in a case where there is a shortage of four delivery objects a in the delivery base w (demand quantity=4), S_{wd} has values of 0, 1, 2, and 3. A point of d=0 is called a road and a point of $d\neq0$ is called a port with respect to a certain delivery base w. The port indicates a place where one delivery object d is disposed.

[0041]

Fig. 4 shows a time space network in a case of Depot={0}, W={1,2}, P={a}, T={0,1,2}, $S_{1a}=\{0\}$ (a supply quantity with respect to a delivery object a in a delivery base 1 is one), and $S_{2a}=\{0\}$ (a supply quantity with respect to the delivery object a in a delivery base 2 is one). Next, the branch set E will be described with reference to Fig. 5.

[0042]

Fig. 5 is a second diagram showing a second time space network model according to a delivery plan in the first embodiment of the present invention.

Hereinafter, the branch set E is set to be $E=E_x\cup E_y\cup E_z$. In addition, E_x represents a branch set of delivery objects, E_y represents a branch set of delivery means, and E_z represents a branch set of delivery staff members.

The branch set Ex of delivery objects is defined as follows.

$E_x=E_{wwx}\cup E_{wx}\cup E_{wpx}\cup E_{pwx}\cup E_{px}$

Here, E_{wwx} represents a set of branches indicating the movement of the delivery objects between the bases, E_{wx} represents a set of branches in which the delivery objects stay on the road of the delivery base (meeting or the like), E_{wpx} represents a set of branches indicating the movement of the delivery objects from the road to the port, E_{pwx} represents a set of branches indicating the movement of the delivery objects from the port to the road, and E_{px} represents a set of branches in which the delivery objects stay at the port.

[0043]

A branch set E_y of delivery means is defined as follows.

$E_y=E_{wwy}\cup E_{wy}\cup E_{wpy}\cup E_{pwy}$

E_{wwy} represents a set of branches indicating the movement of the delivery means between the bases, E_{wy} represents a set of branches in which the delivery means are staying on the road of the delivery base (meeting or the like), E_{wpy} represents a set of branches indicating the movement of the delivery means from the road to the port, and E_{pwy} represents a set of branches indicating the movement of the delivery means from the port to the road.

[0044]

A branch set E_z of delivery staff members is defined as follows.

$E_z=E_{wwz}\cup E_{wz}\cup E_{wpz}\cup E_{pwz}$

E_{wwz} represents a set of branches indicating the movement of the delivery staff members between the bases, E_{wz} represents a set of branches in which the delivery staff members stay on the road of the delivery base (meeting or the like), E_{wpz} represents a set of branches indicating the movement of the delivery staff members from the road to the port, and E_{pwz} represents a set of branches indicating the movement of the delivery staff

members from the port to the road.

[0045]

Fig. 5 shows a display example of the branch sets defined above. A solid arrow in an oblique direction indicates a branch corresponding to each of the sets E_{wwx}, E_{wwy}, and E_{wwz}. A double line arrow in a vertical direction indicates a branch corresponding to each of the sets E_{wx}, E_{wy}, E_{wz}. A two dots-dashed arrow in a horizontal direction indicates a branch corresponding to each of the sets E_{wpx}, E_{wpy}, and E_{wpz}. A dotted-dashed arrow in an oblique direction indicates a branch corresponding to each of the sets E_{pwx}, E_{pwy}, and E_{pwz}. A dashed arrow in the vertical direction indicates a branch corresponding to the set E_{px}.

In the second time space network model, the inside of a delivery base is treated as a 0-1 integer problem, the branches of the alternating two dots-dashed arrow in a horizontal direction, the alternating dotted-dashed arrow in an oblique direction, and the dashed arrow in a vertical direction are branches added in the present embodiment in association with the 0-1 integer problem.

[0046]

Fig. 6 is a third diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Flow rate vectors set for respective branches will be described with reference to Fig. 6. As shown in (a) of Fig. 6, the following flow rate vector is set for each branch e.

[0047]

$$\begin{pmatrix} x[d,e] \\ y[d,e] \\ z[e] \end{pmatrix}$$

[0048]

In this flow rate vector, x[d, e]($d \in P, e \in E_x$) indicates a flow rate of delivery objects, y[d, e]($d \in D, e \in E_y$) indicates a flow rate of delivery means, and z[e]($e \in E_z$) indicates a flow rate of delivery staff members. Some examples will be described. In a case of P={a} and D={vehicle}, a flow rate vector is as follows.

[0049]

$$\begin{pmatrix} a \\ \text{VEHICLE} \\ \text{PERSON} \end{pmatrix}$$

[0050]

A branch e shown in (b) of Fig. 6 indicates the movement of one a, one delivery vehicle (vehicle), and two delivery staff members (persons). In a case of P={a,b} and D={vehicle,bicycle}, a flow rate vector is as follows.

[0051]

$$\begin{pmatrix} a \\ b \\ \text{VEHICLE} \\ \text{BICYCLE} \\ \text{PERSON} \end{pmatrix}$$

[0052]

A branch e shown in (c) of Fig. 6 indicates the movement of one a, one b, one delivery vehicle (vehicle), one bicycle, and two delivery staff members (persons).

[0053]

Fig. 7 is a fourth diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

In Fig. 7, a flow rate vector is as follows.

[0054]

$$\begin{pmatrix} a \\ \text{VEHICLE} \\ \text{PERSON} \end{pmatrix}$$

[0055]

A time space network model in a case where one delivery object a is moved from the delivery base 1 to the delivery base 2 will be described. First, two delivery staff members (persons) and one delivery vehicle (vehicle) move from a Depot exit to the delivery base 1 (solid arrow 91). In the delivery base 1, one delivery staff member moves to a place for the delivery object a (port 0) (alternating two dots-dashed arrow 92). At the port 0 of the delivery object a, the delivery object a is present from time 0 to time 1 (dashed arrow 93). Subsequently, one delivery staff member and one delivery object a move to the exit of the delivery base 1 (alternating dotted-dashed arrow 94). Next, one delivery object a, one delivery vehicle, and two delivery staff members move from the exit of the delivery base 1 to the entrance of the delivery base 2 (solid arrow 95). Next, one delivery staff member and one delivery object a move to the port 0 of the delivery base 2 (alternating two dots-dashed arrow 96). Subsequently, one delivery staff member moves from the port 0 to the exit of the delivery base 2 (alternating

dotted-dashed arrow 97). Next, two delivery staff members and one delivery vehicle move from the exit of the delivery base 2 to a Depot entrance (solid arrow 98). At the port 0 of the delivery base 2, the delivery object a is present from time 2 to time 3 (dashed arrow 100). As shown in Fig. 7, in the present embodiment, a point is allocated for each delivery object a and a point is allocated to each of an entrance and an exit of a delivery base in the delivery base 1 and the delivery base 2. For this reason, the value of each element of a flow rate vector within the delivery base 1 and the delivery base 2 is 0 or 1. Thereby, the inside of the delivery base is treated as a 0-1 integer programming problem, and thus it is possible to reduce a calculation time.

[0056]

Fig. 8 is a fifth diagram showing a second time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 8 is a table represented using a second time space network model obtained by representing the first time space network model shown in Fig. 3. In Fig. 8, the point set represented by the column of the parking lot A in Fig. 3 is represented by point sets of respective columns (1,0,0,0), (1,a,0,0), and (1,a,1,0) obtained by subdivision. The same is true of the parking lot B and the parking lot C.

Point sets corresponding to an entrance and an exit are imparted to each of the center and the parking lot A to the parking lot C.

[0057]

<Delivery plan generation method based on second time space network model>

As a countermeasure for speeding up a process in the second time space network model, setting the inside of a delivery base as the 0-1 integer programming problem has been described above. Next, a delivery plan generation method will be described. Delivery means will be described with respect to each of a case where delivery is

performed using a delivery vehicle and a bicycle (a case where delivery is performed using only a delivery vehicle is also included) and a case where delivery is performed (by loading delivery objects) using a truck. A bicycle which is delivery means is used such that a delivery staff member moves to a delivery base with a supply while riding a bicycle, loads the bicycle on a remaining vehicle in that place, and drives the remaining vehicle to a delivery base with a demand.

[0058]

First, an objective function will be described. In Fig. 3, a case where costs are minimized has been described as an example. Here, a description will be given inclusive of a case where a moving time required for delivery is minimized.

(Case Where Delivery is Performed Using Delivery Vehicle and Bicycle)

1. An objective function in a case where costs required for delivery is minimized is obtained by multiplying costs of each of a delivery object, a delivery vehicle, and a delivery staff member per hour by a moving time and adding up the costs.

2. An objective function in a case where a moving time required for delivery is minimized is obtained by adding up moving times of a delivery object, a delivery vehicle, and a delivery staff member.

[0059]

(Case Where Delivery is Performed Using Truck)

1. An objective function in a case where costs required for delivery are minimized is obtained by multiplying costs of each of a delivery truck and a delivery staff member per hour by a moving time and adding up the costs.

2. An objective function in a case where a moving time required for delivery is minimized is obtained by adding up moving times of a delivery truck and a delivery staff member.

[0060]

Next, constraint conditions will be described.

(Common To Case Where Delivery is Performed Using Delivery Vehicle and Bicycle and Case Where Delivery is Performed Using Truck)

1. Flow rate conservation law

(1) Regarding flow rate of delivery objects

A flow rate of delivery objects leaving a port with a supply is set to 1 when delivery is started. A flow rate of delivery objects entering a port with a demand is set to 1 at a point in time when delivery is completed. At the other points, a flow rate of incoming delivery objects and a flow rate of outgoing delivery objects are equal to each other.

