

Multiagent-based Sustainable Bus Route Optimization in Disaster

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Abstract: This paper proposes a multiagent-based route optimization method as a next-generation transportation system to generate a *sustainable* route network which can transport stranded persons effectively even if the road conditions are changed in a disaster situation. For this purpose, we apply a multiagent approach into the route optimization method where an agent corresponds to one route. Such an approach is very useful in a disaster situation because it is easy to add/delete routes and modify their routes according to the dynamic condition change and constraints. Towards a sustainable route network by multiagent approach, our route optimization method (1) employs the bus stop clustering method to generate clustered routes, (2) introduces a cluster-extension method to connect routes in different clusters and (3) adopts the evaluation function in consideration of damage by a change in the condition of roads. Intensive simulations on Mandl's urban transport benchmark problem have revealed the following implications: (1) the proposed method has succeeded in reducing stranded persons, detour persons, detour time, all of which are caused by road condition changes; (2) detour routes have emerged, which contribute to an increasing network sustainability; and (3) we have succeeded in reducing both the passenger's transportation time and the number of buses in a non-damaged situation.

Keywords: genetic algorithm, clustering, disaster, transit route optimization

1. Introduction

When a disaster occurs in the center of a city, it is difficult for a large number of persons to get home owing to the suspension of the train service by the destruction of railroads. It is difficulty (almost impossible) for the government to take care of many stranded persons. There is also have a high risk of suffering a second accident [2], [3]. To cope with this situation, we have to construct a transit network which can transport the stranded persons as soon as possible.

In this situation, the bus transportation system attracts attention particularly as the solution of this problem. The reasons are summarized as follows: (1) the bus route can be changed flexibly according to road conditions (e.g., car accident, traffic jam, road repair), (2) unlike train transportation, bus transportation is not affected by other buses' travel. Especially, in a disaster situation, it is necessary to develop a next-generation network which can generate a sustainable route network to transport stranded persons effectively even if road conditions have changed.

For route optimization in the ordinary situation (i.e., the situation without disaster), a lot of methods have been proposed. For example, Baaj and Zhao proposed the heuristics-based optimization method [1], [10], Fan and Zhao proposed the optimization method based on simulated annealing [5], [11], and Charkroborty and Ngamchai proposed the optimization method by genetic algorithm [4], [8]. In comparison with these methods, we apply

a multiagent-based route optimization method to generate a sustainable route for the disaster situation. This is because it is easy to deal with adding/deleting the routes or modifying their routes according to the dynamic condition change and constraints by regarding one agent as one route. In this situation, Majima proposed the multiagent-based route optimization method [9], and succeeded in minimizing the passenger's transportation time and the number of buses in comparison with other methods. However, it cannot take into consideration the damage situation caused by the destruction of roads. For example, Majima's method can optimize the route network in terms of the transportation time and the number of buses, but it is hard to reduce the number of stranded persons, and detour persons, and their detour time. This is because Majima's method generates long-distance routes and a lot of overlapping routes, which cannot commit passengers' transportation and the routes performance (i.e., the transportation time and the number of buses) will be significantly affected by a change in road conditions.

To tackle this problem, we propose the novel multiagent-based bus route optimization method which can (1) not only generate the effective route by reducing both the passenger's transportation time and the number of buses as the ordinary route optimization, (2) but can also generate a *sustainable* route which can minimize the influence of a dynamical change of the road conditions, (i.e., the number of stranded persons, and detour persons, and their detour times are reduced as much as possible). In fact, the proposed method tries to generate the route network which consists of short-distance routes with less overlapping, which is efficient to transport stranded persons in a time of disaster. To

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verify the effectiveness of the proposed method, we compare the proposed method with the conventional method through Mandl’s urban transport benchmark problem [7].

This paper is organized as follows. Section 2 introduces the conventional route network optimization method. Section 3 describes the proposed method. The experiments are conducted in Sections 4 and 5. Their results are discussed in Section 6. Finally, our conclusion is given in Section 7.

