

REST-AREA LOCATION MODEL FOR TIME-DRIVEN DEMANDS TO THE EXPEND BUFFER TIME OF FREIGHT VEHICLES

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ABSTRACT. *In a typical transport schedule of freight vehicles, buffer times are inserted to deal with the risk of a delay. If no delays and extra buffer times exist, the buffer times must be properly consumed for a rest. The rest-area location model without considering the temporal demands is the same structure as the conventional location set covering model and can be easily formulated; however, time conflicts of demands and transportation scheduling of freight vehicles cannot be considered. Therefore, a rest-area location model for time-driven demands (RALMTD) on a road network is developed. The RALMTD considers time-driven demands and achieves to simultaneously provide facility locations and a transportation schedule. In experiments, the effectiveness of the RALMTD is confirmed using a virtual road network, which is generated based around Tokyo in Japan.*

Keywords: Location set covering, Transportation scheduling, Time-driven demand, Rest-area location, Just-in-time

1. **Introduction.** Transportation planning of vehicles moving on a road network should include a buffer time with the aim to reduce the risk of a delay. In particular, transportation by heavy freight vehicles must often arrive at their destinations just-in-time. However, if there are no delays and there is some extra buffer time, the freight vehicles would stay on the road to expend that time, (i.e., on-street parking). This is a source of traffic jams and is associated with environmental pollution [1]. This problem can be solved by proper use of rest stops where vehicles expend buffer time. Much research has been reported on the economic benefits of proper arrangement of rest areas for freight vehicles [2, 3]. The location model for such facilities can be considered as a rest-area location model (RALM) for properly expending buffer times that is incorporated into the freight vehicle transportation schedule. The main requirements of the RALM are that the number of deployed facilities is minimized to reduce costs and the deployed facilities expend buffer times of all freight vehicles.

A well-known example of the typical vehicle transportation problems is the vehicle routing problem (VRP) [4, 5]. The VRP involves searching for the optimal paths that the freight vehicle should take while providing service to demand points scattered around a certain depot. There are considerable amount of studies on the VRP [6, 7]. However, since the VRP is unable to arrange the facility locations, RALM is not applied. Csehi

and Farkas [8] proposed a single-vehicle scheduling method that takes account of the selection of routes, driver's resting places, and fueling facilities that are necessary when generating a transportation schedule for long-distance freight vehicles, but it cannot be applied to multiple vehicles; further, the model does not consider vehicle crowding at the given facility. Praserttaweelap and Kiatwanidvilai [9] proposed a model for searching the shortest path and multi-robot task allocation in a hard disk drive manufacturing layout. This model focuses on the shortest path and task allocation; however, it is unable to consider the task layout and resource crowding, that is, facility location and vehicle crowding.

Here, we consider an approach based on a facility location model. If the buffer time of each vehicle is the demand and the rest-area is the facility, the RALM can be considered as the location set covering model (LSCM) [10]. Facilities located by the LSCM are targeted at static demands distributed in an area, such as population, while the RALM targets dynamic demands that move from one point to another in the area, such as traffic flow. The differences in demand types can be addressed by simply reviewing the definition of a demand set. [11, 12] applied the LSCM for dynamic demand to the traffic sensor location problem for origin-destination (OD) traffic estimation. However, the RALM or models proposed in [11, 12] do not consider the temporal component, (i.e., when, where, and how much demand uses the facility). Several facility location models for time-based dynamic demand have been proposed in [13, 14]; however, these studies have focused on maximizing the demand coverage by the facility and cannot be applied to the rest-area location. Therefore, this study aims to construct the rest-area location model for a time-driven demand (RALMTD). The RALMTD can provide a transportation schedule for vehicles simultaneously as a facility location by considering the time-driven demand on a road network. Applying the RALMTD to real-world road networks, the problem of on-street parking for consuming buffer times may be solved.

In Section 2, the LSCM which is the base of the proposed model is introduced and the RALM and RALMTD are proposed. In Section 3, the validities of the RALM and RALMTD are verified using virtual road networks. In particular, these models are evaluated qualitatively and quantitatively using a virtual road network, which is generated based around Tokyo in Japan in Section 3.2. We summarize the results of this research and discuss the future work in Section 4.

2. Model Formulation.

2.1. Location set covering model. The conventional LSCM is formulated as follows:

$$\text{Maximize } z = \sum_{i \in I} x_i, \quad (1)$$

$$\text{subject to } \sum_{i \in I_j} d_i x_i \geq 1, \quad \forall j \in J, \quad (2)$$

$$x_i \in \{0, 1\}, \quad (3)$$

where I and J are the set of nodes and demand points and i and j are their indices, respectively. The symbol d_i is a 0-1 constant, which takes 1 if node i covers the demand point j , or 0 otherwise. The decision variable x_i is also a 0-1 integer variable defined as follows:

$$x_i = \begin{cases} 1: & \text{facility is located on a node } i, \\ 0: & \text{otherwise.} \end{cases}$$

The objective function (1) minimizes the number of facilities to be located on the network, while constraint (2) guarantees that all demand points are covered by at least one facility. Because of this structure, the LSCM can be applied to a facility to locate a model for expending buffer times of freight vehicles. Although a research [15] that examines the placement of rest areas from economic and other perspectives has been conducted, no approach using LSCM has been found.