[0061]

(2) Regarding flow rate of delivery vehicles

A flow rate of delivery vehicles leaving a road on which the delivery vehicles are located when delivery is started corresponds to the number of existing delivery vehicles. A flow rate of delivery vehicles entering a road on which the delivery vehicles are located when delivery is completed corresponds to the number of existing delivery vehicles. At the other points, a flow rate of outgoing delivery vehicles and a flow rate of incoming delivery vehicles are equal to each other.

(3) Regarding flow rate of delivery staff members

A flow rate of delivery staff members leaving a road on which the delivery staff members are located when delivery is started corresponds to the number of delivery staff members. A flow rate of delivery staff members entering a road on which the delivery staff members are located when delivery is completed corresponds to the number of delivery staff members. At the other points, a flow rate of outgoing delivery staff

members and a flow rate of incoming delivery staff members are equal to each other.

2. Capacity constraint

An amount of movement of delivery objects and persons within a delivery base is equal to or less than 1.

[0062]

3. Constraint 1 within delivery base

$\forall e \in E_{wp}$

(E_{wp} is a set of a delivery object, delivery means, and a branch indicating movement of a person from a road to a port)

(1) When a destination of e is a supply point of d,

delivery objects do not enter a port from a road.

(2) When a destination of e is a demand point of d,

a flow rate of delivery objects and a flow rate of delivery staff members have the same value (0 or 1).

(3) In either case,

the number of bicycles is equal to or less than the number of delivery staff members.

[0063]

4. Constraint 2 within delivery base

$\forall e \in E_{pw}$

(E_{pw} is a set of a delivery object, delivery means, and a branch indicating movement of a person from a port to a road)

(1) When a departure point of e is a supply point of d,

a flow rate of delivery objects and a flow rate of delivery staff members have the same value (0 or 1).

(2) When a departure point of e is a demand point of d,

delivery objects do not come out on a road from a port.

(3) In either case,

the number of bicycles is equal to or less than the number of delivery staff members.

[0064]

Hereinafter, a case where delivery is performed using a delivery vehicle and a bicycle and a case where delivery is performed using a truck will be described separately.

(In Case Where Delivery Is Performed Using Delivery Vehicle And Bicycle)

5. Constraints on branches in case of movement from base to another base

$\forall e \in E_{ww}$

(E_{ww} is a set of a delivery object, delivery means, and a branch indicating movement of a person between bases)

(1) When e is a branch of a bicycle and a branch of a vehicle,

there may be a case where delivery staff members respectively boarding the bicycle and the vehicle move separately and a case where a delivery staff member moves in the vehicle with the bicycle loaded thereon, and constraints are as follows: a delivery staff member necessarily boards the vehicle; the number of delivery staff members is equal to or less than the number of persons able to board; and the number of undrivable bicycles is equal to or less than the number of bicycles loadable on the vehicle.

(2) When e is a branch of a bicycle but not a branch of a vehicle (moves in a bicycle),

the number of bicycles and the number of persons are the same.

[0065]

6. Constraints on branch staying in delivery base

A constraint is that a person necessarily boards a vehicle.

[0066]

(Case Where Delivery is Performed Using Truck)

5. Constraint on branch during movement from delivery base to another delivery base

Constraints are as follows: a delivery staff member necessarily boards a truck; the number of delivery staff members is equal to or less than the number of persons able to board; and the total volume of delivery objects is equal to or less than an amount of loading on the truck.

[0067]

6. Constraint on branch staying in delivery base

A constraint is that the total volume of delivery objects is equal to or less than an amount of loading on the truck.

[0068]

Further, a constraint expression called a cut can be applied to reduce a calculation time. In an integer programming problem, an inequality that a point in an executable region can satisfy is called a valid inequality. Since it is difficult to solve the integer programming problem, the integer programming problem is often treated as a linear relaxation problem from which integer conditions are first excluded. The addition of a valid inequality cutting a solution space of the linear relaxation problem is called the addition of a cut. The linear relaxation solution approaches an integer optimal solution by the addition of a cut, thereby exerting a strong effect on the acceleration of calculation. The executable region is not cut by the addition of a cut, and thus the optimality of a solution is secured. For example, a cut for specifying that one or more delivery vehicles come is added. Then, an impractical case where 3/4 of

delivery vehicles come can be excluded from a calculation target, and a calculation speed can be improved. A specific example of a cut is disclosed in the specification of Japanese Patent Application No. 2016-051550 filed by the applicant of the present application. An integer programming problem requiring several hours in a case where a cut is added and a case where a cut is not added can be solved in several minutes.

[0069]

The delivery plan generation unit 12 generates a time space network model obtained by dividing a delivery base in a road (d=0) and a parking port (d≠0), and further calculates branch information using the constraint conditions and the added cuts. According to the present embodiment, the inside of a delivery base can be modeled as a 0-1 integer programming problem, and thus it is possible to obtain an effect that time required for the calculation of a delivery plan can be reduced, in addition to the effects in a case where a delivery plan is generated using the first time space network. Further, it is possible to drastically reduce a calculation time by the addition of a cut. Thereby, there is an improvement in the convenience of a person making a delivery plan such as a lower cost delivery plan being selectable by comparing delivery plans generated under various initial conditions with each other.

[0070]

Next, an example in which a delivery plan is generated using a second time space network will be described.

Fig. 9 is a diagram showing an example of a delivery problem in the first embodiment of the present invention.

Fig. 10 is a diagram showing an example of a delivery plan generated for a delivery problem.

A point c0 (depot) in Fig. 9 is a departure base. The other points w1 to w9 are

delivery bases. For example, "d1:2" at the point w7 indicates a state where two delivery objects d1 are left, and "d2:-1" at the point w5 indicates a state where there is a shortage of one delivery object d2. "d1:-1, d2:1" at the point w2 indicates a state where there is a shortage of one delivery object d1 and one delivery object d2 is left. A problem that the delivery objects d1 to d3 are delivered so as to eliminate a state where there is a shortage of the delivery objects d1 to d3 in the respective delivery bases is considered from a state where the delivery objects d1 to d3 shown in Fig. 9 are unevenly distributed.

Hereinafter, a description will be given of an example of a delivery plan generated by the delivery plan device 10 with respect to each of a case where delivery is performed using a vehicle and a bicycle and a case where delivery is performed using a truck.

[0071 0 0 0 1]

1. Case where delivery is performed using vehicle and bicycle

(1) Input

· One delivery vehicle, three bicycles, and three delivery staff members at depot

· Delivery deadline: 120 minutes

· Costs of delivery vehicle: 1.5 yen/minute

· Costs of delivery staff member : 17 yen/minute

· Costs of d1, d2, and d3: 1.5 yen/minute

· The number of persons able to board of delivery vehicle: 4, the number of loadable bicycles: 1

· The number of persons able to board of d1: 1, the number of loadable bicycles: 0

· The number of persons able to board of d2: 4, the number of loadable bicycles: 1

· The number of persons able to board of d3: 2, the number of loadable bicycles: 0

(2) Objective function

Minimization of costs

[0072]

When the delivery plan device 10 is caused to calculate this objective function by adding the above-described constraint conditions and cuts, the following output results are obtained.

(3) Output

· Delivery is performed by division into two routes of a delivery route shown in S1 to S7 and a delivery route shown in T1 to T9 as shown in Fig. 10, using one delivery vehicle, one bicycle, and two delivery staff members.

· Costs of delivery: 2768 yen

· Required time: 60 minutes

In this manner, it is possible to obtain a delivery plan for minimizing costs within conditions of delivery means, a delivery staff member, and a delivery deadline which are set under initial conditions.

[0073]

The generation of a delivery plan using the first time space network or the second time space network by the delivery plan device 10 can also be applied to delivery, supply, and an after-sales service round of delivery objects applicable to boarding transport. For example, in an after-sales service, it is necessary to provide a service by going to a customer or visiting a plurality of customers after supplying parts required for the after-sales service. It is possible to solve an integer programming problem by applying the above-described mathematical model by setting a delivery object to be parts

or the like used for the after-sales service, setting a delivery subject to be a service person, setting delivery means to be a vehicle used for movement of the service person, a delivery vehicle required for the transport of parts or the like, or the like, setting a base to be a customer or an installation location of a product to be subject to the after-sales service, and to calculate a rounding route (rounding means, rounding course) for minimizing rounding cost or times in a case where the service person performs the after-sales service for a plurality of customers. In a case of Fig. 2, for example, the parking lot A to the parking lot C (delivery base) may be set to be customers provided with an after-sales service, the vehicle (delivery object) may be set to be a part, a car (delivery means) may be means used for movement of a service person, and a delivery person (delivery subject) may be the service person. In a case of an after-sales service, not only visiting customers but also operations such as inspection and repairs for the customers are performed. According to the delivery plan devices 10, 10A, and 10B using a time space network model, it is possible to model a rounding operation of a service person by taking these operation times into consideration.