2. Route Network Optimization Method Based on Route Agent

2.1 Overview

The Majima’s agent-route network optimization method [9] succeeded in minimizing the passenger’s transportation time and the number of buses (i.e., the bus company’s cost). In this method, the following two procedures are executed sequentially. Firstly, the network evolution procedure generates the initial route network. Secondly, the network modification procedure modifies the initial route network.

2.2 Evaluation of a Route Network

The evaluation value of a route network Z is calculated by the following equation, where T_{S_i,S_j} represents the transportation time of the passenger from the origin station (S_i) to the destination station (S_j), D_{S_i,S_j} represents the demand of the passengers which occur per unit time from S_i to S_j , B_{L_k} represents the number of buses in the route L_k , and w_1 represents the weighting coefficient. The route network with minimum value of Z is evaluated as a good route network.

$$Z = \sum_{S_i \neq S_j} T_{S_i,S_j} D_{S_i,S_j} + w_1 \sum_{L_k} B_{L_k} \quad (1)$$

2.3 Network Evolution Procedure (Initial Route Network Generation)

The network evolution procedure generates the initial route network. The initial route network consists of all of the one-destination route networks, which have been generated independently in different one-destination route networks. Note that the one-destination route network is the network where the passengers at all nodes want to move to one destination.

In detail, such a one-destination route network is generated by connecting the destination node with the node near by the destination sequentially. The outline of the bus stop connection is shown in Fig. 1. In this figure, each circle represents a bus stop and the number indicates each bus stop index (St. i). The dotted arrow represents the candidate of the connection bus stops. Here, St. 0 is the destination and the unconnected St. 3 has the three connection candidates.

In this connection method, the two types of bus stop connection were proposed. The first one is the route addition type, while the second one is route absorption type as shown in Fig. 2. The route addition type (Fig. 2 (A)) is the method of adding the new route, which connects the connection nodes to the bus stops which are finally connected. The absorption type (Fig. 2 (B)), on the other hand, is the method by which a connection node is absorbed into the existing route (Route 1). Note that the number of

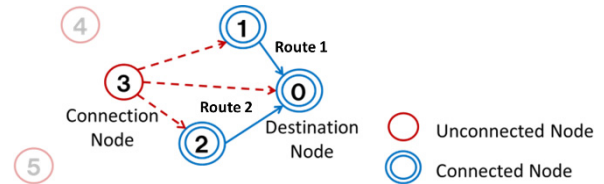


Fig. 1 Outline of node connection.

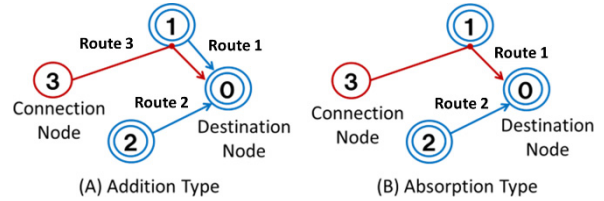


Fig. 2 Two connection types.

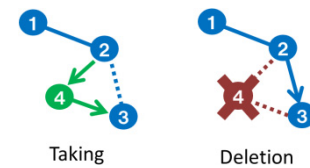


Fig. 3 Patterns of the route evolution.

vehicles in each connection type is assigned minimally to satisfy the passenger’s required demand. After temporally connecting all combinations of the connection node with the existing network, and calculating their evaluation value Z , one of the connection ways which has the smallest Z is selected. By continuing these connections, one-destination network is generated. Finally, the initial route network is generated by integrating all of the one-destination networks.

2.4 Network Modification Procedure (Route Evolution)

After the network evolution procedure, the network modification procedure is executed. In particular, each route in this procedure is regarded as the agent. Concretely, each agent evolves its own network by taking nodes in other routes (agents) or deleting nodes from its own route selfishly to satisfy passengers’ demands. This procedure executes the following two steps.

The first step generates the passenger’s transportation path which is calculated by using the *dijkstra* algorithm (i.e., it is assumed that all passengers move by using the shortest path). Here, the number of passengers of each route is calculated and then the route which has no passengers is deleted.

The second step modifies the route as shown in Fig. 3. In this method, two types of modification were proposed. In the first one, the route (agent) takes the bus stop which does not belong to itself. (In Fig. 3, the St. 4 is taken between St. 2 and 3.) In the other one, the route (agent) deletes the bus stop which belongs to its own route. (In Fig. 3, St.4 is deleted from the route, and the St.2 and 3 are connected.)