2.2. Rest-area location model. The RALM is a type of LSCM that covers all demands, that is, the buffer times of all freight vehicles on the road network with a minimum facility, which can be formulated using the variable defined in Section 2.1 as follows:

$$\text{Maximize } z = \sum_{i \in I} x_i, \quad (4)$$

$$\text{subject to } \sum_{i \in I_j} u_i x_i \geq b_j, \quad \forall j \in J, \quad (5)$$

$$x_i \in \{0, 1\}, \quad (6)$$

where I and J are the set of nodes and freight vehicles, respectively. In addition, I_j is the set of nodes that the freight vehicle j passes through. Constants b_j and u_i are the buffer time that freight vehicle j must consume, and the expendable time at node i , respectively. If $u_i \in \{0, 1\}$, $\forall i \in I$ and $b_j = 1$, $\forall j \in J$, the RALM expressed by Equations (4), (5), and (6) is equivalent to conventional LSCM.

The main difference between conventional LSCM and RALM is the type of demand. In the LSCM, static demands are distributed in a target area, such as the population. Conversely, the RALM targets demands such as traffic flow moving from one point to another. The typical facility location model for static demands is the maximal covering location model (MCLM) [16], in addition to the LSCM, but the MCLM maximizes the amount of demand that can be covered by a fixed number of facilities. The flow-capturing location-allocation model (FCLM) [17] is a typical location model for dynamic demands and is a type of MCLM; extension from MCLM to FCLM is possible by redefining the set of demands. The extension from conventional LSCM to the RALM is possible by the same context, and the only basic difference is the definition of demand.

While Equations (4), (5), and (6) can express the RALM, they are unable to consider the time conflicts between the vehicles in demand. Furthermore, the RALM cannot provide a detailed transportation schedule of when, where, and how much time each vehicle resource will use the facility.

2.3. Rest-area location model for time-driven demands. By considering time-driven demands in the RALM proposed in Section 2.2, the facility location and transportation schedule of when, where, and how many vehicles use the facility can be provided simultaneously. In this section, we formulate the RALMTD. The requirements that RALMTD must satisfy are (i) to find the minimum number of facilities and their location that consumes all the buffer time allocated to each vehicle, (ii) demands, that is, freight vehicles are moved every unit of time, and (iii) the given capacity of the facility. (i) is satisfied by the RALM proposed in Section 2.2. (ii) can be achieved by giving all vehicles an identification number and a constraint on their movement per unit of time. (iii) can be achieved by ensuring that the total number of vehicles present in the potential facility location (PFL) i at each time step does not exceed a specified value. To formulate the RALMTD satisfying (i)-(iii), the following symbols and variables are newly defined in addition to those defined in Section 2.2.

P : set of PFLs ($P \subseteq I$)

P_j : set of PFLs through which freight vehicle j passes ($P_j \subseteq I_j$)

$\bar{P}_j := P_j \setminus \{o_j, d_j\}$

T : set of time steps (index t is an entry)

$\bar{T} := \{t \mid t \leq |T| - u_i, t \in T\}$

$y_{i,t}^j = \begin{cases} 1: & \text{freight vehicle } j \text{ drives on a node } i \text{ at time step } t, \\ 0: & \text{otherwise.} \end{cases}$

$z_{i,t}^j = \begin{cases} 1: & \text{freight vehicle } j \text{ starts rest on a PFL } i \in P \text{ at time step } t, \\ 0: & \text{otherwise.} \end{cases}$

The symbols o_j and d_j indicate an OD of a freight vehicle j . The RALMTD is formulated using these symbols and variables as follows:

$$\text{Minimize } z = \sum_{i \in P} x_i, \quad (7)$$

$$\text{subject to } \sum_{i \in \bar{P}_j} \sum_{t \in T} u_i z_{i,t}^j \geq b_j, \quad \forall j \in J, \quad (8)$$

$$\sum_{j \in J} \sum_{s=t-u_i}^t z_{i,s}^j \leq c_i + M(1 - x_i), \quad \forall i \in \bar{P}_j, \quad \forall t \in T, \quad (9)$$

$$y_{i,j,t+1}^j - y_{i,t}^j \geq 0, \quad \forall i \in I_j \setminus \bar{P}_j, \quad \forall j \in J, \quad \forall t \in \{t \mid t \leq |T| - 1, t \in T\}, \quad (10)$$

$$y_{i,j,t+1}^j - y_{i,t}^j + \sum_{s=t-u_i}^t z_{i,s}^j \geq 0, \quad \forall i \in P_j, \quad \forall j \in J, \quad \forall t \in \{t \mid t > u_i, t \in T\}, \quad (11)$$

$$y_{i,j,t+u_i}^j - y_{i,t}^j + M(1 - z_{i,t}^j) \geq 0, \quad \forall i \in P_j, \quad \forall j \in J, \quad \forall t \in \bar{T}, \quad (12)$$

$$z_{i,t}^j - y_{m_{i,j},t-1}^j \leq 0, \quad \forall i \in P_j, \quad \forall j \in J, \quad \forall t \in \bar{T}, \quad (13)$$

$$\sum_t^{t+u_i} y_{i,t}^j + M(1 - z_{i,t}^j) \geq u_i, \quad \forall i \in \bar{P}_j, \quad \forall j \in J, \quad \forall t \in \bar{T}, \quad (14)$$

$$\sum_{t \in T} y_{i,t}^j \leq 1, \quad \forall j \in J, \quad \forall i \in I_j \setminus \bar{P}_j, \quad (15)$$

$$\sum_{t \in T} y_{i,t}^j \leq Mx_i + 1, \quad \forall j \in J, \quad \forall i \in \bar{P}_j, \quad (16)$$

$$\sum_{t \in T} z_{i,t}^j \leq x_i, \quad \forall j \in J, \quad \forall i \in \bar{P}_j, \quad (17)$$

$$\sum_{t \in T} z_{i,t}^j \leq 0, \quad \forall j \in J, \quad \forall i \in \{o_j, d_j\}, \quad (18)$$

$$z_{i,t}^j \leq 0, \quad \forall j \in J, \quad \forall i \in \bar{P}_j, \quad \forall t \in \{t \mid t + u_i > |T|, t \in T\}, \quad (19)$$

$$y_{o_j, a_j}^j \geq 1, \quad \forall j \in J, \quad (20)$$

$$x_i, z_{i,t}^j \in \{0, 1\}, \quad \forall i \in P, \quad \forall j \in J, \quad \forall t \in T, \quad (21)$$

$$y_{i,t}^j \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in J, \quad \forall t \in T. \quad (22)$$