[0074]

In addition to the above-described example, the present invention can also be applied to the delivery of delivery objects not applicable to boarding transport. For example, there is a cargo collecting method called a milk run. The milk run refers to a supply method in which a manufacturer of certain products collects raw materials and the like from each supplier by making rounds of suppliers instead of carrying raw materials and parts used for the products into the suppliers in a case where the manufacturer purchases the raw materials and the parts from a plurality of suppliers. When cargo collecting is performed through a milk run, for example, cargo is collected using one truck, and thus it is possible to achieve cost reduction, a reduction in congestion around a

factory, and a reduction in the load of an environment as compared to a case where raw materials and parts are carried into suppliers. In a case where an optimum rounding method of a milk run is calculated by the delivery plan device 10 of the present embodiment, it is possible to calculate a delivery plan by setting the same objective functions, constraint conditions, and the like as those in the above-described "case where delivery is performed using a truck", for example, when a factory or the like which is a supply destination of a product manufacturer is set to be a delivery base having a demand in car sharing and a factory or the like of a supplier of raw materials and parts is set to be a delivery base where there is a remaining vehicle. A constraint condition that "the total volume of delivery objects is equal to or less than an amount of loading on a truck" in the above-described case where delivery is performed using a truck is changed to a constraint condition that "(the weight of raw materials×the amount of raw materials+the weight of parts×the number of parts) is equal to or less than an amount of loading on a truck". In a case where a cargo collecting time frame of a certain supplier is designated, it is possible to deal with such a case by adding information on the designated cargo collecting time frame to constraint conditions. For example, in a case where the time of arrival at a certain supplier has to be set to 30 minutes later or less (from the start of cargo collection), it is possible to generate a cargo collecting plan satisfying a time frame constraint of the supplier by adding the following constraint condition.

Time of arrival at a certain supplier≥30 minutes later

[0075]

The process of generating a delivery plan by the delivery plan device 10 of the present embodiment has been described so far. According to the above-described method, the delivery plan device 10 can obtain a strict optimum solution in a delivery problem. However, it may be difficult to obtain a solution in a practical amount of time

only by the above-described method when the scale of a problem is increased (for example, 20 delivery bases and 20 vehicles to be delivered). Consequently, the first area division unit 14 divides delivery bases for respective delivery areas and divides given delivery problems into delivery problems for respective areas obtained by division. Next, an area division process (first area division process) performed by the first area division unit 14 will be described.

[0076]

Fig. 11 is a first diagram showing a first area division process in the first embodiment of the present invention.

The left drawing of Fig. 11 shows positions of delivery bases and departure bases which are present in an area which is a target for a delivery plan. In the drawing, a round point indicates a delivery base (w1 to w17), and a square point indicates a departure base (c1 to c3). There is a demand or surplus of a delivery object in the delivery bases w1 to w17, and there is a delivery vehicle or a delivery staff member in the departure bases c1 to c3. The first area division unit 14 generates a set of a certain delivery base (demand point) having a demand and a certain delivery base (supply point) having a surplus which are near and associated with each other, and generates one divided area by collecting one or a plurality of sets each of which is constituted by a demand point and a supply point. The generation of an area by the first area division unit 14 is called a first area division process.

[0077]

The right drawing of Fig. 11 shows results obtained by performing the first area division process by the first area division unit 14. The delivery bases w1 to w5 belong to an area j1, the delivery bases w6 to w9 belong to an area j2, and the delivery bases w10 to w17 belong to an area j3. The delivery plan generation unit 12 generates a

delivery plan for each of the area j1 to the area j3 after division by the above-described method. Each of the area j1 to the area j3 includes only less than 10 delivery bases and has a relatively small size. For this reason, the delivery plan generation unit 12 can generate a delivery plan in a practical amount of time using the above-described time space network model.

[0078]

Next, an outline of the first area division process will be described using Fig. 11. First, the first area division unit 14 divides the delivery bases w1 to w17 into demand points, supply points, and delivery bases which are neither demand points nor supply points. Next, the first area division unit 14 associates demand points and supply points with each other on a one-to-one basis. In this case, the first area division unit 14 associates a demand point and a supply point with each other, wherein the demand point and the supply point are separated from each other by a short distance (moving time). For example, in Fig. 11, there is one delivery object d1 left in the delivery base w4, and there is a shortage of one delivery object d1 in the delivery base w5. There is one delivery object d1 left in the delivery base w6, and there is a shortage of one delivery object d1 in the delivery base w7. It is assumed that there is one delivery object d2 left in the delivery base w8, and there is a shortage of one delivery object d2 in the delivery base w9. In this case, the first area division unit 14 associates delivery bases with each other, wherein the delivery bases have a demand and a supply consistent with each other and are separated from each other by a short distance. That is, the first area division unit 14 associates the delivery base w4 and the delivery base w5 with each other (assumed to be a set 1), associates the delivery base w6 and the delivery base w7 with each other (assumed to be a set 2), and associates the delivery base w8 and the delivery base w9 with each other (assumed to be a set 3). The first area division unit similarly

performs association on the other demand points and supply points.

[0079]

Next, the first area division unit 14 collects a plurality of sets each of which is constituted by a demand point and a supply point associated with each other and separated from each other by a short distance to generate one area. In this case, one set may be assumed to be one area in a case where there is no more set of a demand point and a supply point which are separated from each other by a short distance. For example, in a case of the above-described examples, the first area division unit 14 calculates a distance between the delivery base w4 of the set 1 and the delivery base w6 of the set 2. In addition, the set 1 and the set 2 are classified as the same area when the calculated distance is smaller than a predetermined threshold value, and the set 1 and the set 2 are determined to be different areas when the calculated distance is larger than the predetermined threshold value. Regarding calculation of a distance between sets, for example, in a case of a distance between the set 1 and the set 2, a distance between the delivery base w4 and the delivery base w7 may be calculated, or a distance between the delivery base w4 and the delivery base w6, a distance between the delivery base w4 and the delivery base w7, a distance between the delivery base w5 and the delivery base w6, and a distance between the delivery base w5 and the delivery base w7 are calculated, so that an average of the calculated distances may be set to be a distance between the set 1 and the set 2. Alternatively, the largest (or the smallest) distance among the calculated distances may be set to be a distance between the set 1 and the set 2. In a case of the example shown in Fig. 11, the first area division unit 14 classifies, for example, the set 2 and the set 3 as the same area j2 and classifies the set 1 as the area j1 different from the area j2. The first area division unit 14 performs the same processing on the other delivery bases, and classifies the delivery bases w1 to w17 for respective areas to

generate the area j1 to the area j3 shown in Fig. 11.

[0080]

When an area is generated through the first area division process, the delivery plan generation unit 12 may generate a delivery plan using the first time space network model or the second time space network model on a delivery problem having a supply quantity, a demand quantity, and the like of delivery objects in each delivery base within each area as initial conditions with respect to each of the area j1 to the area j3, but can use the association of a demand point and a supply point at the time of the first area division process as branch information even when the delivery plan generation unit does not perform calculation using a time space network model from a completely initial state. That is, the delivery plan generation unit 12 can generate branch information from the demand point to the supply point associated with the demand point and can generate a delivery plan satisfying all demands by connecting the pieces of branch information. However, it is severely limited only by a delivery route connecting delivery bases closest to each other, and there is a possibility that it will recede from an optimized state when seen from the whole delivery plan for moving between a plurality of bases. Consequently, the first area division unit 14 performs a process of adding a delivery route likely to be selected when the delivery plan generation unit 12 generates branch information. In addition, the delivery plan generation unit 12 selects a suitable delivery route from among all delivery routes serving as candidates obtained by adding the delivery route likely to be selected and added to the delivery route connecting delivery bases closest to each other and satisfying a demand and a supply to generate branch information and generates a delivery plan for each area.

In Fig. 11, description has been given on the assumption that a demand point and a supply point are delivery bases, but a demand point and a supply point may be a port

having a demand and a port having a supply, respectively.

[0081]

Next, a first area division process will be described in detail.

Fig. 12 is a second diagram showing the first area division process in the first embodiment of the present invention.

Hereinafter, an algorithm of the first area division process of the present embodiment will be described. The first area division unit 14 performs each process in the following procedure.

1. First, ports (delivery bases in a case of the first time space network model) of respective delivery bases are divided into supply points and demand points to generate a set A of supply points and a set B of demand points. The relation of $V_1=A\cup B$ is established.

2. Next, new points s and t are added to V_1 to establish the relation of $V=V_1\cup\{s,t\}$.

3. Delivery routes e_{11} to e_{19} are formed from A to B, and a cost function c(e) based on a moving time in a case where delivery is performed through a route indicated by each delivery route is defined for each delivery route.

4. Delivery routes from s to A and from B to t are formed, and costs thereof are set to 0. A set of the delivery routes from s to A and from B to t is set to E_2, and the union of E_1 and E_2 is set to be E.

5. A bipartite graph G=(V,E) is configured through the process described so far.

6. Minimum weight maximum matching of G, that is, a route from s to t having a minimum cost is calculated. More specifically, a delivery route in a case where the sum of costs of delivery routes connecting s, the supply points of the set A, the demand points of the set B, and t to each other is minimized is calculated under conditions that the

number of delivery routes coming out from the supply points included in the set A, among the routes from s to t, is 1 and the number of delivery routes entering the demand points included in the set B is 1 (main problem). From 4 described above, the costs from s to the supply points of the set A and the costs from the demand points of the set B to t are 0, and thus it is possible to obtain a method of associating a supply point a1 to a supply point a3 and a demand point b1 to a demand point b3 with each other in a case where the cost is minimized. Here, since the cost is a function based on a moving time, it is possible to obtain one-to-one matching between a supply point and a demand point which are closest to each other. In the example of Fig. 12, for example, a combination of the delivery route e_{11} connecting a1 and b1 to each other, the delivery route e_{16} connecting a2 and b3 to each other, and the delivery route e_{18} connecting a3 and b2 to each other is a delivery route for minimizing the sum of costs, and in this case, a1 and b1, a2 and b3, and a3 and b2 are associated with each other on one-to-one basis,

7. Next, all of the ports are divided into areas so that two ports associated with each other are included in the same area. In this case, the ports are classified as one area when a moving time between the two ports associated with each other is equal to or less than a predetermined value. In the example of Fig. 12, for example, among the associations of a1 and b1, a2 and b3, and a3 and b2, a set of a1 and b1 is classified as one area (j4), and a set of a2 and b3 and a set of a3 and b2 are classified as one area (j5).

