

[DESCRIPTION]

[TITLE OF INVENTION]

DELIVERY PLANNING SYSTEM, DELIVERY PLANNING METHOD, AND
PROGRAM

5 [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. 2016-051550, filed
10 March 15, 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 a 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.

20 [0003]

In addition, even in a case of so-called travelling salesman problem in which a service man travels to a customer in order to provide an 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,
25 it is necessary to select an effective 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 trip 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]

Note that 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 means.

[Citation List]

[Patent Literature]

[0005]

[Patent Document 1]

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

[Summary of Invention]

[Technical Problem]

[0006]

Incidentally, even in a case of delivery of a vehicle in car sharing, there is a likelihood that a technique such as Patent Document 1 described above can be applied in a case of a method in which a vehicle is carried on a truck and delivered. However, in a case where a vehicle is delivered in car sharing, there is also a 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. Regarding a delivery method of the related art in

which loads or the like are delivered by being loaded on a vehicle, a method of optimizing a delivery route according to a mathematical model, and the like have been provided. However, a technique for performing optimal delivery planning in delivery including boarding transport has not been provided.

5 Similarly, in a case where parts used for a service are delivered to a customer in an after-sales service round trip, a round trip plan can be made by a method in the related art when only parts are delivered to each customer from a service center. However, 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
10 takes the remaining parts to the next customer, and the like, a technique for making an optimal round trip plan of a service person has not been provided, similar to boarding transport.

[0007]

 In addition, generally, a combination optimization problem of discrete values
15 often uses a method called linear relaxation, that is, a method in which a problem is solved by once 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 restrictions like a delivery problem, an excessive calculation time is required in this state, and thus it is necessary to devise a solution in a practical time.

20 [0008]

 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 and to reduce a calculation time.

[Solution to Problem]

25 [0009]

According to a first aspect of the present invention, a delivery planning system includes an initial condition setting unit that is configured to receive inputs of a demand quantity and a supply quantity of a delivery object for each delivery base which is a place where any one of the delivery object, a delivery subject, and a delivery means moving the delivery object or the delivery subject stays, information regarding one or a plurality of departure bases which indicates initial positions of the delivery subject and the delivery means, information regarding a delivery means and a delivery subject which are usable in the departure base, and information regarding a delivery deadline, to thereby set initial conditions in a delivery plan, and a delivery plan generation unit that is configured to calculate pieces of point information having a set of the delivery base, the departure base, and a time according to start of delivery and pieces of branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to delivery of the delivery object between two pieces of point information related to the delivery among the pieces of point information, to thereby generate at least one set of the pieces of branch information in a case where a delivery object satisfying the demand quantity within the delivery deadline is delivered to a delivery base in which the demand quantity is set.

[0010]

The delivery plan generation unit in a second aspect of the present invention calculates an evaluation value for the generated set of the pieces of branch information, and may determine a set of pieces of optimal branch information on the basis of the evaluation value.

[0011]

The delivery plan generation unit in a third aspect of the present invention generates pieces of branch information indicating the flow rates between the different

delivery bases, and pieces of branch information indicating the flow rates within the same delivery base and the same departure base.

[0012]

The delivery plan generation unit in a fourth aspect of the present invention
5 generates 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, and may set values of flow rates of the delivery subject and the
10 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.

[0013]

The delivery plan generation unit in a fifth aspect of the present invention sets
15 an objective function for minimizing costs according to the flow rates and moving times of the delivery subject, the delivery means, and the delivery object, and determine a set of the pieces of branch information by solving an integer programming problem including the following conditions in constraint conditions, the conditions including: a difference between a flow rate for entering the delivery base and a flow rate for leaving
20 the delivery base is 0 with respect to each of the delivery object, the delivery means, and the delivery subject, each of the flow rate of the delivery objects, the flow rate of the delivery means, and the flow rate of the delivery subjects is equal to or greater than 0, each of the flow rate of the delivery objects and the flow rate of the delivery subject within the delivery base is equal to or less than 1, the flow rate of the delivery subjects
25 related to the flow rate of the delivery objects is 1 in a case where the flow rate of the

delivery objects within the delivery base, the delivery subject necessarily boards the delivery means during movement from the delivery base to another delivery base, the number of delivery subjects boarding the delivery means during movement from the delivery base to another delivery base is equal to or less than the number of boardable
5 persons, the sum of the delivery objects, which is to be loaded on the delivery means, and the delivery means during movement from the delivery base to another delivery base is equal to or less than the amount of loading on the delivery means related to the movement, the delivery subject gets on the delivery means in a case of staying within the delivery base, and the number of delivery subjects onboard the delivery means is equal to
10 or less than the number of persons able to board in a case of staying within the delivery base.

[0014]

The delivery plan generation unit in a sixth aspect of the present invention sets an objective function for minimizing moving times of the delivery subject, the delivery
15 means, and the delivery object instead of the objective function for minimizing the costs, and may determine a set of the pieces of branch information by solving the integer programming problem.

[0015]

The delivery plan generation unit in a seventh aspect of the present invention
20 may determine a set of the pieces of branch information by adding constraint conditions related to the delivery means leaving the delivery base supplying the delivery object.

[0016]

The delivery plan generation unit in an eighth aspect of the present invention is configured to determine a set of the pieces of branch information by adding constraint
25 conditions related to the delivery means entering the delivery base having a demand for

the delivery object.

[0017]

The delivery plan generation unit in a ninth aspect of the present invention is configured to determine a set of the pieces of branch information by adding constraint
5 conditions related to a relationship between an increase and a decrease in the number of delivery objects in a place for the delivery object within the delivery base and the number of delivery subjects entering the place.