The objective function (7) minimizes the number of facilities to be placed in a road network. The left-hand side of Equation (8) represents the total time that freight vehicle j has rested at node i and the right-hand side represents the total time that the freight vehicle j should rest. This constraint aims to locate facilities so that the entire buffer time for all vehicles can be consumed. Here, we focus on a structure of the equation. The left-hand side is the product of the variable $z_{i,t}^j$ and constant u_i which indicate the start of the break at time step t and the amount of expendable time step at a facility located on PFL i , respectively. Meanwhile, since the right-hand side is the buffer time b_j to be consumed, the constraint (8) is designed to always consume the given buffer time b_j .

Constraint (9) is on the capacity of facilities, which guarantees that if a facility is located in PFL i , the number of freight vehicles using the facility during the same time period does not exceed the capacity c_i of PFL i . The left-hand side represents the total number of vehicles starting break on a facility located on the PFL i from time step $t - u_i$ to t . Note that, symbol M at the second term on the right side is a sufficiently large constant. If a facility is not located on the PFL i , the second term on the right-hand side equals M and the constraint is always satisfied. On the contrary, if a facility is located on the PFL i , the second term equals 0 and the constraint is enabled. This method using sufficiently large constant M is called the big-M method.

Equations (10) and (11) are the constraints on the movement of the vehicle. Constraint (10) guarantees that at node i ($\notin P$), the vehicle j always moves to an adjacent node in the next time step. The constant $l_{i,j}$ implies the adjacent nodes in the direction of travel of node i that exist in a path traveled by the freight vehicle j . When freight vehicle j exists on node $i \in I_j \setminus P_j$, the value of variable $y_{i,t}^j = 1$. In addition, since the freight vehicle j must move to the adjacent node $l_{i,j}$ at time step $t + 1$ if $y_{i,t}^j = 1$, the difference between $y_{l_{i,j},t+1}^j$ and $y_{i,t}^j$ must be more than 0, that is $y_{l_{i,j},t+1}^j = 1$. This constraint (10) satisfies the requirement. Constraint (11) implies that if a vehicle j does not rest at the PFL i , the freight vehicle j must move to an adjacent node in the next time step. The specifications of this constraint are almost the same as the constraint (10). The difference is target nodes. If the freight vehicle j starts break on PFL $i \in P_j$ at time step t , the third term on the left-hand side equals 1 and the variable $y_{l_{i,j},t+1}^j$ is not fixed to 1. By this structure, Equation (11) guarantees that the constraint will be disabled if a freight vehicle uses a facility and be enabled if otherwise.

Constraint (12) guarantees to move to an adjacent node $l_{i,j}$ after resting for time step u_i if freight vehicle j starts break at PFL i . The third term on the left-hand side determines the enabling and disabling of the constraint by the value of variable $z_{i,t}^j$. If $z_{i,t}^j = 1$, the constraint is satisfied by that freight vehicle j moving to adjacent node $l_{i,j}$ after time step $t + u_i$.

Constraint (13) implies that the freight vehicle j must exist on the adjacent node $m_{i,j}$ at time step $t - 1$ if the freight vehicle j starts break on the PFL i at time step t . Note that the constant $m_{i,j}$ indicates the adjacent node that exists before the node i on the path of the freight vehicle j .

Constraint (14) permits the freight vehicle j to rest at PFL i , if a facility is located. If freight vehicle j uses a facility located on PFL $i \in P_j$, the second term on the left-hand side equals 0 and this constraint is enabled. On the other hand, if freight vehicle j does not use the facility, the second term on the left-hand side becomes sufficiently large and this constraint is disabled. If this constraint enabled, the first term on the left-hand side equals the amount of time step using the facility, thus making Equation (14) reasonable.

Constraints (15) and (16) imply that a freight vehicle j cannot stay at a node i where a facility is not located. The left-hand sides of these constraints describe the amount of

time step for which the freight vehicle j stays on node i . Thus, Equation (15) constrains the amount of staying time step on $i \in I_j \setminus P_j$ to be less than or equal to 1. Moreover, Equation (16) has the structure that enables freight vehicle j to stay at PFL $i \in \bar{P}_j$ by disabling the constraint if a facility is located on the PFL.

Constraint (17) guarantees that at PFL i , a freight vehicle j cannot start to rest if a facility is not located. If a facility is not located on the PFL $i \in \bar{P}_j$, Equation (17) constrains $\sum_{t \in T} z_{i,t}^j$ to equal 0 since $x_i = 0$.

Equation (18) is a location prohibition constraint on the OD of freight vehicle $\forall j \in J$. Constraint (19) implies that a freight vehicle j cannot rest beyond a given time step, that is, $|T|$. Constraint (20) guarantees that freight vehicle j departs from the origin o_j at departure time a_j . Equations (21) and (22) are the 0-1 constraints of the decision variables.