[0082]

8. Next, the bipartite graph created through the procedure of 1 to 5 is created again to generate a dual problem of 6 (the dual problem can be generated through a mathematical operation). With respect to branch e=(u,v), when an optimum solution $X^*(e)$ of the main problem is 1, the relation of $c(e)-Y^*(u)-Y^*(v)=0$ (complementary slackness) is established in a case where an optimum solution of the dual problem is set

to Y. Here, c^(e) is defined by $\hat{c}(e)=c(e)-Y^{*}(u)-Y^{*}(v)$, and c^(e) is given a width under a condition of $0\leq\hat{c}(e)\leq\varepsilon$ (ε is a predetermined constant).

This condition means recognition as a candidate for a delivery route not only in a case of $\hat{c}(e)=0$ but also in a case where $\hat{c}(e)$ is equal to or less than ε. That is, the cost is minimized even in the main problem, and a solution with a width is also obtained. In the example of Fig. 12, for example, a candidate e_{19} of the delivery route connecting a1 and b1 to each other is newly obtained by relaxation of the condition of the solution.

[0083]

Thus, the first area division process is completed. When the first area division process is completed, the delivery plan generation unit 12 generates a delivery plan for each area after division. In this case, the delivery plan generation unit 12 generates a delivery plan satisfying a condition by using a candidate of a delivery route obtained through the first area division process. Specifically, a set of pieces of branch information is calculated by adding using the candidates (e_{11}, e_{16}, e_{18}, e_{19}) for delivery routes obtained through the first area division process to constraint conditions, in addition to the above-described "1. Flow rate conservation law" to "6. Constraints on branch staying in delivery base".

[0084]

Next, a flow of a delivery plan generation process of the present embodiment will be described.

Fig. 13 is a flowchart showing an example of a delivery plan generation process in the first embodiment of the present invention.

First, a delivery staff member performing a delivery plan inputs initial conditions of a delivery plan to the delivery plan device 10. The input and output unit 13 receives the input and outputs the received information to the initial conditions setting

unit 11. The initial conditions setting unit 11 acquires information regarding the initial conditions input by the delivery staff member (step S11). The initial conditions setting unit 11 sets the acquired information regarding the initial conditions to be initial conditions of the delivery plan. The initial conditions include, for example, a supply quantity of delivery objects (the number of remaining delivery objects) in each base, a demand quantity (a shortage quantity), the number of delivery vehicles in a departure base, the number of delivery staff members, a moving time between bases, a delivery deadline, and the like.

Next, the first area division unit 14 performs the first area division process using a supply quantity and a demand quantity of delivery objects in each delivery base (or a port) included in information of initial conditions (step S12). The first area division process is as described using Figs. 11 and 12.

[0085]

Next, the delivery plan generation unit 12 generates branch information so as to satisfy the above-described constraint conditions on the time space network models illustrated in Figs. 3 and 8 for each area obtained through the first area division process and generates a plurality of sets of pieces of branch information satisfying conditions such as a delivery time limit (step S13). Specifically, the delivery plan generation unit 12 adds information such as the number of delivery objects, the number of delivery vehicles, and the number of delivery staff members for the candidates of the delivery routes which are obtained through the first area division process to generate branch information satisfying constraint conditions ("1. Flow rate conservation law" to "6. Constraints on branch staying in delivery base"). The delivery plan generation unit 12 combines the generated pieces of branch information to generate a plurality of sets of pieces of branch information indicating delivery satisfying the number of demanded

deliver objects of each base until a delivery time limit.

[0086]

Next, the delivery plan generation unit 12 calculates the total cost for each of the generated sets of branch information for each area (step S14). For example, a unit cost generated per unit time for each of delivery vehicles, delivery staff members, and delivery objects is recorded in the storage unit 15 in advance, and the delivery plan generation unit 12 calculates costs (the sum of costs required for the delivery vehicles, the delivery staff members, and the delivery objects) for each branch by multiplying unit costs of the delivery vehicles, the delivery staff members, and the delivery objects by a time indicated by each branch. The delivery plan generation unit 12 calculates and adds up costs for each branch included in the sets of branch information. The added-up costs are costs for one set of branch information. The delivery plan generation unit 12 calculates the costs for each of all of the sets of branch information for each area.

[0087]

Next, the delivery plan generation unit 12 compares costs calculated for the calculated sets with each other for each area and selects a set of pieces of branch information for minimizing the total cost (step S15). The selected set of pieces of branch information represents movement of delivery objects, delivery means, and delivery staff members with the elapse of time from the state of a departure base and delivery bases indicated by the initial conditions (Figs. 3 and 8). Therefore, when delivery is executed on the basis of the set of pieces of branch information, delivery corresponding to a user's demand can be performed. That is, the set of pieces of branch information is a delivery plan to be obtained for one area after division. When the delivery plan generation unit 12 terminates the generation of a delivery plan for each area, delivery plans for all delivery bases which are given as initial conditions are

generated.

[0088]

According to the present embodiment, all of the delivery bases given under the initial conditions are divided into sets (areas) of delivery bases within a short distance, and thus it is possible to reduce the scale of a delivery problem and to reduce the amount of calculation of a delivery plan generation process in each area. Branch information is generated by calculating candidates for delivery routes when area division is performed and selecting a delivery route from among the candidates, and thus it is possible to further reduce the amount of calculation. Thereby, even when the number of delivery objects and the number of delivery bases are large and the scale of a delivery problem is increased, it is possible to generate a delivery plan in a practical amount of time (for example, 10 minutes).

The delivery plan generation unit 12 may generate branch information without using candidates for delivery routes in step S13 and may generate a delivery plan.

An area may be reconfigured by adding the cost of a delivery plan of the area. For example, it may be possible to reduce the overall cost by increasing an area where delivery is completed early and reducing an area where delivery is completely late for a pair of areas where delivery costs are significantly different from each other.

[0089]

<Second embodiment>

Next, a delivery plan system according to another method of generating a delivery plan in a practical amount of time with respect to a large-scale delivery problem (second embodiment) will be described with reference to Figs. 14 to 18. In the first embodiment, a small-size area is generated by collecting a demand point and a supply point which are paired, focusing on demand points and supply points which are present

in a relatively short distance. In the second embodiment, an area division process is performed centering on a departure base, and a delivery plan is generated within each area after division. An area division process in the second embodiment is called a second area division process.

[0090]

Fig. 14 is a functional block diagram showing an example of a delivery plan system in the second embodiment of the present invention.

Among components according to the second embodiment of the present invention, the same components as the functional units constituting the delivery plan device 10 according to the first embodiment of the present invention are denoted by the same reference numerals, and description thereof will be omitted. A delivery plan device 10A according to the second embodiment includes a second area division unit 16 instead of the first area division unit 14 in the configuration of the first embodiment.

The second area division unit 16 acquires a plurality of pieces of unit route information indicating a preset delivery route including departing from a departure base, performing delivery between some delivery bases, and returning to the original departure base and the cost when delivery is performed through the delivery route. The second area division unit 16 selects a combination in which the number of delivery bases included in the combination is equal to or less than a predetermined number and costs are minimized, from among combinations of the plurality of pieces of unit route information. A set of a departure base and a delivery base included in the combination of the pieces of unit route information is an area after division.

The second area division unit 16 is realized by reading out and executing a program from a storage unit 15 using a CPU included in the delivery plan device 10A.

[0091]

Fig. 15 is a first diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

In Fig. 15, round points indicate a delivery base w1 to a delivery base w17, and square points indicate a departure base c1 to a departure base c3. In the present embodiment, first, all conceivable patterns of a demand and a supply are listed, and a large number of simple delivery routes satisfying a demand and a supply of each pattern are created for each departure base. Here, the departure base c1 to the departure base c3 include a sufficient amount of delivery vehicles (trucks) and delivery staff members, and it is assumed that the delivery bases w1, w3, w6, w8, and w10 are supply points and the delivery bases w2, w5, w7, w9, and w11 are demand points. It is assumed that the types of delivery objects related to delivery are the same. In this case, the simple delivery route satisfying a demand and a supply for each departure base is, for example, a delivery route (referred to as a delivery route 1) including departing from the departure base c1, arriving at the delivery base w1 (R1), taking a delivery object at the delivery base w1, transporting the delivery object to the delivery base w2 (R2), and returning to the departure base c1 (R3) after delivery is terminated. Similarly, simple delivery routes include a route (referred to as a delivery route 2) including departing from the departure base c1 and returning to the departure base c1 through the delivery base w3 and the delivery base w5, a delivery route (referred to as a delivery route 3) including departing from the departure base c1 and returning to the departure base c1 through the delivery base w6 and the delivery base w7, a delivery route (referred to as a delivery route 4) including departing from the departure base c2 and returning to the departure base c2 through the delivery base w8 and the delivery base w9 (referred to as a delivery route 4), a delivery route (referred to as a delivery route 5) including departing from the departure base c3 and returning to the departure base c3 through the delivery base w10 and the

delivery base w11, and the like. A large number of such simple routes are created in advance and recorded in the storage unit 15. Although not shown in the drawing, for example, the following routes are also created and recorded in the storage unit 15 in advance. Simple delivery routes include a delivery route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w1 and the delivery base w5, a delivery route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w1 and the delivery base w7, a delivery route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w3 and the delivery base w2, a delivery route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w10 and the delivery base w11, a delivery route including departing from the departure base c2 and returning to the departure base c2 through the delivery base w1 and the delivery base w2, a delivery route including departing from the departure base c3 and returning to the departure base c3 through the delivery base w1 and the delivery base w2, and the like.