To decide the modification type (i.e., taking or deletion), all route’s (agent’s) profit P is calculated by the following equation,

$$P_{L_k} = R_{L_k} - w_2 B_{L_k} \quad (2)$$

where L_k represents the route of index k , R_{L_k} represents the number of passengers which use L_k , B_{L_k} represents the number of

buses of L_k , and w_2 represents the weighting coefficient. Concretely, all of modification profits P in the target route are calculated according to Eq. (2). Then, the modification type with maximum P is selected. If all modification type of P is negative value, the target route is changed to the next route which has second-maximum P .

The above described two steps are executed repeatedly until the modifications of all the routes' P become negative value.

3. Bus Route Optimization Method Based on Bus Stops Clustering and Evaluation of Damages

3.1 Overview

The conventional method described in Section 2 tends to generate the long-distance routes because each agent evolves its own route selfishly which means that it tries to take many passengers' demand' as much as possible. Moreover, it generates the overlapping route network because all of one-destination route networks are integrated. Such a route network is not suitable in the disaster because it suffers much damage by the destruction of roads. In fact, the long-distance routes cannot commit passengers' transportation and a lot of overlapping routes performance (i.e., the transportation time and the number of buses) will be significantly affected by a change of road conditions.

To overcome this problem, i.e., to obtain a *sustainable* route which suffer little influence of road destruction in a disaster, this paper (1) adopts bus stop clustering to prevent generating the long-distance and much overlapping routes and (2) evaluates the influence of road destruction by extending the conventional evaluation function.

3.2 Route Network Optimization Method Based on the Bus Stops Clustering

3.2.1 Overview

The proposed route network optimization method based on bus stops clustering is executed (described in Section 3.2.3). This purpose is to generate short-distance routes. What should be noted here is that initial clustering is very critical for this method. To obtain the effective clusters which contribute to generating a *sustainable* route network, we employ Genetic Algorithm (GA).

3.2.2 Cluster Representation

Among the network clustering methods, several methods have been proposed so far [6]. Some typical methods cluster the network from the viewpoint of the index of betweenness, modularity, or the number of links. However, it is difficult to apply these methods to decide effective cluster for the route network optimization which have the OD values (the number of passenger demands between each station) in addition to the network topology. Moreover, even if we applied the network clustering method which considers OD, these methods have limitations for generating a robust route network in the case of the destruction of roads. For the above reasons, we proposed the clustering method which explores robust clusters by using GA.

For effective clustering, this paper starts by representation of a cluster. **Figure 4** represents an example of the physical network, while **Fig. 5** represents the representation of a cluster. In Fig. 5,

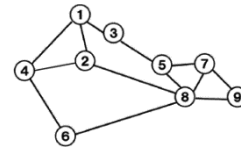


Fig. 4 Physical network (e.g., Road network).

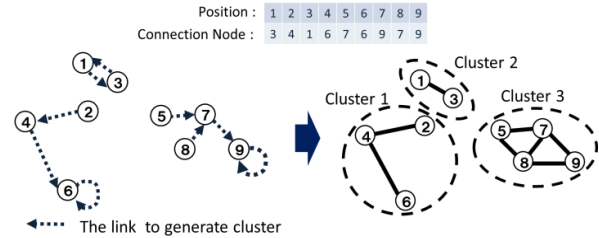


Fig. 5 Cluster representation.

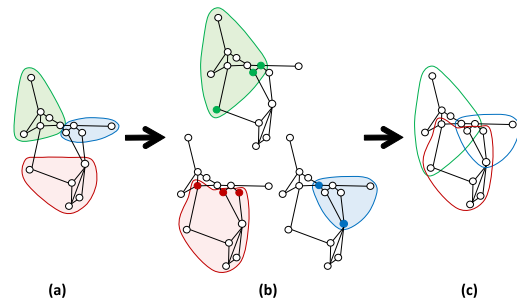


Fig. 6 Outline of the cluster extension method.