2.4. Complexity of the problems. The RALM and RALMTD proposed in Sections 2.2 and 2.3, respectively, are regarded as extensions of the LSCM. All the decision variables of the LSCM are the 0-1 integer and the problem formulated by the LSCM is called the 0-1 integer programming (0-1 IP) problem. The 0-1 IP problem generally comes under the NP-complete classification that cannot obtain the optimal solution in polynomial time. The problems formulated by RALM and RALMTD may also come under NP-complete, similar to the LSCM. It is difficult to obtain an optimal solution to these problems in realistic time if the scale is significantly large.

Table 1 indicates the number of variables of the problems formulated by the LSCM, RALM, and RALMTD. The difficulty level of solving the 0-1 IP problems cannot be estimated using only the number of variables. However, since the RALM and RALMTD are the extensions of the LSCM, the number of variables is an essential factor for discussing the difficulty of these three problems. The RALMTD requires consideration of the set of time step T , freight vehicle J and time-dependent vehicle position I in addition to the set of PFLs P . As a result, the number of these elements significantly increases compared to the LSCM and RALM with the scale of road network. Therefore, the problem formulated by the RALMTD is expected to require a significantly higher computational cost than the LSCM and RALM.

TABLE 1. The number of variables by the models

Model	The number of variables
LSCM	$ P $
RALM	$ P $
RALMTD	$ P + J P T + J I T $

Furthermore, the settings of several coefficients in the RALMTD must be carefully selected. In an optimization problem, an extremely large number, such as big-M, is known to create a calculation instability [19]. Hence, these coefficients must be properly defined.

3. Numerical Experiments. In the numerical experiments, we conducted preliminary experiments on the RALMTD using a small-scale network to confirm the behavior of the model. The RALM and RALMTD are evaluated by being applied to the virtual road network generated based on the highway network around the Tokyo region of Japan as an example. The specifications of the machine used in the experiments were: Apple® M1

chip@ 3.2GHz, 16GB RAM, running macOS™ Big Sur version 11.4. Gurobi Optimizer™ version 9.1 was used as the optimization solver.

3.1. Preliminary experiments using a small virtual network. The RALM is applied to a small-scale virtual network. Figure 1(a) is a network constructed by [18]. The numbers assigned to the nodes and edges are the IDs and costs, respectively. All edge costs are assumed to be time steps, and we use Figure 1(b), which is divided into units of one. The node IDs in Figures 1(a) and 1(b) correspond to each other. The networks shown in Figures 1(a) and 1(b) have 25 nodes with 43 edges and have 180 nodes with 198 edges, respectively. The edges are bidirectional. The algorithm proposed in [20] was used to draw the network. The conditions are organized for the experiment. 25 nodes in Figure 1(a) are assumed to be PFLs. The number of freight vehicles $|J|$ is 10, and the set of nodes I_j where freight vehicle j passes through is the shortest path between a random OD-pair. Let r_j be the number of rests for freight vehicles j and $r_j = 2, \forall j \in J$. In addition, we assume that the parameters are $u_i = 3, \forall i \in P$ and $a_j = 1, b_j = 3 \cdot r_j, \forall j \in J$.

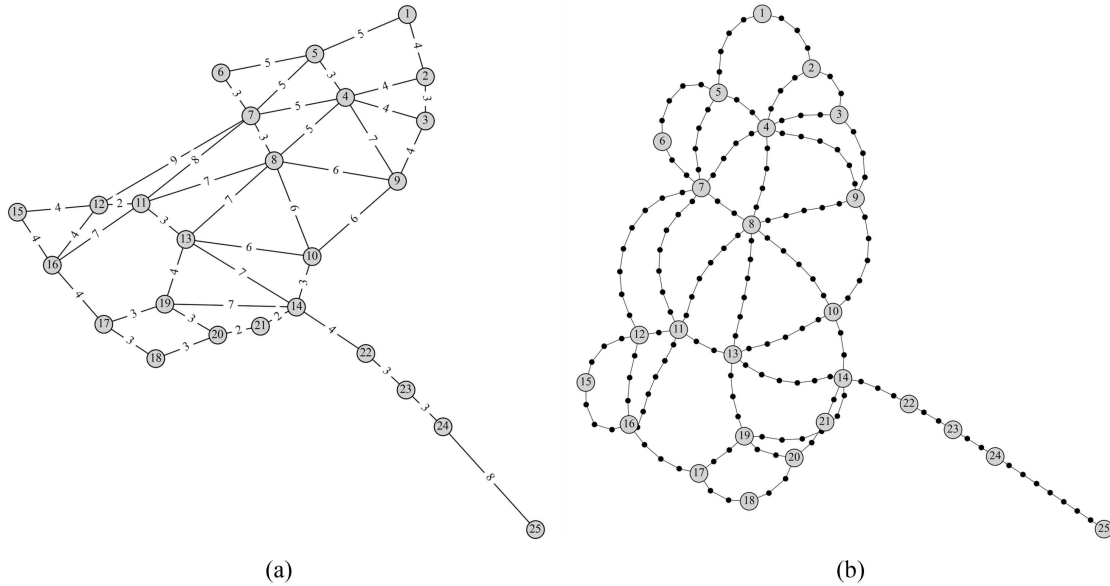


FIGURE 1. (a) Small network consisting of 25 nodes; (b) divided network by time steps based on (a)

Figure 2 shows the facility locations and movements of freight vehicles from time steps 1 to 6. The pentagons in the figure show the facility locations, and the number of located facilities is seven. The black points indicate the location of the vehicles, and the numbers in the circles indicate the number of vehicles at that node. We can confirm that three freight vehicles expend three steps because they start a break in two locations at $t = 3$ and move to the neighboring node at $t = 6$.