[0092]

A simple delivery route may not indicate only a delivery route including returning to the original departure base through one supply point and one demand point (a route including rounding between two delivery bases and returning to the original departure base) but indicate a delivery route including departing from the departure base c1, taking two delivery objects at the delivery base w1, delivering one delivery objects to each of the delivery base w2 and the delivery base w4, and returning to the departure base c1 (an example in which the number of delivery bases is three). Alternatively, a simple delivery route may be a delivery route including departing from the departure base c1, taking one delivery object at the delivery base w1, delivering the delivery object

to the delivery base w2, taking one delivery object at the delivery base w3, delivering the delivery object to the delivery base w4, and returning to the departure base c1 (an example in which the number of delivery bases is four).

[0093]

Fig. 16 is a second diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

As shown in Fig. 16, a plurality of simple delivery routes prepared in advance are recorded in the storage unit 15. The cost in a case where delivery is performed through a simple delivery route is recorded in association with the simple delivery route. The cost is given as, for example, a function of a moving time. As the number of pieces of information on the simple delivery route and the cost which are recorded in advance increases, a delivery plan with higher accuracy (closer to a strict optimum solution) can be generated. Information including the simple delivery routes and the costs corresponding to the delivery routes which are illustrated in Fig. 16 is called unit route information.

[0094]

Fig. 17 is a third diagram showing a second area division process of a delivery problem in the second embodiment of the present invention.

Next, a second area division process performed by the second area division unit 16 will be described using Figs. 15 to 17.

As a premise, the unit route information illustrated in Fig. 16 is recorded in the storage unit 15. It is assumed that initial conditions of requirements related to delivery (a demand quantity and a supply quantity for each delivery base, the number of delivery vehicles at departure bases, the number of delivery staff members, and the like) are given.

1. First, the second area division unit 16 reads out unit route information including a delivery route satisfying some of delivery requests (demands) given under initial conditions from the storage unit 15.

2. Next, the second area division unit 16 combines delivery routes included in the read-out unit route information to create a route satisfying all delivery requests and sets the created route to be a provisional solution. Here, a mathematical method called set division approach is used as a method of combining simple delivery routes recorded in advance to obtain a combination satisfying all requests and minimizing the cost. However, in this method, when the number of simple delivery routes becomes huge, an optimization problem of the combination may not be solved in a practical amount of time. For this reason, the second area division unit 16 generates an initial solution using a small number of delivery routes among a large number of simple delivery routes stored in the storage unit 15 and obtains an optimum solution while adding a simple delivery route by using a mathematical method called a column generation technique. A small number of simple delivery routes for generating the initial solution may be selected by any method. A generally provided solver can be used for the generation of the initial solution. In this case, a constraint (for example, six bases or less including a demand point and a supply point, or the like) is provided for the number of delivery bases handled by one departure base. Here, providing a constraint (upper limit) for the number of delivery bases is to reduce the amount of calculation and speed up processing. Regarding the constrained number of delivery bases, for example, the number of delivery bases in a case where calculation is actually performed and a solution is obtained within a practical amount of time may be determined as an upper limit. As the initial solution, for example, the solutions shown in Fig. 15 (the delivery route 1 to the delivery route 5) are obtained.

[0095０００２]

3. Next, the second area division unit 16 selects one or a plurality of delivery routes from among unselected simple delivery routes by a column generation technique (a known mathematical method), and calculates reduced cost in a case where a certain simple delivery route having already been selected and the selected simple delivery route are replaced with each other. The reduced cost is a value obtained by subtracting the sum of costs recorded in association with the original simple delivery route selected before replacement from the sum of the costs (the cost column in Fig. 16) which are recorded in association with a simple delivery route newly selected as a solution by the replacement.

[0096]

4. When the reduced cost calculated in 3 is a negative value (lower after replacement is performed), the second area division unit 16 updates some of all of the existing delivery routes by the simple delivery route selected in 3. For example, regarding delivery to the delivery base w7, the delivery route 3 is selected in the initial solution shown in Fig. 15, but the second area division unit 16 calculates reduced cost when the delivery route 3 is replaced with a route (referred to as a delivery route 6) including departing from the departure base c2 and returning to the departure base c2 through the delivery base w6 and the delivery base w7. From Fig. 16, the cost of the delivery route 3 is 2500 and the cost of the delivery route 6 is 1500, and thus reduced cost is -1000. Therefore, the second area division unit 16 updates the delivery route 3 to the delivery route 6. Combinations of simple delivery routes after updating are shown in Fig. 17. Also in a case where reduced cost is calculated, the second area division unit 16 selects a delivery route so that the number of bases handled by one departure base falls within a constraint.

[0097]

In this example, an example in which a simple delivery route is shifted from a handling range of the departure base c1 to a handling range of the departure base c3 is described, but the updating of a delivery route is not limited to this example. For example, in the state shown in Fig. 15, a method of updating a combination of the delivery route 1 and the delivery route 2 within a route handled by the departure base c1 to a combination of a route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w3 and the delivery base w2 and a route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w1 and the delivery base w5 may be used. Alternatively, a method of assuming that there are two target delivery objects in the delivery base w1 and updating a combination of the delivery route 1 and the delivery route 2 to a delivery route including departing from the departure base c1 and returning to the departure base c1 through the delivery base w1, the delivery base w2, the delivery base w3, and the delivery base w5 may be used.

[0098]

5. The second area division unit 16 repeats the processes of 3 to 4 and terminates the second area division process at a point in time when there is no more route capable of reducing the cost. When the second area division process is terminated, a delivery base within constraint conditions (for example, six bases) is associated with each departure base. A plurality of sets (for example, an area j6 to an area j8) of delivery bases and departure bases associated with each other are areas obtained through the second area division process.

[0099]

Next, a flow of a delivery plan generation process of the present embodiment

will be described.

Fig. 18 is a flowchart showing an example of a delivery plan generation process in the second embodiment of the present invention. The same processes as those in Fig. 13 will be simply described.

First, the initial conditions setting unit 11 acquires information on initial conditions in which delivery staff members and the like are input (step S11).

Next, the second area division unit 16 performs the second area division process using a supply quantity and a demand quantity of delivery objects at each base, the number of delivery staff members at a departure base, and the types and number of delivery vehicles which are included in the information on initial conditions (step S121). The second area division process is as described using Figs. 15 to 17.

[0100]

Next, the delivery plan generation unit 12 generates branch information so as to satisfy the above-described constraint conditions on the time space network models illustrated in Figs. 3 and 8 for each area (a departure base obtained through the second area division process and a set of a plurality of delivery bases associated with the departure base) which is obtained through the second area division process, and generates a plurality of sets of pieces of branch information satisfying conditions such as a delivery time limit (step S131). In the example of Fig. 17, the delivery plan generation unit 12 generates a plurality of sets of pieces of branch information for each of the area j6 to the area j8. The delivery plan generation unit 12 may generate branch information regardless of simple delivery routes using the second area division process and a combination thereof or may generate branch information using simple delivery routes and a combination thereof.

[0101]

Next, the delivery plan generation unit 12 calculates the total cost for each set of the generated branch information (step S14). In the example of Fig. 17, the delivery plan generation unit 12 calculates the total cost for each set of the generated branch information for each of the area j6 to the area j8.

Next, the delivery plan generation unit 12 compares the calculated total costs with each other and selects a set of pieces of branch information for minimizing the total cost (step S15). In the example of Fig. 17, the delivery plan generation unit 12 selects a set of pieces of branch information for minimizing the total cost for each of the area j6 to the area j8.

The selected set of pieces of branch information indicates a delivery plan in each area. That is, when the delivery plan generation unit 12 terminates the generation of a delivery plan for each area, delivery plans for all delivery bases before division are generated.

[0102]

According to the present embodiment, it is possible to perform division into delivery areas for each departure base by associating each of all delivery bases having a demand and a supply given under initial conditions with a departure base. It is possible to reduce the amount of calculation required for the generation of a delivery plan, as compared to a case where a delivery plan is generated for all delivery bases having a demand which are given under initial conditions by performing division into small-size delivery areas and performing a delivery plan generation process for each delivery area. Thereby, it is possible to make a delivery plan in a practical amount of time (for example, 10 minutes) even in a case where the number of delivery objects and the number of delivery bases are large and the scale of a delivery problem is increased.

[0103]

<Third embodiment>

Further, a delivery plan system according to another method (third embodiment) of generating a delivery plan in a practical amount of time with respect to a large-scale delivery problem will be described with reference to Figs. 19 to 22. The first embodiment and the second embodiment relate to a method of realizing speeding-up of processing by spatially dividing (area division) delivery problems into small-size delivery problems on the basis of information on a demand and a supply for each delivery base included in initial conditions and solving a small-scale delivery problem. In the third embodiment, the scale of a delivery problem is reduced through temporal division on the basis of information on a delivery time limit of delivery objects included in initial conditions, and a delivery plan is generated for each time after division.

[0104]

Fig. 19 is a functional block diagram showing an example of a delivery plan system in the third embodiment of the present invention.