[0018]

The delivery plan generation unit in a tenth aspect of the present invention is
10 configured to determine a set of the pieces of branch information by adding constraint conditions related to an increase and a decrease in the number of delivery objects in the place for the delivery object within the delivery base.

[0019]

The delivery plan generation unit in an eleventh aspect of the present invention
15 is configured to determine a set of the pieces of branch information by adding constraint conditions related to the order of addition and taking-out of the delivery objects with respect to a plurality of places for the delivery objects in a case where there are the plurality of places for the delivery objects within the delivery base.

[0020]

20 The delivery plan generation unit in a twelfth aspect of the present invention is configured to determine a set of the pieces of branch information by adding constraint conditions related to the number of delivery means entering the delivery base.

[0021]

According to a thirteenth aspect of the present invention, the delivery object is
25 movable by the delivery subject onboard the delivery object, and the branch information

calculated by the delivery plan generation unit may include branch information indicating that the delivery subject boards the delivery object to move the delivery object, in addition to branch information indicating movement of the delivery object by the delivery means.

5 [0022]

According to a fourteenth aspect of the present invention, a delivery planning method includes causing a delivery plan device to receive inputs of a demand quantity and a supply quantity of a delivery object for each delivery base which is a place where any one of the delivery object, a delivery subject, and a delivery means moving the
10 delivery object or the delivery subject stays, information regarding one or a plurality of departure bases which indicates initial positions of the delivery subject and the delivery means, information regarding a delivery means and a delivery subject which are usable in the departure base, and information regarding a delivery deadline, to thereby set initial conditions in a delivery plan, and calculate pieces of point information having a set of the
15 delivery base, the departure base, and a time according to start of delivery and pieces of branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to delivery of the delivery object between two pieces of point information related to the delivery among the pieces of point information, to thereby generate at least one set of the pieces of branch information in a case where a delivery
20 object satisfying the demand quantity within the delivery deadline is delivered to a delivery base in which the demand quantity is set.

[0023]

According to a fifteenth aspect of the present invention, a program causes a computer of a delivery plan device to function as means for receiving inputs of a demand
25 quantity and a supply quantity of a delivery object for each delivery base which is a place

where any one of the delivery object, a delivery subject, and a delivery means moving the delivery object or the delivery subject stays, information regarding one or a plurality of departure bases which indicates initial positions of the delivery subject and the delivery means, information regarding a delivery means and a delivery subject which are usable in the departure base, and information regarding a delivery deadline, to thereby set initial conditions in a delivery plan, and means for calculating pieces of point information having a set of the delivery base, the departure base, and a time according to start of delivery and pieces of branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to delivery of the delivery object between two pieces of point information related to the delivery among the pieces of point information, to thereby generate at least one set of the pieces of branch information in a case where a delivery object satisfying the demand quantity within the delivery deadline is delivered to a delivery base in which the demand quantity is set.

[Advantageous Effects of Invention]

15 [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 in a case where a delivery staff member picks up delivery objects exist in various places and deliver the delivery objects to appropriate delivery destinations.

20 [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.

25

Fig. 3 shows an example of a time space network model according to the delivery plan in the first embodiment of the present invention.

Fig. 4 is a flowchart showing an example of a delivery plan generation process in the first embodiment of the present invention.

5 Fig. 5 is a functional block diagram showing an example of a delivery planning system in a second embodiment of the present invention.

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

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

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

Fig. 9 is a fourth diagram showing a time space network model according to the delivery plan in the second embodiment of the present invention.

15 Fig. 10 is a fifth diagram showing a time space network model according to the delivery plan in the second embodiment of the present invention.

Fig. 11 is a first diagram showing an example of a cut in the second embodiment of the present invention.

20 Fig. 12 is a second diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 13 is a third diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 14 is a fourth diagram showing an example of a cut in the second embodiment of the present invention.

25 Fig. 15 is a fifth diagram showing an example of a cut in the second

embodiment of the present invention.

Fig. 16 is a sixth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 17 is a seventh diagram showing an example of a cut in the second
5 embodiment of the present invention.

Fig. 18 is an eighth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 19 is a ninth diagram showing an example of a cut in the second embodiment of the present invention.

10 Fig. 20 is a tenth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 21 is an eleventh diagram showing an example of a cut in the second embodiment of the present invention.

15 Fig. 22 is a twelfth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 23 is a diagram showing an example of a restriction in the second embodiment of the present invention.

Fig. 24 is a diagram showing an example of a problem of a delivery plan in the second embodiment of the present invention.

20 Fig. 25 is a first diagram showing an example of a result of making a delivery plan in the second embodiment of the present invention.

Fig. 26 is a second diagram showing an example of a result of making a delivery plan in the second embodiment of the present invention.

[Description of Embodiments]

25 [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 4.

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 a 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, a delivery means and a delivery route for minimizing costs be selected. Regarding making a delivery plan for minimizing costs, various methods have been provided so far. 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 determining a delivery plan, for example, for minimizing costs by introducing a mathematical model and restrictions according to mathematical knowledge with respect to a delivery plan in a case where boarding transport can be performed.

[0028]

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

The initial condition setting unit 11 sets information such as a delivery object which is movable by a delivery subject 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 moving a delivery object or a delivery subject stays, information regarding one or a plurality of departure bases indicating the initial positions

of a delivery subject and a delivery means, information regarding a delivery means and a delivery subject which are usable in a departure base, and information regarding a delivery deadline, as initial conditions in calculating a delivery plan. These parameters will be described later in detail.