Figure 3 shows the movement locus between the starting and ending points of a certain vehicle, with the black circles representing the number of rested steps. The vehicle shown in Figure 3 takes three steps at each of the two facilities during the movement. From these results, it was confirmed that the RALMTD could provide the facility locations and transportation schedules for each vehicle while satisfying various conditions.

3.2. Evaluation of the RALMTD. Assuming a long-distance freight vehicle, we conducted experiments using the virtual road network shown in Figures 4(a) and 4(b), which

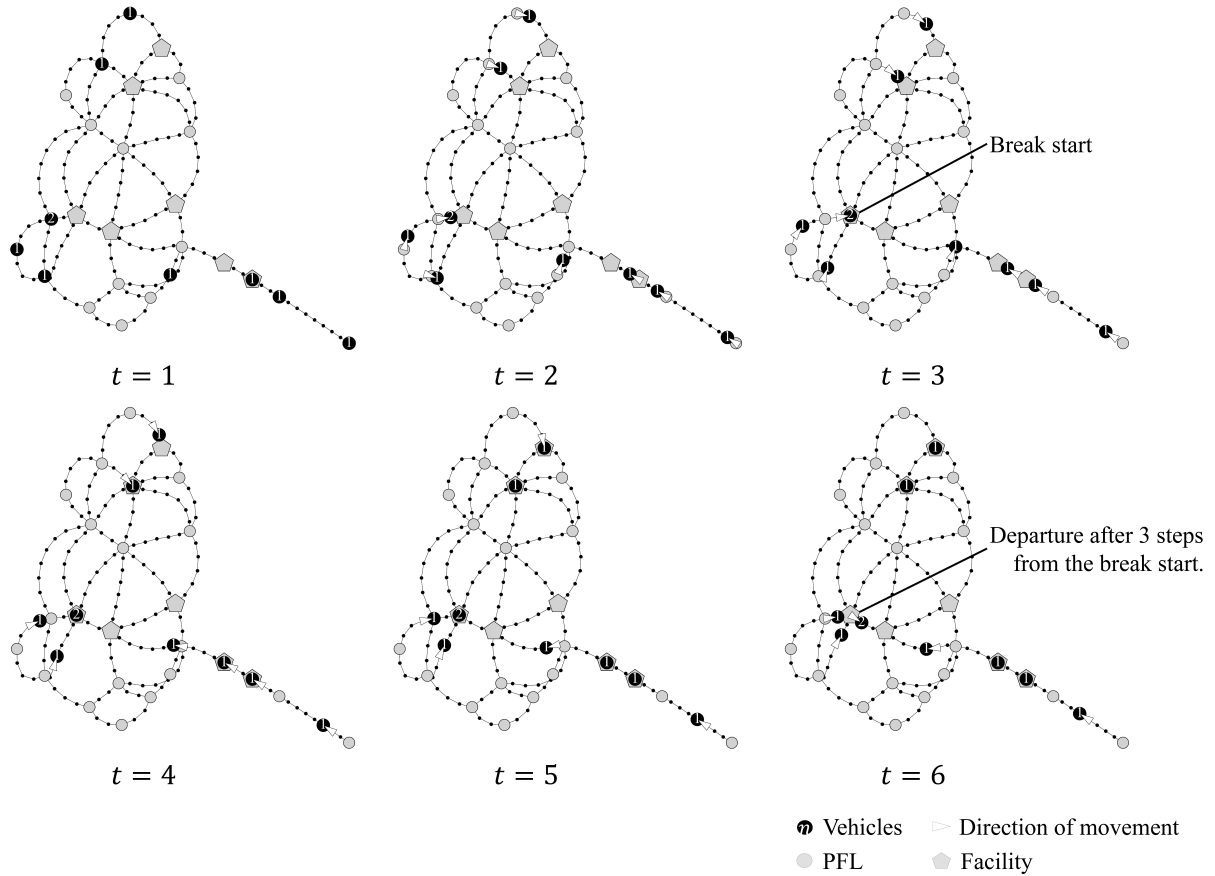


FIGURE 2. Location of facilities and movement locus of vehicles

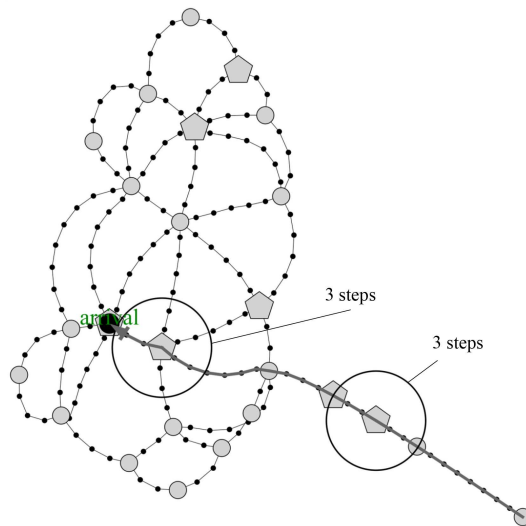


FIGURE 3. Example of movement locus

is generated based on the highway network around Tokyo, Japan. While Figure 4(a) describes only the edges and nodes, Figure 4(b) indicates the number of freight vehicles passing through each edge by the color depth. The extracted area is $[34.88-37.00^\circ\text{N}, 139.00-141.00^\circ\text{E}]$ and the scale is about $182.64 \text{ km} \times 236.00 \text{ km}$. The black nodes represent the PFLs. Given that the raw network has a large number of nodes and edges, the size of the instance can be reduced by aggregating a group of nodes that are concentrated