Among components according to the third embodiment of the present invention, the same components as the functional units constituting the delivery plan device 10B according to the first embodiment of the present invention are denoted by the same reference numerals, and description thereof will be omitted. The delivery plan device 10B according to the third embodiment includes a time division unit 17 instead of the first area division unit 14 in the configuration of the first embodiment. The delivery plan device 10B includes a delivery plan generation unit 12a instead of the delivery plan generation unit 12.

The time division unit 17 divides a delivery time limit given under initial conditions into a plurality of times to perform division into a small-scale delivery problem for each time obtained by dividing a delivery problem. Each time obtained by

the division performed by the time division unit 17 is called a section.

The delivery plan generation unit 12a generates a delivery plan by solving a delivery problem for which a different objective function and constraint are set, in accordance with the section obtained by the division performed by the time division unit 17. For example, the delivery plan generation unit 12a starts delivery from a delivery situation (a progress situation of delivery when the immediately previous section is terminated) of delivery objects at a first time of each section after division to generate a delivery plan in which delivery objects are delivered to a delivery base having as many demands as possible within the section. With respect to the last section among the sections obtained by division, the time division unit 17 generates a delivery plan for delivering delivery objects to all of the delivery bases which are non-delivery bases among delivery bases having demands indicated by initial conditions within the last section.

The time division unit 17 and the delivery plan generation unit 12a are realized by reading out and executing a program from the storage unit 15 using a CPU included in the delivery plan device 10B.

[0105]

Fig. 20 is a first diagram showing a time division process of a delivery problem in the third embodiment of the present invention.

The left drawing of Fig. 20 shows the initial state of a certain delivery problem. There are two delivery objects d1 left in the delivery base w1, and there are three delivery objects d1 left in the delivery base w2. There is a shortage of four delivery objects d1 in the delivery base w3, and there is a shortage of one delivery object d1 in the delivery base w4. A problem that the delivery object d1 is delivered from the initial state so as to satisfy demands in the delivery base w3 and the delivery base w4 within

120 minutes is conceived. In the first embodiment and the second embodiment, the delivery base w1 to the delivery base w4 are divided for each area. In the present embodiment, a delivery time limit of 120 minutes given as initial conditions is divided.

Specifically, the time division unit 17 divides a delivery time limit of 120 minutes into a plurality of times (sections). For example, the time division unit 17 divides the delivery time limit of 120 minutes into two 60-minute sections, i.e., 60 minutes in the first half and 60 minutes in the second half. The length of a period of time in one section and the number of sections obtained by the division performed by the time division unit 17 may be arbitrary. For example, the time division unit 17 may divide 120 minutes into 90 minutes and 30 minutes or may classify 120 minutes into three sections for every 40 minutes. The time division unit 17 may set a time shorter than the delivery time limit given under the initial conditions by a predetermined time as a first section after division and sets the remaining times as the last section.

[0106]

The right drawing of Fig. 20 shows that the time division unit 17 divides a delivery time limit of 120 minutes into two sections each of which corresponds to 60 minutes. When the time division unit 17 divides the delivery time limit, the delivery plan generation unit 12a generates a delivery plan for the first section obtained by the division. In this case, the delivery plan generation unit 12a generates a delivery plan satisfying as many requests as possible at the time of termination of the first section instead of aiming to satisfy all requests. In a case of this example, aiming to satisfy all requests is delivering the delivery object d1 in 60 minutes so as to satisfy demand quantities of the delivery base w3 and the delivery base w4. For example, in a case where it is possible to generate a delivery plan in which there is a shortage of three delivery objects d1 in the delivery base w3 and there is no shortage of the delivery object

d1 in the delivery base w4 after 60 minutes from the start of delivery and a delivery plan in which there is a shortage of two delivery objects d1 in the delivery base w3 and there is no shortage of the delivery object d1 in the delivery base w4, the delivery plan satisfying as many requests as possible refers to the latter delivery plan.

[0107]

Next, an objective function and constraints which are set for the first section will be described. More generally, an objective function and the like to be described below are an objective function and the like which are used for all sections (the first section to an N-first section in order along the flow of time) except for the last section (N-th section) in a case where the time division unit 17 divides a delivery time limit into N parts.

[0108]

(Objective function)

The sum of the following (1) to (7) is minimized.

(1) The cost of movement between bases

It is possible to curb the cost of movement between bases.

(2) A time satisfying a demand and a supply

Options of a solution are reduced by prompting advancement of a time satisfying a demand and a supply as soon as possible (it is possible to reduce options by setting only the first delivery as a solution even in a case where the same delivery can be performed at a later time, which leads to a reduction in the amount of calculation).

(3) The number of a port in which a supply is performed in a case where a demand is satisfied

Options of a solution are reduced by prompting the execution of a supply from a port with a smaller number (it is possible to reduce options of a solution and the amount

of calculation by determining a port with the smallest number even in a case where there is no problem even when delivery to a port with the largest number is performed).

(4) Among persons and delivery means in a delivery base, the number of unused persons and delivery means in a later section (g[w])

At the last time in a section where calculation is being performed, the remaining persons and delivery means which are not used for delivery of delivery objects in the next section are prompted to be moved to a departure base. For example, at the last time in the first section, in a case where there is no more delivery means capable of loading and moving a bicycle, a bicycle is not used for delivery in the second section and is thus moved to the departure base.

(5) The number of persons and delivery means present in delivery bases of a demand point and a supply point in a case where the demand in the demand point and the supply in the supply point are satisfied.

In a delivery base in which a demand and a supply are satisfied, it is prompted that there is no persons and delivery means left. In the present embodiment, a delivery plan is independently calculated for each of sections for which time division is performed (although transfer of a delivery situation in the immediately previous section is performed), it is also conceivable that the remaining delivery staff members and delivery means that are not used in a later section are left in a delivery base. Consequently, the remaining delivery staff members and the like are not left in the delivery base by adding (4) and (5).

(6) The number of delivery objects remaining at a supply point, the number of delivery objects insufficient at a demand point

(7) The number of demand points where delivery objects are insufficient

It can be prompted that as many demand and supply conditions as possible are

satisfied at the last time of the section by (6) and (7).

An objective function is represented by minimization of the sum of functions corresponding to contents of the items (1) to (7), but weighting may be performed by multiplying each term (a function of each item) of the objective function by any coefficient.

[0109]

Next, constraints will be described.

1. Flow rate conservation law

(A) A case of sections other than the last section among sections after division

(1) With regard to a flow rate of delivery objects

At the start of a section, an outgoing flow rate from a port having a supply is 1 and an outgoing flow rate from a port not having a supply is 0. In the other points, an outgoing flow rate and an incoming flow rate are equal to each other in a case of not being the time of termination of a section.

(2) With regard to a flow rate of delivery vehicles

At the start of a section, an outgoing flow rate from a road is the number of delivery vehicles present at a corresponding base. In the other points, an outgoing flow rate and an incoming flow rate are equal to each other in a case of not being the time of termination of a section.

(3) With regard to a flow rate of delivery staff members

At the time of start of a section, an outgoing flow rate from a road is the number of delivery staff members present at a corresponding base. In the other points, an outgoing flow rate and an incoming flow rate are equal to each other in a case of not being the time of termination of a section.

[0110]

(B) A case of the last section among sections after division

(1) With regard to a flow rate of delivery objects

At the time of start of a section, an outgoing flow rate from a port having a supply is 1 and an outgoing flow rate from a port not having a supply is 0. At the time of termination of a section, an incoming flow rate into a port having a demand is 1 and an incoming flow rate into a port not having a demand is 0. In the other points, an out-going flow rate and an incoming flow rate are equal to each other.

(2) With regard to a flow rate of delivery vehicles

At the start of delivery of a section, an outgoing flow rate from a road is the number of delivery vehicles present at a corresponding base. At the time of termination of a section, an incoming flow rate from the road is the number of delivery vehicles having a demand at a corresponding base. In the other points, an out-going flow rate and an incoming flow rate are equal to each other.

(3) With regard to a flow rate of delivery staff members

At the start of delivery of a section, an outgoing flow rate from a road is the number of delivery staff members present at a corresponding base. At the time of termination of a section, an incoming flow rate from the road is the number of delivery staff members having a demand at a corresponding base. In the other points, an out-going flow rate and an incoming flow rate are equal to each other.

[0111]

2. Capacity constraint

The amount of movement of delivery objects and persons within a delivery base is equal to or less than 1.

[0112]

3. Constraint 1 within delivery base

$\forall e \in E_{wp}$

(E_{wp} is a set of a delivery object, delivery means, and a branch indicating movement of a person from a road to a port)

(1) When a destination of e is a supply point of d,

delivery objects do not enter a port from a road.

(2) When a destination of e is a demand point of d,

a flow rate of delivery objects and a flow rate of delivery staff members have the same value (0 or 1).

(3) In either case,

the number of bicycles is equal to or less than the number of delivery staff members.

[0113]

4. Constraint 2 within delivery base

$\forall e \in E_{pw}$

(E_{pw} is a set of a delivery object, delivery means, and a branch indicating movement of a person from a port to a road)

(1) When a departure point of e is a supply point of d,

a flow rate of delivery objects and a flow rate of delivery staff members have the same value (0 or 1).

(2) When a departure point of e is a demand point of d,

delivery objects do not come out on a road from a port.

(3) In either case,

the number of bicycles is equal to or less than the number of delivery staff members.