5 The delivery plan generation unit 12 calculates pieces of point information having a set 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
10 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 a base.

 The input and output unit 13 receives a user's input operations. In addition, the
15 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 storage unit 14 stores various information necessary for the generation of a delivery plan.

20 The delivery plan generation unit 12 is realized, for example, by reading out and executing a program from the storage unit 14 by a Central Processing Unit (CPU) included in the delivery plan device 10.

[0029]

 Fig. 2 is a diagram showing an example of a delivery plan in the first
25 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). In addition, 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 lots A to 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 one delivery object shortage 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 user can use the delivery object as desired. Fig. 2 shows an example of the realization of delivery satisfying this condition.

First, two delivery staff members (k, l) from the center boards 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. In addition, 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. In addition, 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 parking lot A 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.

[0031]

Fig. 3 shows an example of a 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 into 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). In addition, each element of a matrix displayed together with each arrow represents each of the number of delivery objects, the number of delivery vehicles, and the number of delivery staff members having moved by 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 is no delivery object, one delivery vehicle, and two delivery staff members having moved from the center to the parking lot A between times $t=0$ and $t=1$. In addition, a double line arrow 32 indicates that there are two delivery objects, no delivery vehicle, and no delivery staff member having stayed in the parking lot A between times $t=0$ and $t=1$. Further, 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 $t=2$. In addition, a double line arrow 34 indicates that there is one delivery object, no delivery vehicle, and no delivery staff member having stayed in the parking lot A between times $t=1$ and $t=2$. The number of delivery objects at the parking lot A is 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. Note that 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 with a time-related action such as meeting a delivery staff member or a 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 space network. Thereby, it is possible to represent not only spatial movement between bases but also the movement of a vehicle or a person with time interposed.

[0032]

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 a delivery means in places other than a departure base.

(4) A delivery staff member necessarily boards a delivery object or a 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 a delivery

means.

[0033]

In order to solve the above-described integer programming problem, the delivery plan generation unit 12 generates a branch between points according to deliver as shown in Fig. 3 on the basis of information regarding the initial conditions received by the initial condition setting unit 11, 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. Note that more specific details of the objective function and the constraint conditions will be described in a second embodiment.

[0034]

Fig. 4 is an example of a flowchart 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 condition setting unit 11. The initial condition setting unit 11 acquires information regarding the initial conditions input by the delivery staff member (step S11). The initial condition 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 delivery plan generation unit 12 generates branch information so as to satisfy the above-described constraint conditions on the time space network model shown in Fig. 3, and generates a plurality of sets of branch information for performing delivery
5 so as to satisfy a demand number in each base up to a delivery deadline (step S12).

Next, the delivery plan generation unit 12 calculates costs for each of the generated sets of branch information (step S13). 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 14 in advance, and the delivery plan generation unit 12
10 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
15 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.

Next, the delivery plan generation unit 12 compares costs calculated for the calculated respective sets with each other, and selects a set of branch information for minimizing costs (step S14). The selected set of branch information indicates the
20 movement of delivery objects, delivery means, and delivery staff members with elapse of time from the states of a departure base and each delivery base indicated by the initial conditions (Fig. 3). Therefore, when delivery is executed on the basis of the set of branch information, it is possible to perform the delivery according to a demand from users. That is, the set of branch information is a delivery plan to be obtained.

Mathematical models and programs of delivery plans that have existed 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
5 obtained by adding constraint conditions using the existing technique, but it is considered that there is no practicality because the number of combinations of means and routes increase 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
10 object applicable to boarding transport, and thus it is possible to obtain a delivery plan for minimizing costs among executable delivery methods.

[0036]

<Second Embodiment>

Hereinafter, a delivery planning system according to a second embodiment of
15 the present invention will be described with reference to Figs. 5 to 26.

In the second embodiment, 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 time space network model in the first embodiment. Thereby, the inside of the delivery base is treated as a 0-1 integer
20 programming problem. In the 0-1 integer programming problem, the width of a variable is limited as compared to an integer programming problem, and thus the number of combinations is reduced, thereby achieving a reduction in a calculation time. Further, in the second embodiment, the speed of calculation is further increased by adding a cut. Note that, in the second embodiment, it is possible to more effectively insert a cut by
25 subdividing movement within a delivery base.

[0037]

Fig. 5 is a functional block diagram showing an example of a delivery planning system in the second embodiment of the present invention.

Among components according to the second embodiment of the present invention, the same functional units as those constituting the delivery plan device 10 according to the first embodiment of the present invention are denoted by the same reference numerals and signs, and a description thereof will be omitted.

A delivery plan device 10a according to the second embodiment includes a delivery plan generation unit 12a instead of the delivery plan generation unit 12 among the components in the first embodiment.

The delivery plan generation unit 12a 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, and 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. In addition, the delivery plan generation unit 12a 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 10a 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 vehicles (D), an amount of loading on a delivery means (cp), the cost of delivery object cx (yen/minute), the cost of a delivery vehicle 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 a 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 condition setting unit 11 acquires these parameters and sets the parameters as initial conditions of a delivery plan.

10 [0039]

In addition, the delivery plan generation unit 12a 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 vehicles, and a flow rate z ((v,s), (w,t)) of delivery staff members to an input and output unit 13, as output items. Note that 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)). Note that the output items also include costs required for delivery, and the like.

[0040]

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

A time space network to be used in the second embodiment will be described with reference to Fig. 6. 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

25 follows.