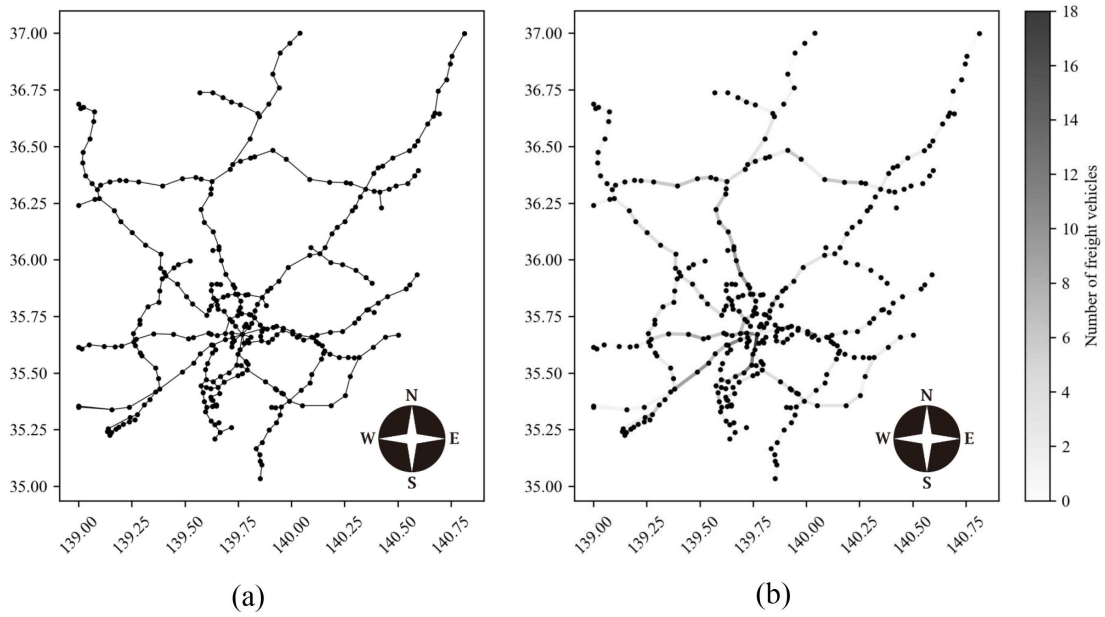


FIGURE 4. (color online) Network instance based on highway network around Tokyo, Japan: (a) Nodes and edges; (b) including color depth expressing the number of freight vehicles

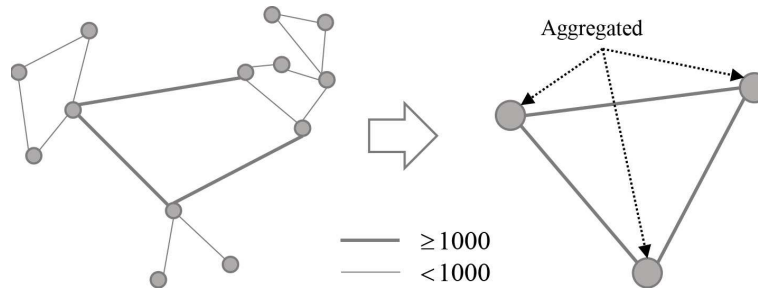


FIGURE 5. Aggregation method

in a narrow area (e.g., junction) to a single node. The road network shown in Figure 4 was generated by aggregating the nodes with distances of less than 1000 m, as shown in Figure 5, and composed of 332 nodes and 735 edges. The RALM and RALMTD are applied to the road network shown in Figure 4, and their performance is evaluated. First, the conditions are summarized for the experiment. All edges of the road network are divided every 1000 m, assuming that the distance a freight vehicle can move in one unit of time is 1000 m. Let the pre-split and post-split nodes be P and I , respectively. Note that $|P| = 332$ and $|I| = 1381$. The number of freight vehicles $|J|$ is assumed to be 100, and the set of nodes I_j that freight vehicle j passes through is the shortest path between a random OD-pair. The travel time of a freight vehicle j is $|I_j|$ units, and the number of rests is given by $r_j = \lceil |I_j| / 120 \rceil, \forall j \in J$. This indicates that freight vehicles take a break once within 120 units of time. Moreover, we assume the parameters as $u_i = 15, \forall i \in P$ and $a_j = 1, b_j = 15 \cdot r_j, \forall j \in J$. Note that the vehicle rates with $b_j = 15$ and 30 are 97% and 3%, respectively.

Figures 6(a) and 6(b) show the results obtained by the RALM and RALMTD with $c_i = 100, \forall i \in I$. The number of located facilities was nine in both models. While both models could locate facilities on nodes that freight vehicles frequently pass, the distributions are