[0114]

5. Constraints on variables related to penalty at last time of section

With respect to any road w, when the number of persons and delivery means which are not used in the next section is set to be g[w], a constraint of g[w]≤f[w] is input.

Here, f[w] represents any number. It is possible to change the number of persons and delivery means allowable to remain in the last section by adjusting the value of f[w].

[0115]

6. Constraints on branch from road to road

(1) When a branch from a road to a road is a branch of a vehicle (there is a likelihood that the bicycle is loaded),

constraints are as follows: a delivery staff member necessarily boards a delivery vehicle; the number of delivery staff members is equal to or less than the number of persons able to board; and the number of bicycles not capable of being driven is equal to or less than the number of bicycles loadable on the vehicle.

(2) When a branch from a road to a road is a branch of a bicycle and a branch of walking but is not a branch of a vehicle (movement by the bicycle or on foot),

the sum of the number of bicycles and the number of persons movable on foot is equal to the number of delivery staff members moving through the branch.

(3) When a branch from a road to a road is a branch of a bicycle but is not a branch of a vehicle and a branch of walking (movement by the bicycle),

the number of bicycles and the number of delivery staff members moving through the branch are equal to each other.

(4) When a branch from a road to a road is a branch of walking but is not a branch of a vehicle and a branch of a bicycle (movement on foot),

the number of persons moving on foot and the number of delivery staff members

moving through the branch are equal to each other.

[0116]

7. Constraints on branch staying in delivery base

Constraints are as follows: a person necessarily boards a vehicle; bicycles cannot be parked on a street; and the total volume of delivery objects is equal to or less than an amount of loading on a truck.

[0117]

The delivery plan generation unit 12a solves a delivery problem (integer programming problem) formulated under these objective functions and constraint conditions using a first or second time space network. In the actual calculation, a further increase in speed may be further achieved by adding a cut. In the right drawing of Fig. 20, an example of results obtained by generating a delivery plan for a first section by the delivery plan generation unit 12a is shown. According to this plan, it can be understood that there is one delivery object d1 left in each of the delivery base w1 and the delivery base w2, there is a shortage of two delivery objects d1 in the delivery base w3, and the shortage of the delivery object d1 is canceled in the delivery base w4 after 60 minutes from the start of delivery.

[0118]

The following points can be described as advantages of a method of dividing a time and performing calculation. First, it is possible to reduce the number of parameters necessary for calculation and to reduce the amount of calculation by changing a delivery time limit from 120 minutes to 60 minutes. In Fig. 20, for convenience of description, an example in which both the number of delivery bases and the number of delivery objects are small is shown. However, in a case where a problem that 20 or more delivery objects are delivered to 20 delivery bases within 120 minutes is calculated, it is

understood that, for example, there are 41000 variables and 61000 constraints. On the other hand, in a case where a time is partitioned into 60 minutes in the first half and the above-described delivery plan satisfying as many request as possible is generated, for example, it is possible to curb the number of variables and the number of constraints to approximately 14000 and 18000, respectively. It is possible to reduce the amount of calculation by reducing the number of parameters in this manner and to speed up processing. Next, a delivery plan generation process of 60 minutes in the second half will be described.

[0119]

Fig. 21 is a second diagram showing a time division process of a delivery problem in the third embodiment of the present invention.

Fig. 21 shows a delivery plan generation process performed using 60 minutes in the second half after division. A demand quantity and a supply quantity in each delivery base at the beginning of the 60 minutes in the second half will be described. There is one delivery object d1 left in each of the delivery base w1 and delivery base w2 at the start of the 60 minutes in the second half, and there is a shortage of two delivery objects d1 in the delivery base w3. A delivery plan which has to be generated by the delivery plan generation unit 12a using 60 minutes in the second half is a problem that the delivery objects d1 in the delivery base w1 and the delivery base w2 are delivered so as to satisfy a demand in the delivery base w3 within the remaining 60 minutes. Regarding the delivery base w4, the shortage of the delivery base w4 is canceled in 60 minutes in the first half, and thus the delivery base w4 is not included in a delivery problem in the second half.

[0120]

Next, an objective function and constraints which are set for a delivery problem

with respect to the last section in a case where a delivery time limit is divided into N parts will be described. The objective function, the constraints, and the like in this case are the same as those described using the first time space network model (Fig. 3) and the second time space network model (Fig. 8). That is, the delivery plan generation unit 12a generates a delivery plan for minimizing costs and a moving time required for delivery at most among delivery plans capable of terminating the delivery of delivery objects so as to satisfy all demands until the last time in the last section.

[0121]

Advantages of processing for 60 minutes in the second half (the last section) are as follows. First, similarly to 60 minutes in the first half, it is possible to reduce the number of parameters by setting a delivery time limit to 60 minutes and to achieve speeding-up of processing by reducing the amount of calculation. Further, the remaining demands are reduced due to a delivery plan satisfying as many requests as possible calculated in each section until reaching the last section, and thus a reduction in the scale of a delivery problem that has to be solved can be described as one of the advantages. For example, in the examples shown in Figs. 20 and 21, not only a demand quantity at each demand point is reduced but also a demand in the delivery base w4 is satisfied, so that the number of delivery bases is successfully reduced. Thereby, it is possible to further reduce the scale of the delivery problem. In a case where a problem that 20 delivery objects or more are delivered to 20 delivery bases within 120 minutes is divided for every 60 minutes, for example, the number of variables and the number of constraints can be reduced to approximately 8000 and 12000, respectively, in the section of 60 minutes in the second half. In this manner, according to the present embodiment, it is possible to reduce the scale of a delivery problem in the latter section by a reduction in the number of parameters due to the division of a time and a delivery plan generated in

a temporally preceding section, and thus it is possible to speed up the delivery plan generation process. In the third embodiment, area division is not performed, and thus it is possible to generate a delivery plan while securing a large-scale delivery base distribution and to generate a more optimized delivery plan, as compared to the first embodiment and the second embodiment.

[0122]

Next, a flow of a delivery plan generation process of the present embodiment will be described.

Fig. 22 is a flowchart showing an example of a delivery plan generation process in the third embodiment of the present invention. The same processes as those in Figs. 13 and 18 will be simply described.

First, a delivery staff member performing a delivery plan inputs initial conditions of the delivery plan to the delivery plan device 10B. The input and output unit 13 receives the input and outputs the received information to the initial conditions setting unit 11. The initial conditions setting unit 11 acquires information on the initial conditions input by the delivery staff member (step S11).

Next, the time division unit 17 performs a time division process using a delivery time limit included in the information on the initial conditions (step S122). The time division process is as described using Fig. 20. For example, the time division unit 17 divides the delivery time limit of the initial conditions into two or three parts. Alternatively, in a case where a time (for example, 75 minutes) when the completion of delivery to a delivery base having a demand can be expected at a fixed ratio by the rule of thumb or the like is known, the time division unit 17 may divide the original delivery time limit in the time unit (for example, 75 minutes) and may set the remaining time as the last section by a user's setting. Alternatively, the time division unit 17 may set a

time shorter than the delivery time limit given under the initial conditions by a predetermined time as a first section after division and may set the remaining times as the last section. Next, the delivery plan generation unit 12a generates a delivery plan for each section obtained by division in time order. First, the delivery plan generation unit 12a sets 1 for a counter variable n (step S123). Next, the delivery plan generation unit 12a sets a delivery problem for an n-th section (step S124). For example, in a case of the first section, the delivery plan generation unit 12a formulates an integer programming problem according to an objective function and constraint condition for generating a delivery plan that satisfies as many requests as possible and minimizes costs by using a demand quantity and a supply quantity of each delivery base, the number of delivery means present in a departure base, the number of delivery staff members, and a time of the first section, which are included in the information on the initial conditions, for a delivery time limit.

[0123]

Next, the delivery plan generation unit 12a generates a plurality of sets of pieces of branch information satisfying a demand of each delivery base as much as possible while satisfying constraints by using the first or second time space network model illustrated in Figs. 3 and 8 with respect to the formulated integer programming problem (step S132). Next, the delivery plan generation unit 12a calculates the total cost for each of the generated sets of pieces of branch information (step S14). Next, the delivery plan generation unit 12a compares the calculated total costs with each other and selects a set of pieces of branch information for minimizing the total cost (step S15). Thereby, a delivery plan for an n-th section (first section this time) is generated.

[0124]

Next, the delivery plan generation unit 12a determines whether or not n is equal

to N (step S16). In a case where n is equal to N (step S16; Yes), delivery plans for all sections after division are generated, and thus the delivery plan generation process is terminated. In a case where n is not equal to N (step S16; No), the delivery plan generation unit 12a adds 1 to n (step S17) and repeats the processes from step S124.

[0125]

Specifically, for example, in a case where the value of n to which 1 is added is 2, the delivery plan generation unit 12a formulates an integer programming problem by using a demand quantity and a supply quantity of each delivery base, the number of delivery means present in a departure base, the number of delivery staff members, and a time of the second section, which are results obtained by executing the delivery plan generated for the first section, for a delivery time limit in step S124. In this case, when n is equal to N, the delivery plan generation unit 12a formulates an integer programming problem according to an objective function and constraints for generating a delivery plan satisfying all request (the same objective function and the like as those in the first embodiment and the second embodiment). In a case where n is not equal to N, the delivery plan generation unit 12a formulates an integer programming problem according to an objective function and constraints for generating a delivery plan satisfying any many requests as possible. The delivery plan generation unit 12a generates a delivery plan for an n-th section by solving the integer programming problem. The delivery plan generation unit 12a repeats the processes of steps S124 to S17 until delivery plans for all sections are generated (until n becomes equal to N). All of the delivery plans generated in order for the first to N-th (last) sections are delivery plans satisfying requests given under the initial conditions.