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

Here, $S_{wd}=\{0,1\}$ ($d=0$), $S_{wd}=\{0,1,\dots,m\}$ ($d\neq 0$). 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 addition, in a case of $d\neq 0$, 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. In addition, for example, in a case where there is a shortage of four delivery objects in the delivery base w (demand quantity=4), S_{wd} has values of 0, 1, 2, and 3. Note that a point of $d=0$ is called a road and a point of $d\neq 0$ 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. 6 shows a time space network in a case of $\text{Depot}=\{0\}$, $W=\{1,2\}$, $P=\{a\}$, $T=\{0,1,2\}$, $S_{1a}=\{0\}$ (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. 7.

[0042]

Fig. 7 is a second diagram showing a time space network model according to a delivery plan in the second 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 E_x of delivery objects is defined as follows.

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

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_{wp_x} 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]

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

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

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_{wp_y} 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.

20 $E_z = E_{wwz} \cup E_{wz} \cup E_{wp_z} \cup E_{p wz}$

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_{wp_z} represents a set of branches indicating the movement of the delivery staff members from the road to the port, and $E_{p wz}$ represents a set of branches indicating the movement of the delivery staff

members from the port to the road.

[0045]

Fig. 7 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_{wpw} , E_{wpw} , and E_{wpw} . An 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 present embodiment, 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. 8 is a third diagram showing a time space network model according to the delivery plan in the second embodiment of the present invention.

Flow rate vectors set for respective branches will be described with reference to Fig. 8. As shown in (a) of Fig. 8, 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 vehicles, and $z[e](e \in E_z)$ indicates a flow rate of delivery staff members. Some examples will be described. In

5 a case of $P=\{a\}$ and $D=\{\text{vehicle}\}$, 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. 8 indicates the movement of one a , one delivery

10 vehicle, and two delivery staff members (persons). Further, in a case of $P=\{a,b\}$ and $D=\{\text{vehicle}, \text{bicycle}\}$, a flow rate vector is as follows.

[0051]

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

15 [0052]

A branch e shown in (c) of Fig. 8 indicates the movement of one a , one b , one delivery vehicle, one bicycle, and two delivery staff members (persons).

[0053]

Fig. 9 is a fourth diagram showing a time space network model according to the delivery plan in the second embodiment of the present invention.

In Fig. 9, a flow rate vector is as follows.

[0054]

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

[0055]

Fig. 9 shows 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. First, two delivery staff members and one delivery 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). Further, 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. 9, 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. 10 is a fifth diagram showing a time space network model according to the delivery plan in the second embodiment of the present invention.

Fig. 10 shows a time space network model obtaining by representing the time space network model shown in Fig. 3 of the first embodiment by a method in the second embodiment. In the present embodiment, 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.

In addition, 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]

Next, a cut for further reducing a calculation time will be described. 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. In addition, the executable region is not cut by the addition of a cut, and thus the optimality of a solution is secured.

[0058]

5 Fig. 11 is a first diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 11 is a diagram showing a cut related to the number of delivery vehicles leaving a road with a supply object.

E_1 represents a set of branches entering the road, and E_2 represents a set of
10 branches leaving the road. The following Expression (A) is established by constraint conditions 5 and 6 to be described later.

[0059]

$$\therefore \sum_{e \in E_1} y(e) \geq \left\lceil \frac{\alpha}{\beta - 1} \right\rceil \quad \dots (A)$$

[0060]

15 Expression (A) is a cut related to the number of delivery vehicles leaving a road with a supply object. Note that the right side in Expression (A) indicates that digits after a decimal point of a value obtained by dividing α by $\beta - 1$ are rounded up. The same is true of the following expression.

Here, α represents a maximum number of persons capable of boarding delivery
20 objects in all delivery objects. In addition, β represents a maximum number of persons capable of boarding delivery vehicles in all delivery vehicles.

[0061]

Fig. 12 is a second diagram showing an example of a cut in the second

embodiment of the present invention.

Fig. 12 is a diagram showing a cut related to the number of delivery vehicles entering a road with a demand object.

Here, E_1 represents a set of branches entering a road, and E_2 represents a set of
5 branches leaving the road. The following Expression (B) is established by the constraint conditions 5 and 6 to be described later.

[0062]

$$\therefore \sum_{e \in E_2} y(e) \geq \left\lceil \frac{\alpha}{\beta - 1} \right\rceil \quad \dots (B)$$

[0063]

10 Expression (B) is a cut related to the number of delivery vehicles entering a road with a demand object.

Here, α represents a maximum number of persons capable of boarding delivery vehicles in all delivery objects. In addition, β represents a maximum number of persons capable of boarding delivery vehicles in all delivery vehicles.

15 [0064]

Fig. 13 is a third diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 13 is a diagram showing a cut related to the number of delivery vehicles leaving a road with a supply object until time t . Note that the leaving until time t means
20 leaving before time $t-1$.

Here, E_1 represents a set of branches entering the road by time t , and E_2 represents a set of branches leaving the road by time t , and E_3 represents a set of vertical branches of a port which come out at time t . The following Expression (C) is

established by the constraint conditions 5 and 6 to be described later.

[0065]

$$\therefore \sum_{e \in E_1} y(e) + \sum_{e \in E_3} x(e) \geq \left\lceil \frac{a}{\beta - 1} \right\rceil \quad \dots (C)$$

[0066]

- 5 Expression (C) is a cut related to the number of delivery vehicles leaving a road with a supply object by time t.

[0067]

Fig. 14 is a fourth diagram showing an example of a cut in the second embodiment of the present invention.

- 10 Fig. 14 is a diagram showing a cut related to the number of delivery vehicles leaving a road with a demand object after time t.