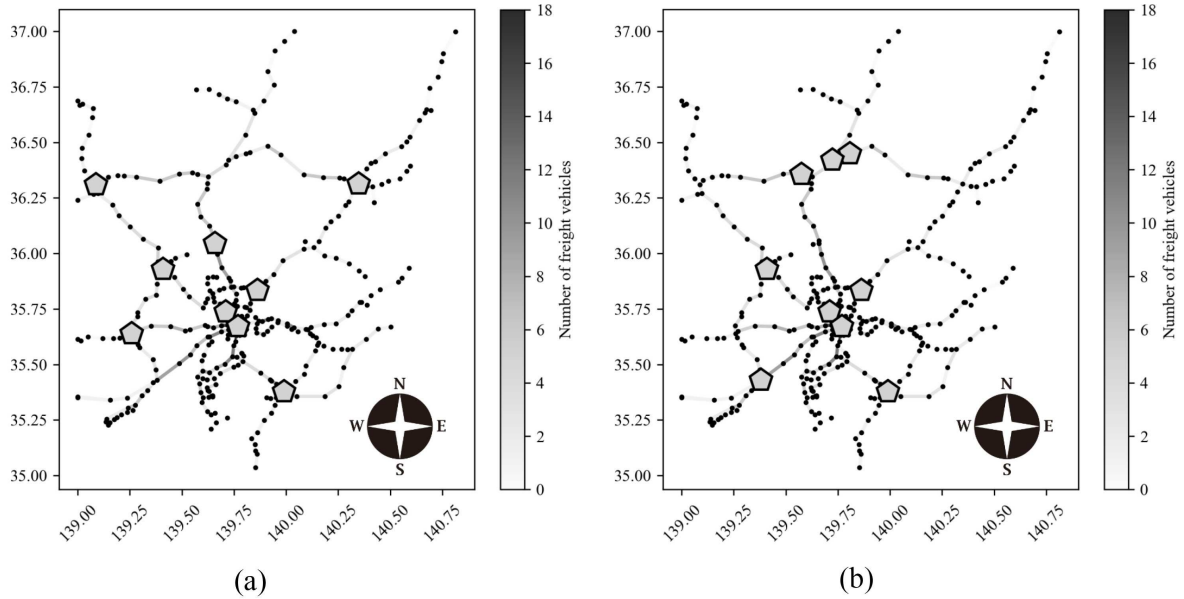


FIGURE 6. (color online) Optimal location: (a) RALM; (b) RALMTD with $c_i = 100, \forall i \in I$

quite different. In the RALM, all facilities are located on the nodes with degree 3 or more, that is, at intersections; however, the results of the RALMTD are not primarily focused on only the distribution. This is because, if the time is not considered, a facility can hold many freight vehicles if it is located at a position where many paths intersect. On the contrary, considering the movement of freight vehicles by time, the occurrences of multiple freight vehicles passing through an identical intersection simultaneously are reduced. Thus, the RALMTD locates the facilities efficiently in accordance with dynamic vehicle movements, instead of locating facilities on intersections to cover the prior static number of freight vehicles. Therefore, the RALMTD would be a more feasible model, compared with the RALM, which is a conventional LSCM.

Figure 7 shows the locations obtained by varying the facility capacity of the RALMTD. The black nodes represent the PFLs, and the numbers in pentagons represent the maximum utilization of freight vehicles at the same time step. The number of facilities increased as the capacity decreased, and the maximum utilization of the facilities was also distributed. In Figure 7, although the facility arrangement is similar outside the center of a road network at all capacities, the number of vehicles using these facilities is different. From Figure 4, it can be seen that many vehicles pass the center of network. Thus, if the capacity of the facilities is sufficiently large, the demands of the facilities located outside the road network decrease by those many vehicles, which are covered by the facilities located on the center. This indicates that the adjustment of the parameter c_i not only enables us to consider vehicle crowding but also control the supplying capacity of all the facilities.

Table 2 shows the calculation time and objective values for each capacity and expendable time parameters. We adopted the capacity parameter $c_i = 100$, which always satisfies the capacity constraint (9). The other c_i values were set to 3-7 since the objective value did not vary from $c_i = 100$ until $c_i = 6$. In addition, the expendable time parameters $u_i = 6, 9, 12$, and 15 were adopted. Varying u_i is equivalent to increasing the number of rests for each vehicle as well as varying the buffer b_j . Thus, if u_i decreases, the required number of facilities is expected to increase.