[0126]

In the flowchart of Fig. 22, a delivery time limit which is first given under the

initial conditions is divided into some sections, but delivery plan processing may be configured as follows, for example.

1. First, a section (first delivery time limit) shorter than the delivery time limit given under the initial conditions is set, and a delivery plan capable of delivering as many delivery objects as possible at low costs is generated within the section.

2. Next, with regard to delivery objects of which the delivery cannot be terminated within the first delivery time limit, a section having a predetermined length (second delivery time limit) subsequent to the first delivery time limit is set, and a delivery plan capable of delivering as many delivery objects as possible is generated within the set section.

3. The steps of 1 and 2 are repeated while the sum of lengths of sections from the start of delivery does not exceed a delivery time limit. That is, a solution is found while extending a time (time expansion method). The length of the first section or an extended section may be arbitrarily set depending on delivery situations.

4. In a case where the sum of times from the start of delivery is about to exceed a delivery time limit, the next section is set as the last section, and a delivery plan satisfying all demands and minimizing costs is generated within the last section (within a time when a point in time of completion of a delivery plan generated immediately before is set as a start time and a time when a delivery time limit included in the initial conditions elapses on the basis of a start time of the first delivery time limit is set as a termination time).

[0127]

When the delivery plan generation process of the present embodiment is actually performed, it is possible to calculate a semi-optimum solution (a difference in the value of an objective function from a strict optimum solution is equal to or less than 10%) in a

practical amount of time (within 10 minutes) for a delivery problem having approximately 20 delivery bases and 20 delivery objects.

[0128]

The delivery plan generation method of the present embodiment can be used in the following scenes. For example, in a case where all vehicles have to be delivered to a parking lot having a demand for 120 minutes, first, a delivery plan is generated for 60 minutes in the first half. When the generation of the delivery plan is terminated, the delivery of the vehicles is actually started on the basis of the delivery plan. While the delivery of the vehicles is performed, a delivery plan for the remaining 60 minutes is generated. In this manner, it is possible to use a time effectively at a site where, for example, a car sharing service is performed by performing the delivery plan generation process and the delivery in parallel.

[0129]

The process of each processing in the above-described delivery plan devices 10, 10A, and 10B is stored in a computer-readable recording medium in the form of a program, and the process is performed by reading out and executing the program by a computer of a delivery planning system. Here, the computer-readable recording medium refers to a magnetic disk, a magneto-optical disk, a CD-ROM, a DVD-ROM, a semiconductor memory, and the like. The computer program may be delivered to the computer through a communication line, and the computer receiving the computer program may execute the program.

[0130]

The program may be a program for realizing some of the above-described functions. Further, the program may be a so-called differential file (differential program) that can realize the above-describe functions by a combination with a program

recorded in a computer system in advance. The delivery plan devices 10, 10A, and 10B may be constituted by one computer, or may be constituted by a plurality of computers which are communicably connected to each other.

[0131]

In addition, components in the above-described embodiment can be appropriately replaced with well-known components without departing from the scope of the present invention. The technical scope of the present invention is not limited to the above-described embodiments, and various modifications can be added without departing from the scope of the present invention.

[0132]

A delivery staff member is an example of a delivery subject, a delivery vehicle, a truck, and a bicycle are examples of delivery means, and a shared vehicle in car sharing is an example of a delivery object. Each of the first area division unit 14, the second area division unit 16, and the time division unit 17 is an example of a division unit.

[Industrial Applicability]

[0133]

According to the above-described delivery plan system, delivery plan method, and program, it is possible to make a delivery plan for minimizing costs and a moving time for a large-scale delivery problem in a practical amount of time.

[Reference Signs List]

[0134]

10, 10A, 10B Delivery plan device

11 Initial conditions setting unit

12, 12a Delivery plan generation unit

13 Input and output unit

14 First area division unit

15 Storage unit

16 Second area division unit

17 Time division unit

5

[CLAIMS]

[Claim 1]

A delivery plan system comprising:

a division unit that divides a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand; and

a delivery plan generation unit that generates a delivery plan for the delivery problems obtained by the division performed by the division unit.

[Claim 2]

The delivery plan system according to claim 1,

wherein the division unit associates one demand point included in a delivery base group having a demand for the delivery object and one supply point included in a delivery base group serving as a supply source of the delivery object with each other so that a time of movement from the one demand point to the one supply point is minimized, generates a set of combinations of the demand point and the supply point associated with each other, and divides the delivery problem indicated by the initial conditions into delivery problems from a demand point group to a supply point group which are included in the generated set.

[Claim 3]

The delivery plan system according to claim 2,

wherein the division unit calculates a delivery route from a supply point to a demand point in which a time of movement from one supply point to one demand point is set to be equal to or less than a predetermined value among correspondence relationships between a plurality of supply points and a plurality of demand points which are included in the generated set, and

the delivery plan generation unit generates a delivery plan for the small-scale delivery problem by using a delivery route in which a time of movement is set to be equal to or less than the predetermined threshold value among the delivery routes from the supply point group to the demand point group which are included in the generated set.

[Claim 4]

The delivery plan system according to claim 1,

wherein the division unit acquires a plurality of pieces of unit route information indicating a preset delivery route including departing from a departure base, performing delivery related to some delivery bases, and returning to the departure base and costs when delivery is performed through the delivery route, calculates a combination in which the number of delivery bases included in a combination, among the combinations of the plurality of pieces of unit route information, is equal to or less than a predetermined number and the sum of costs is minimized, generates a set of a departure base and a delivery base which are included in the combination, and divides the delivery problem indicated by the initial conditions into delivery problems from a demand point group to a supply point group which are included in the generated set of the departure base and the delivery base.

[Claim 5]

The delivery plan system according to claim 4,

wherein the division unit calculates a combination of the pieces of unit route information by a column generation technique.

[Claim 6]

The delivery plan system according to claim 1,

wherein the division unit divides a delivery time limit of the delivery object into

a plurality of times to divide the delivery problem indicated by the initial conditions into delivery problems for respective times obtained by the division, and

the delivery plan generation unit generates a delivery plan in which the delivery object is delivered to a base having as many demands as possible within each time after the division from a delivery situation of the delivery object at a first time of the times after the division.

[Claim 7]

The delivery plan system according to claim 6,

wherein with regard to a delivery problem related to a last time obtained by the division performed by the division unit, the delivery plan generation unit generates a delivery plan in which the delivery object is delivered to all delivery bases having a demand which is indicated by the initial conditions until the last time ends.

[Claim 8]

The delivery plan system according to claim 1,

wherein the division unit divides the delivery problem indicated by the initial conditions into delivery problems in which a first delivery time limit shorter than a delivery time limit included in the initial conditions by a predetermined time is set as a new delivery time limit, and

the delivery plan generation unit generates a delivery plan in which the delivery object is delivered to a base having as many demands as possible within the first delivery time limit.

[Claim 9]

The delivery plan system according to claim 8,

wherein the division unit sets a time having a predetermined length and subsequent to the first delivery time limit as a second delivery time limit, and

the delivery plan generation unit generates a delivery plan in which the delivery object is delivered to a base having as many demands as possible within the second delivery time limit.

[Claim 10]

The delivery plan system according to claim 8 or 9,

wherein the delivery plan generation unit generates a delivery plan for terminating delivery of delivery objects of which delivery has not been completed as a result of execution of the delivery plan within a last time when a point in time of completion in a case where the generated delivery plan is executed is set as a start time and a time when the delivery time limit included in the initial conditions elapses from the start time of the first delivery time limit is set as a termination time.

[Claim 11]

The delivery plan system according to any one of claims 6 to 10,

wherein in generating a delivery plan in which the delivery object is delivered to a base having as many demands as possible, the delivery plan generation unit generates a delivery plan on a condition that a delivery staff member and delivery means required for execution of the delivery plan are not left in the delivery base as a result of the execution of the delivery plan.

[Claim 12]

The delivery plan system according to any one of claims 1 to 11,

wherein the delivery plan generation unit solves an integer programming problem based on a time space network model constituted by point information and branch information to generate at least one set of pieces of branch information related to the delivery in the delivery problem after the division performed by the division unit, the point information having a set of a delivery subject delivering the delivery object, a

departure base and the delivery base indicating an initial position of delivery means moving the delivery object or the delivery subject, and times based the start time of delivery, and the branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to the delivery between two pieces of point information related to the delivery of the delivery object among the pieces of point information.

[Claim 13]

The delivery plan system according to claims 12,

wherein the delivery plan generation unit is configured to generate point information regarding an entrance having a set of an entrance and a time of the delivery base, point information regarding an exit having a set of an exit and a time of the delivery base, and point information regarding a place for the delivery object having a set of a time and each delivery object related to the delivery base with respect to one delivery base in the time space network model, and set values of flow rates of the delivery subject and the delivery object between the point information regarding the entrance and the point information regarding the delivery object and between the point information regarding the exit and the point information regarding the delivery object to 0 or 1.

[Claim 14]

A delivery plan method comprising:

causing a delivery plan system to divide a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand, and to generate a delivery plan for the delivery problems obtained by the division.

[Claim 15]

A program causing a computer of a delivery plan system to function as:

means for dividing a delivery problem indicated by initial conditions into delivery problems having a smaller size in a delivery problem in which a delivery object is delivered to a delivery base having a demand; and

means for generating a delivery plan for the delivery problems obtained by the division.