E_1 represents a set of branches entering the road by time t, E_2 represents a set of branches leaving the road by time t, and E_3 represents a set of vertical branches of a port which enter the road at time t. The following Expression (D) is established by the

- 15 constraint conditions 5 and 6 to be described later.

[0068]

$$\therefore \sum_{e \in E_2} y(e) + \sum_{e \in E_3} x(e) \geq \left\lceil \frac{a}{\beta - 1} \right\rceil \quad \dots (D)$$

[0069]

- 20 Expression (D) is a cut related to the number of delivery vehicles leaving a road with a demand object by time t.

[0070]

Fig. 15 is a fifth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 15 is a diagram showing a cut obtained by expanding the cuts described in Figs. 11 and 13.

5 E_1 represents a set of branches leaving a road by time t , E_2 represents a set of branches entering the road by time t , and E_3 represents a set of vertical branches of a port which come out at time t . In addition, e_4 represents a set of vertical branches of a road which enter the road at time t . The following inequality (cut) (E) is derived by a numerical expression operation of the same restriction expression as those described in
10 Figs. 11 and 13.

[0071]

$$y(E_1) + x(E_2) + x(E_3) + z(e_4) \geq \left\lceil \frac{a}{\beta - 1} \right\rceil \quad \cdot \cdot \cdot (E)$$

[0072]

The above expression is established in a road having a supply quantity of a .

15 [0073]

Fig. 16 is a sixth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 16 is a diagram showing a cut obtained by expanding the cuts described in Figs. 12 and 14.

20 E_1 represents a set of branches entering a road after time t , E_2 represents a set of branches leaving the road at time t , and E_3 represents a set of vertical branches of a port which enter the road at time t . In addition, e_4 represents a set of vertical branches of the road which come out at time t . The following inequality (cut) (F) is derived by a numerical expression operation of the same restriction expression as those described in

Figs. 12 and 14.

[0074]

$$y(E_1)+x(E_2)+x(E_3)+z(e_4) \geq \left\lceil \frac{a}{\beta-1} \right\rceil \quad \cdot \cdot \cdot (F)$$

[0075]

5 The above expression is established in a road having a supply quantity of a.

[0076]

Fig. 17 is a seventh diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 18 is an eighth diagram showing an example of a cut in the second
10 embodiment of the present invention.

A cut operating between a road and a port will be described with reference to Figs. 17 and 18.

Here, $x(e)$ represents the number of delivery objects on a branch e , and $z(e)$ represents the number of persons on the branch e . Fig. 18 is a table in which
15 relationships between $z(e_1)$, $x(e_2)$, $x(e_3)$, and $x(e_4)$ are arranged. For example, in a case where a delivery staff member does not enter the port from the road, the number of delivery objects at the port does not change.

Further, in a case where a delivery staff member enters the port from the road, the number of delivery objects at the port changes necessarily. For example, when $x(e_2)$
20 is 1, it is indicated that the delivery objects are taken. In addition, for example, when $x(e_4)$ is 1, it is indicated that the delivery objects are brought. The following expression is obtained from the table of Fig. 18.

$$z(e_1)-x(e_2)+x(e_3)-x(e_4)=0$$

This expression is a cut operating between the road and the port. By adding

this cut, it is not necessary to meaninglessly perform calculation in a case where the delivery staff member enters and out of the port.

[0077]

In addition, it is possible to add a monotonously increasing cut to a port with a demand. The monotonously increasing cut is specified such that, at the port with a demand, the number of delivery objects only increases from 0 to 1, and does not return to 0 again after increasing from 0 to 1.

[0078]

In addition, it is possible to add a monotonously decreasing cut to a port with a supply. The monotonously decreasing cut is specified such that, at the port with a supply, the number of delivery objects only decreases from 1 to 0, and does not increase to 1 again after decreasing 1 to 0.

[0079]

In addition, it is possible to add a cut for determining the order satisfying a request at the port with a demand. Specifically, regarding branches from the road to the port with a demand, a condition that delivery objects are brought in ascending order of a port number is added.

[0080]

In addition, it is possible to add a cut for determining the order satisfying a request at the port with a supply. Specifically, regarding branches from the port with a supply to the road, a condition that delivery objects are taken out ascending order of a port number is added.

[0081]

Fig. 19 is a ninth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 20 is a tenth diagram showing an example of a cut in the second embodiment of the present invention.

A cut of the number of delivery vehicles will be described with reference to Figs. 19 and 20.

5 E_1 represents a set of branches entering a road at time t , e_2 represents branches entering a port from the road at time t , and e_3 represents branches entering the road from a port with a demand at time $t-1$. Fig. 20 is a table in which relationships between $z(e_1)$, $z(e_2)$, and $y(E_1)$ are arranged. Here, $y(E)$ represents the total number of delivery vehicles of branches of a branch set E , and $z(e)$ represents the number of persons on a
10 branch e . The following expression is obtained from the table of Fig. 20.

$$z(e_1) \leq z(e_2) + y(E_1)$$

This expression is a cut of the number of delivery vehicles.

[0082]

Fig. 21 is an eleventh diagram showing an example of a cut in the second
15 embodiment of the present invention.

Fig. 21 shows an example of results in a case where a linear relaxation problem is solved without the cut of the number of delivery vehicles described in Figs. 19 and 20. As shown in the drawing, in a case where a cut of the number of delivery vehicles is not applied, there is a likelihood that 3/4 delivery vehicles come. However, actually, one or
20 more delivery vehicles are supposed to come.