Position is the index of each bus stop, and Connection Node is chosen at random from the bus stop which adjoined Position. By connecting Position and Connection Node with the link, the bus stop can be divided into an independent cluster. In Fig. 5, nine bus stops are divided into three clusters. For example, cluster 1 is composed of St. 2, 4, and 6.

3.2.3 Cluster-based Route Generation

The proposed cluster-extension method integrates clusters as shown in **Fig. 6**. Our cluster-extension method is executed by the following procedure.

- Step1: Each original cluster as shown in Fig. 6 (a) adds adjoining bus stops in the cluster as shown in Fig. 6 (b).
- Step2: The route networks are generated in each cluster by using the Majima's bus route optimization method.
- Step3: The route networks generated in every cluster are integrated. In this situation, the route networks generated in each cluster are partially overlapped as shown in Fig. 6 (c).
- Step4: The network modification procedure of the conventional method is applied to the integrated route to evolve routes by taking nodes or by deleting ineffective nodes.

3.2.4 Cluster Evolution

The whole flow of the route network optimization method based on GA using the bus stops clustering is shown in **Fig. 7**. The individual is represented by *Connection Node* described in Section 3.2.2., the route network is generated according to the cluster generated by the *Connection Node* described in Section 3.2.3. The generated route network is evaluated by the Eq. (1) in Section 2.2 or Eq. (3) in the next subsection (Section 3.3). After

the evaluation, the individual is evolved by using genetic operation (e.g., parent selection, crossover, mutation and children generation). To search optimal clustering, this cycle is repeated.

3.3 Evaluation of Destruction of Road Damage

In order to obtain a sustainable route to road destruction, this paper proposes the extended evaluation function considering the damage of destruction. In fact, the evaluation criteria of robustness (represented by A) are added into the conventional evaluation function as shown in Eq. (3). The proposed evaluation function is shown as follows.

$$Z = \sum_{Si \neq Sj} T_{Si,Sj} D_{Si,Sj} + w_1 \sum_{Lk} B_{Lk} + A$$

$$A = w_2 \sum_{Link_i} StrandedPassengerNum_{Link_i} + \sum_{Link_i} DetourTime_{Link_i} \quad (3)$$

In this equation, the term A is the evaluation criteria of robustness and w_2 indicates the weighting coefficient of the number of stranded passengers', $Link_i$ indicates the broken link as road destruction. $StrandedPassengerNum$ indicates the number of persons which cannot arrive at the destination when $link_i$ is broken. $DetourTime$ indicates the detour time of persons who need to detour to arrive at the destination. As the same as the conventional evaluation function as shown in Eq. (1), the route network with a small value of Z is evaluated as an effective network. The way of calculating robustness is as following.

- Step1: Break a link on the route network
- Step2: Delete the routes on the broken link.
- Step3: (1) the number of stranded, (2) detoured passengers

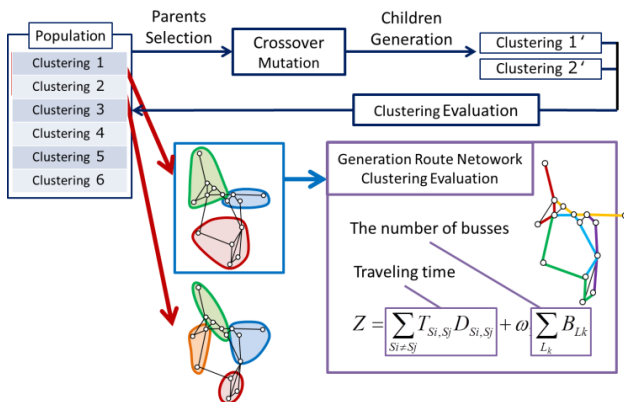


Fig. 7 Outline of route network optimization using GA.



Fig. 8 Routes deletion by destruction of the link.

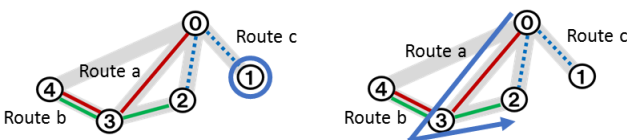


Fig. 9 Outline of stranded persons and detour persons.

and (3) detour times are calculated in the broken network.