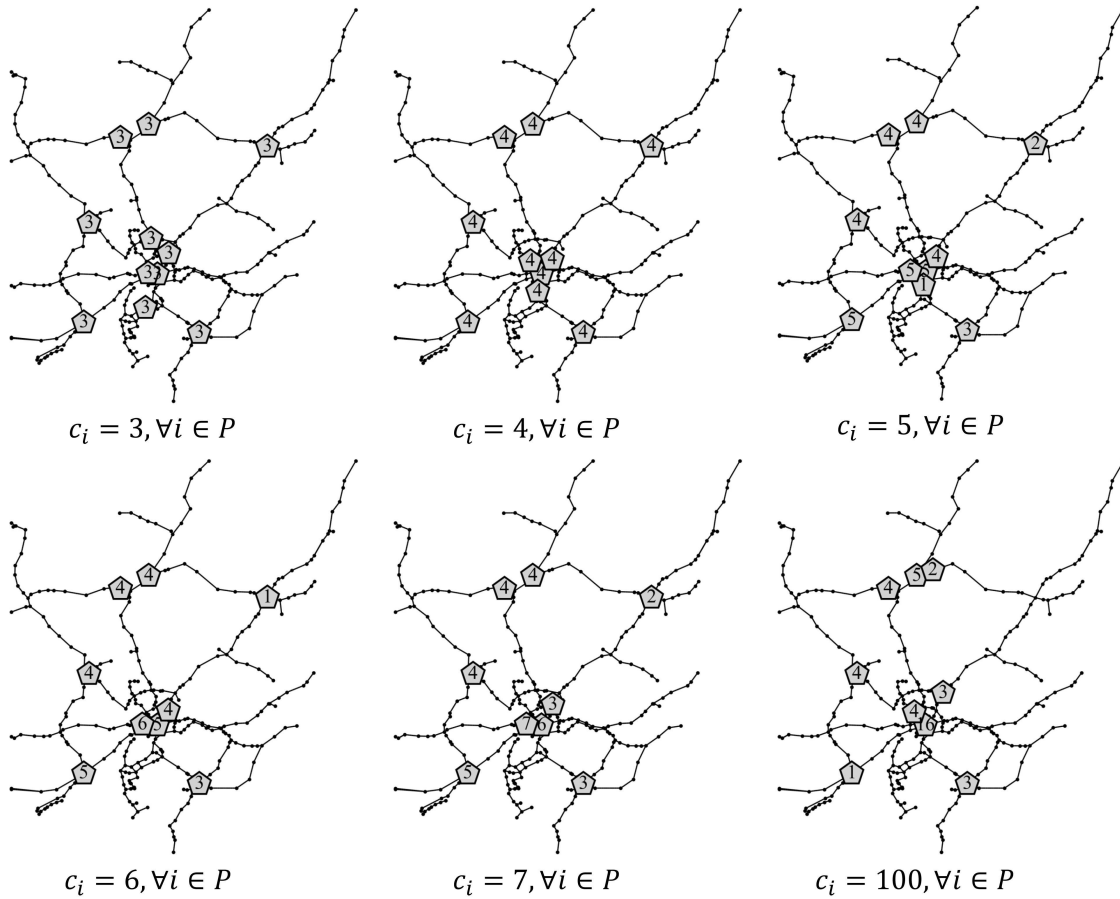


FIGURE 7. Location of facilities and the maximum number of freight vehicles by each capacity

The RALMTD has the same objective function value as the RALM does if the capacity of the PFLs is sufficiently large. If the capacity is small, the number of facilities increases, and the maximum utilization of each facility is distributed to entire road network. However, the calculation time increases substantially if the capacity of the facilities is small. This is possibly because the size of feasible-solution space shrinks with decreased capacities, the RALMTD has a more complex model structure than the RALM does, and the number of variables in the RALMTD is much greater than that of the RALM as mentioned in Section 2.4.

Similarly, in expendable time parameters, the same trend was confirmed in terms of the objective value. In particular, the objective values obviously vary among the expendable time $u_i = 6, u_i = 9, 12,$ and $u_i = 15$. Here, we focus on the required number of rests by each expendable time. The vehicles with $b_j = 15$ should rest one, two, and three times if $u_i = 15, u_i = 9, 12,$ and $u_i = 6,$ respectively. Furthermore, the rate of vehicles with $b_j = 15$ is 97% of total vehicles as mentioned at the beginning of this section. Therefore, it is found that the increase in the objective value is significantly affected by the number of rests. Regarding the calculation time, while increasing trend was confirmed between $u_i = 15$ and $u_i = 6, 9, 12,$ the remarkable tendency was not confirmed among $u_i = 6, 9,$ and $12.$

These results show that the RALMTD is able to control the number of resources and the balance of supply capability by setting parameters. Moreover, the RALMTD has forward compatibility with the RALM in terms of the amount of information obtained, that is the schedules of each vehicle.

TABLE 2. Objective values and computation time by capacity and expendable time of facilities

Model	Capacity (c_i)	Expendable time (u_i)	Objective value	Computation time (sec)
RALMTD	3	6	30	26075.98
		9	20	12263.98
		12	20	25829.67
		15	11	9947.59
	4	6	29	14630.68
		9	19	8641.96
		12	19	19915.92
		15	10	2103.83
	5	6	29	1861.87
		9	19	1699.73
		12	19	2530.52
		15	10	979.58
	6	6	29	4896.96
		9	19	3476.14
		12	19	1765.70
		15	9	980.37
	7	6	29	4079.36
		9	19	1509.94
		12	19	1393.81
		15	9	1060.65
100	6	29	1609.64	
	9	19	1646.02	
	12	19	2206.23	
	15	9	816.78	
RALM	–	–	9	0.01

4. **Conclusion.** A facility location model called RALMTD, which considers the buffer times of freight vehicles as a time-driven demand, is proposed. The RALMTD simultaneously provides the facility locations and transport schedule of each freight vehicle. In preliminary experiments, a simple road network was used to confirm the behavior of the RALMTD. In the experiments that use the virtual road network, which is generated based on the highway network around Tokyo, Japan, the RALMTD was evaluated by varying the capacity of the facilities. Although it is costly in terms of computation time, the RALMTD can consider the temporal conflicts of demands that could not be considered in the RALM, a conventional LSCM, and simultaneously provide transport schedules for freight vehicles. In addition, while conventional transportation scheduling problems typified by the VRP focus on the paths of target vehicles, the transportation problem of freight vehicles driving between long-distance OD should concurrently consider what times the vehicles drive on which points, as well as which facilities are utilized by how many vehicles and locating which facilities in where is more effective. The RALMTD can simultaneously yield a solution satisfying the constraints pertaining to the locations of facilities, time-dependent locations of vehicles, and vehicle crowding at the facilities. Moreover, scheduling of multiple freight vehicles which is not considered in the existing method [8], can be accounted for the RALMTD. The facility locations and transport

schedules obtained by the RALMTD may reduce on-street parking leading to traffic jams, accidents, and atmosphere pollution and improve operational effectiveness of a road network.

In future work, the effectiveness of reducing on-street parking will be verified in more detail by applying the RALMTD to a real-world road network and by simulating real-world traffic conditions. Furthermore, we will attempt to simplify the RALMTD. In Section 2.4, we discussed the complexity of problems formulated by the LSCM, RALM and RALMTD in terms of the number of variables. However, estimating the difficulty of the problems based only on the number of variables is not sufficient. Therefore, identifying the factors determining the difficulty of a problem is necessary to expand the range of road network scales for which the RALMTD is applicable.

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