[0083]

Fig. 22 is a twelfth diagram showing an example of a cut in the second embodiment of the present invention.

Fig. 22 shows an example of results in a case where a linear relaxation problem
25 is solved by adding the cut of the number of delivery vehicles described in Figs. 19 and

20. As shown in the drawing, in a case where a cut of the number of delivery vehicles is added, one or more delivery vehicles have to come. From Figs. 21 and Fig. 22, it can be understood that it is possible to exclude an impractical case where $3/4$ delivery vehicles come from a calculation target by adding a cut.

5 [0084]

In this manner, a range of a solution is limited by adding a cut, and the speed of calculation is increased. Specifically, in a case where cuts including the above-described cut are added with respect to an integer programming problem requiring several hours in a case where a cut is not added to solve a problem, it is possible to solve
10 the integer programming problem in a few minutes.

[0085]

As described above, the treating of the inside of a delivery base as a 0-1 integer programming problem and the addition of a cut have been described as countermeasures for increasing the speed of processing in the second embodiment. Next, an objective
15 function and restrictions of an integer programming problem will be described more specifically than in the first embodiment. In addition, a 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 using a truck. Note that a bicycle
20 which is a 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.

[0086]

First, an objective function will be described. In the first embodiment, a case
25 where costs are minimized has been described as an example. In the present

embodiment, 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
5 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.

10 [0087]

(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.

15 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.

[0088]

Next, restrictions will be described.

20 (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 at a point
25 in time 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 coming-in delivery objects and a flow rate of coming-out delivery objects are equal to each other.

[0089]

5 (2) Regarding flow rate of delivery vehicles

A flow rate of delivery vehicles leaving a road on which the delivery vehicles exist at a point in time 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 exist at a point in time when delivery is completed corresponds to the number of existing delivery vehicles. At the other points, a flow rate of coming-out delivery vehicles and a flow rate of coming-in 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 exist at a point in time 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 exist at a point in time when delivery is completed corresponds to the number of delivery staff members. At the other points, a flow rate of coming-out delivery staff members and a flow rate of coming-in delivery staff members are equal to each other.

20 2. Capacity restriction

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

[0090]

3. Restriction 1 within delivery base

25 $\forall e \in E_{wp}$ (E_{wp} is shown in Fig. 23)

(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

5 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.

[0091]

10 4. Restriction 2 within a delivery base

$\forall e \in E_{pw}$ (E_{pw} is shown in Fig. 23)

(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).

15 (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.

20 [0092]

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. Restrictions on branches in case of movement from base to another base

25 $\forall e \in E_{ww}$

(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 restrictions 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.

10 [0093]

6. Restrictions on branch staying in delivery base

Restrictions are as follows: a person necessarily boards a vehicle; and the number of persons is equal to or less than the number of persons able to board.

[0094]

15 (Case Where Delivery is Performed Using Truck)

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

Restrictions 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 the amount of loading of the truck.

20

[0095]

6. Restriction on branch staying in base

Restrictions are as follows: 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

25

equal to or less than an amount of loading of the truck.

[0096]

The delivery plan generation unit 12a generates a time space network model obtained by dividing a delivery base in a road ($d=0$) and a parking port ($d \neq 0$) in step S12 of Fig. 4, 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 the first embodiment. 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 calculated under various initial conditions with each other.

[0097]

Next, an example in which a delivery plan is calculated by the delivery plan device 10a of the present embodiment will be described.

Fig. 24 is a diagram showing an example of a problem of a delivery plan in the second embodiment of the present invention.

A point 0 (depot) in Fig. 24 is a departure base. The other points 1 to 9 are delivery bases. For example, "d1:2" at the point 7 indicates a state where two delivery objects d1 are left, and "d2:-1" at the point 5 indicates a state where there is a shortage of one delivery object d2. In addition, "d1:-1, d2:1" at the point 2 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. 24 are unevenly distributed. Hereinafter, a description will be given of an example of a delivery plan calculated by the delivery plan device 10a 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.

[0098]

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

[0099]

(2) Objective function

Minimization of costs

(3) Output

- Delivery is performed using one delivery vehicle, one bicycle, and two delivery staff members as shown in Fig. 25.

- Costs of delivery: 2768 yen

- 5 · Required time: 60 minutes

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

[0100]

10 Fig. 25 is a first diagram showing an example of a result of making a delivery plan in the second embodiment of the present invention.

In Fig. 25, a delivery plan for the delivery vehicles d1 to d3 for minimizing costs is displayed. According to the delivery plan calculated by the delivery plan device 10a, delivery is performed by dividing a delivery route into two routes of a delivery route 1 indicated by S1 to S7 and a delivery route 2 indicated by T1 to T9. A delivery staff member taking charge of the delivery route 1 moves in order of S1 to S7 to perform delivery. A delivery staff member taking charge of the delivery route 2 moves in order of T1 to T9 to perform delivery. Note that the delivery staff member of the delivery route 1 and the delivery staff member of the delivery route 2 meet each other at the delivery base 7, and move from the delivery base 7 to the delivery base 2 together. Note that, although not shown in Fig. 25, a flow rate x of delivery objects ((depot, departure time), (delivery base 3, arrival time))=0, a flow rate y of delivery vehicles ((depot, departure time), (delivery base 3, arrival time))=1, and a flow rate z of delivery staff members ((depot, departure time), (delivery base 3, arrival time))=2 are output as output items with respect to, for example, S1. This delivery plan can also be represented by the

25

time space network models shown in Figs. 6, 7, 9, and 10 using these pieces of information.