—Step4: After Step1-3 is repeated to all of the links, the sum of robustness values in Step3 is calculated.

Figures 8 and 9 show the example of the route deletion by destruction of the link. In Fig. 8, the route network has three routes (i.e., routes a, b, and c). If the link between St. 0 and St. 2 is broken, the route c is deleted because of the broken link. Moreover, the passengers moving from St. 0 to St. 1 are added as stranded passengers as the left side of Fig. 9, and the passengers moving from St. 0 to St. 2 via St. 3 are added as detoured passengers and detour time is calculated as the right side of Fig. 9.

4. Experiment 1 (Non-damaged Case)

4.1 Experiment Setup

Before investigating the effectiveness of the proposed method from the viewpoint of the sustainable route in the disaster situation, this paper starts by investigating its effectiveness from the viewpoint of the performance (i.e., the transportation time and the number of buses) in the non-damaged situation (i.e., the situation without disaster). For this purpose, this paper conducted a simulation using Mandl's urban transport benchmark problem [6] in the non-damaged situation. Figure 10 shows the physical network of this problem. This problem consists of 15 stations, 21 links and an OD table which represents the number of passenger between each station. Note that bus stop 14 is the crossing point of roads and there is no demand. In the crossing point, the bus does not stop and can pass through as many times as the route agent needs. We compare the result of the proposed method with the two conventional route network optimization methods, i.e., Zhao's method [11] and Majima's method [9]. The parameters of the experiment are shown in Table 1.

As evaluation criteria, all simulation results are evaluated by (1) the number of vehicles and (2) the total time including the

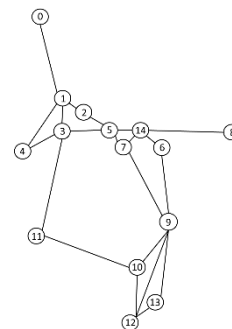


Fig. 10 Mandl's urban transportation problem.

Table 1 Parameter setting.

Population size	30
Max generation	30
Crossover Rate	1.0
Crossover type	1 point crossover
Selection type	Tournament selection
Mutation Rate	0.067 (1/gene length)
Transportation penalty (minutes / transit)	5 (min)
Evaluation equation	Equation (1)
w1	0.7

riding time, waiting time and transportation penalty time. The transportation penalty is defined as 5 minutes according to previous literatures [1], [4], [5], [7], [8], [9], [10], [11]. The route network which has the small value Z as shown in Eq. (1) is evaluated as an effective route network.

4.2 Results

4.2.1 Comparison with the Conventional Methods

Table 2 shows the result of three methods. The column indicates these methods, while the row indicates the detailed result. Regarding the proposed method, the results of the average of 30 runs and the best solution are displayed in the same table. From this result, when we focus on the number of vehicles and total time, we found that not only the best one but also the averaged one are inferior to those of the conventional method. In contrast with these results, when we focus on the number of stranded passengers and detour passengers, detour time, and the influenced buses, we found that not only the best one but also the averaged one are superior to those of the conventional method. These results suggest that the route network generated by the proposed method is sustainable in the situation of road destruction. Figure 11 shows the result of conventional methods and the best solution of the proposed method between 30 runs. The horizontal axis of each graph respectively indicates Zhao’s method (left), Majima’s method (center) and the proposed method (right),

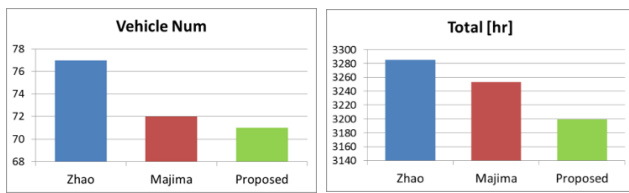


Fig. 11 Comparison to conventional and proposed method.

Table 2 Comparison to conventional and proposed method.