[0101]

2. Case where delivery is performed using truck

5 (1) Input

- One truck and two delivery staff members at depot
- Delivery deadline: 120 minutes
- Costs of truck: 25 yen/minute
- Costs of delivery staff member: 17yen/minute

10

- Amount of loading on truck: 16

· It is assumed that the volume of d1 is 2, the volume of d2 is 4, and the volume of d3 is 3.

[0102]

(2) Objective function

15

Minimization of costs

(3) Output

· Delivery is performed using one truck and one delivery staff member as shown in Fig. 26.

- Costs of delivery: 3456 yen

20

- Required time: 80 minutes

[0103]

Fig. 26 is a second diagram showing an example of a result of making a delivery plan in the second embodiment of the present invention.

In Fig. 26, a delivery plan for the delivery vehicles d1 to d3 for minimizing costs

is displayed. In a case of the delivery plan of Fig. 26 which is calculated by the delivery plan device 10a, delivery is performed by a delivery route indicated by 1 to 9. Similarly to Fig. 25, output items include time information regarding departure and arrival according to the movement of each delivery base and flow rates of delivery objects, delivery vehicles, and delivery staff members.

[0104]

As shown in Figs. 24 to 26, according to the present embodiment, it is possible to calculate a delivery plan for minimizing costs with respect to a case where a boardable delivery object is delivered using a delivery vehicle and a bicycle and a case where a boardable delivery object is delivered using a truck. In addition, a person making a delivery plan can compare delivery plans calculated by setting various initial conditions with each other to examine how many delivery staff members delivery and what kind of delivery means may be used to perform delivery. Note that, although an example of the minimization of delivery costs has been described, it is possible to calculate a delivery plan for minimizing a delivery time by setting the minimization of a moving time required for delivery as an objective function as described above. Further, in the above-described example, there is only one departure base, but it is also possible to calculate a delivery plan in a case where there are a plurality of departure bases. In addition, the second embodiment is more preferable from the viewpoint of a time required for calculation. However, for example, the problems treated in Figs. 24 to 26 can be solved by the delivery plan device 10 of the first embodiment.

[0105]

The process of each processing in the above-described delivery plan devices 10 and 10a 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. In addition, the computer program may be delivered to the computer through a communication line, and the computer receiving the computer
5 program may execute the program.

[0106]

In addition, 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
10 with a program recorded in a computer system in advance.

In addition, the delivery plan devices 10 and 10a may be constituted by one computer, or may be constituted by a plurality of computers which are communicably connected to each other.

[0107]

15 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. In addition, 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. For example, the present
20 invention can also be applied to delivery, supply, and after-sales service round trips of delivery objects applicable to boarding transport. In addition, the present invention can also be used for delivery of delivery objects not applicable to boarding transport.

[0108]

For example, in an after-sales service, it is necessary to provide a service by
25 going to a customer or visiting a plurality of customers after supplying parts required for

the after-sales service. When the above-described mathematical model is applied 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 a 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, it is possible to solve an integer programming problem by the methods described in the first and second embodiments, and to calculate an effective rout (traveling means, traveling course) for minimizing travelling cost or times in a case where the service person performs the after-sales service for a plurality of customers. Taking Fig. 2 as an example, the parking lot A to the parking lot C (delivery base) may be set to be customers providing an after-sales service, the vehicle (delivery object) may be set to be a part, a car (delivery means) may be set to be a means used for movement of a service person, and a delivery person (delivery subject) may be set to be the service person. Further, in a case of an after-sales service, not only visiting to customers but also operations such as inspection and repairs for the customers are performed. According to the delivery plan devices 10 and 10a using a time space network model, it is possible to model an effective route of a service person by taking these operation times into consideration.

[0109]

Costs required for delivery and a moving time required for delivery are examples of evaluation values. 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.

[Industrial Applicability]

[0110]

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 in a case where a delivery staff member collects delivery objects present in various places and deliver the delivery objects to appropriate delivery destinations.

5 [Reference Signs List]

[0111]

10, 10a Delivery plan device

11 Initial condition setting unit

12, 12a Delivery plan generation unit

10 13 Input and output unit

14 Storage unit

[CLAIMS]

What is claimed is:

[Claim 1]

A delivery planning system comprising:

5 an initial condition setting unit that is configured to receive inputs of a demand quantity and a supply quantity of a delivery object for each delivery base which is a place where any one of the delivery object, a delivery subject, and a delivery means moving the delivery object or the delivery subject stays, information regarding one or a plurality of departure bases which indicates initial positions of the delivery subject and the delivery
10 means, information regarding a delivery means and a delivery subject which are usable in the departure base, and information regarding a delivery deadline, to thereby set initial conditions in a delivery plan; and

 a delivery plan generation unit that is configured to calculate pieces of point information having a set of the delivery base, the departure base, and a time according to
15 start of delivery and pieces of branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to delivery of the delivery object between two pieces of point information related to the delivery among the pieces of point information, to thereby generate at least one set of the pieces of branch information in a case where a delivery object satisfying the demand quantity within the
20 delivery deadline is delivered to a delivery base in which the demand quantity is set.

[Claim 2]

The delivery planning system according to claim 1,

 wherein the delivery plan generation unit is configured to calculate an evaluation value for the generated set of the pieces of branch information, and determine a set of
25 pieces of optimal branch information on the basis of the evaluation value.

[Claim 3]

The delivery planning system according to claim 1 or 2,
wherein the delivery plan generation unit is configured to generate pieces of
branch information indicating the flow rates between different delivery bases, and pieces
5 of branch information indicating the flow rates within the same delivery base and the
same departure base.

[Claim 4]

The delivery planning system according to any one of claims 1 to 3,
wherein the delivery plan generation unit is configured to generate point
10 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, and set values of flow rates of the delivery subject and the delivery object between
15 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 5]

The delivery planning system according to claim 4,
20 wherein the delivery plan generation unit is configured to
set an objective function for minimizing costs according to the flow rates and
moving times of the delivery subject, the delivery means, and the delivery object,
and determine a set of the pieces of branch information by solving an integer
programming problem including the following conditions in constraint conditions, the
25 conditions being follows:

wherein a difference between a flow rate for entering the delivery base and a flow rate for leaving the delivery base is 0 with respect to each of the delivery object, the delivery means, and the delivery subject;

wherein each of the flow rate of the delivery objects, the flow rate of the delivery means, and the flow rate of the delivery subjects is equal to or greater than 0;

wherein each of the flow rate of the delivery objects and the flow rate of the delivery subject within the delivery base is equal to or less than 1;

wherein the flow rate of the delivery subjects related to the flow rate of the delivery objects is 1 in a case where the flow rate of the delivery objects within the delivery base is 1;

wherein the delivery subject necessarily boards the delivery means during movement from the delivery base to another delivery base;

wherein the number of delivery subjects onboard the delivery means during movement from the delivery base to another delivery base is equal to or less than the number of persons able to board;

wherein the sum of the delivery objects, which is to be loaded on the delivery means, and the delivery means during movement from the delivery base to another delivery base is equal to or less than an amount of loading on the delivery means related to the movement;

wherein the delivery subject boards the delivery means in a case of staying within the delivery base; and

wherein the number of delivery subjects onboard the delivery means is equal to or less than the number of persons able to board in a case of staying within the delivery base.

[Claim 6]

The delivery planning system according to claim 5,
wherein the delivery plan generation unit is configured to
set an objective function for minimizing moving times of the delivery subject,
the delivery means, and the delivery object instead of the objective function for
5 minimizing the costs, and

determine a set of the pieces of branch information by solving the integer
programming problem.

[Claim 7]

The delivery planning system according to claim 5 or 6,
10 wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to the delivery
means leaving the delivery base supplying the delivery object.

[Claim 8]

The delivery planning system according to any one of claims 5 to 7,
15 wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to the delivery
means entering the delivery base having a demand for the delivery object.

[Claim 9]

The delivery planning system according to any one of claims 5 to 8,
20 wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to a relationship
between an increase and a decrease in the number of delivery objects in a place for the
delivery object within the delivery base and the number of delivery subjects entering the
place.

25 [Claim 10]

The delivery planning system according to any one of claims 5 to 9,
wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to an increase and a
decrease in the number of delivery objects in the place for the delivery object within the
5 delivery base.

[Claim 11]

The delivery planning system according to any one of claims 5 to 10,
wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to the order of
10 addition and taking-out of the delivery objects with respect to a plurality of places for the
delivery objects in a case where there are the plurality of places for the delivery objects
within the delivery base.

[Claim 12]

The delivery planning system according to any one of claims 5 to 11,
15 wherein the delivery plan generation unit is configured to determine a set of the
pieces of branch information by adding constraint conditions related to the number of
delivery means entering the delivery base.

[Claim 13]

The delivery planning system according to any one of claims 1 to 12,
20 wherein the delivery object is movable by the delivery subject onboard the
delivery object, and
the branch information calculated by the delivery plan generation unit includes
branch information indicating that the delivery subject boards the delivery object to move
the delivery object, in addition to branch information indicating movement of the
25 delivery object by the delivery means.

[Claim 14]

A delivery planning method comprising:
causing a delivery plan device to
receive inputs of a demand quantity and a supply quantity of a delivery object
5 for each delivery base which is a place where any one of the delivery object, a delivery
subject, and a delivery means moving the delivery object or the delivery subject stays,
information regarding one or a plurality of departure bases which indicates initial
positions of the delivery subject and the delivery means, information regarding a delivery
means and a delivery subject which are usable in the departure base, and information
10 regarding a delivery deadline, to thereby set initial conditions in a delivery plan, and
calculate pieces of point information having a set of the delivery base, the
departure base, and a time according to start of delivery and pieces of branch information
indicating flow rates of the delivery object, the delivery subject, and the delivery means
related to delivery of the delivery object between two pieces of point information related
15 to the delivery among the pieces of point information, to thereby generate at least one set
of the pieces of branch information in a case where a delivery object satisfying the
demand quantity within the delivery deadline is delivered to a delivery base in which the
demand quantity is set.

[Claim 15]

20 A program causing a computer of a delivery plan device to function as:
means for receiving inputs of a demand quantity and a supply quantity of a
delivery object for each delivery base which is a place where any one of the delivery
object, a delivery subject, and a delivery means moving the delivery object or the
delivery subject stays, information regarding one or a plurality of departure bases which
25 indicates initial positions of the delivery subject and the delivery means, information

regarding a delivery means and a delivery subject which are usable in the departure base, and information regarding a delivery deadline, to thereby set initial conditions in a delivery plan; and

- means for calculating pieces of point information having a set of the delivery
- 5 base, the departure base, and a time according to start of delivery and pieces of branch information indicating flow rates of the delivery object, the delivery subject, and the delivery means related to delivery of the delivery object between two pieces of point information related to the delivery among the pieces of point information, to thereby generate at least one set of the pieces of branch information in a case where a delivery
- 10 object satisfying the demand quantity within the delivery deadline is delivered to a delivery base in which the demand quantity is set.