	Zhao[10]	Majima[6]	Proposed (Ave)	Proposed (Best)
#Vehicle	77	77	73	71
Total(hr)	3285	3225	3222	3199
In-Vehicle	#N/A	2654	2669	2657
Waiting(hr)	#N/A	496	479	458
Transfer(hr)	13.4	74	75	84
Directly(%)	99	94.2	94	93.6
Transfer1(%)	1	5.7	6.9	6.2
Transfer2(%)	0	0	0.1	0.1
#Route	6	6	5.4	5

while the vertical axis respectively indicates the number of vehicles (left) and total time (right). This result shows that the number of vehicles (#Vehicle) and total time (Total (hr)) of the best solution of the proposed method is superior to the conventional methods.

4.3 Comparison with Majima’s Method by Changing $w1$

Since the proposed method is based on the conventional Majima’s method, both of the proposed and conventional methods can investigate the number of buses by changing the parameter $w1$ of Eq. (1).

Figure 12 shows the results of the proposed and Majima’s methods. The horizontal axis of each graph indicates $w1$ value, while the vertical axis respectively indicates the number of vehicles (left), total time (center) and evaluation value Z calculated by Eq. (1) (right). All results show the ratio of the proposed method to the conventional method (i.e., the proposed method result divided by Majima’s method result). The result of the proposed method is average of 30 runs and the error bars of each result indicate the standard deviations.

From the results, about the number of vehicles and total time, the proposed method is superior to the conventional methods in most $w1$ cases. What should be important here is that the result of the proposed method Z is stable and is superior in most of $w1$ values. From this experiment, it is revealed that the proposed method is effective except for the case of $w = 0.1$.

5. Experiment2 (Damaged Case)

5.1 Experimental Setup

To investigate the effectiveness of the proposed method in the damaged case as in the disaster situation, we optimized the route network by using the evaluation function as shown in Eq. (3) and compared the result of the proposed method with that of Majima’s method. We employ the same Mandl’s urban transport benchmark problem as the previous experiment and the same experimental parameters shown in Table 1 except that those shown in Table 3 are set.

As evaluation criteria, all results are evaluated by (1) the number of vehicles, (2) the total time including the riding time, waiting time, and transportation penalty time and (3) the number of stranded passengers, (4) the number of detoured passengers, (5) the detour time, (6) the influenced buses which means the buses which cannot be used when the bus routes are deleted by destruction of a road. As in the previous experiment, the route network with a small value Z as shown in Eq. (3) is evaluated as a good route network.

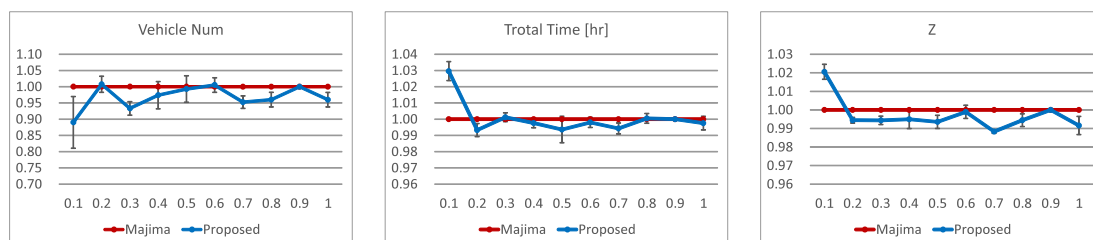


Fig. 12 Result of vehicle num, total time and evaluation value Z .

5.2 Result

Table 4 shows the results of the two methods in the damaged situation. The column indicates the methods, while the row indicates the detailed results. Regarding the proposed method, the results of the average of 30 runs and the typical one are displayed in the same table. From this result, the number of buses and the total time of the proposed method are slightly worse than Majima’s method. While the other aspect such as the robustness evaluations (i.e., the number of stranded passengers and detour passengers, the detour time, the number of the influenced buses) of the proposed method are better than Majima’s method. In fact, the proposed method reduces 72% of the number of stranded passengers, 11% of the number of detoured passengers, 11% of their detour time, and 30 % of the number of influenced buses, respectively, while only slightly increasing 2% of the number of buses and 3% of the total time. This result indicates the proposed route network is able to transport passengers constantly in the disaster situation.

Table 5 shows the result of the destruction of the multiple roads cases. We compared the robustness of the route network generated by Majima’s method and the proposed method. The column indicates the methods, while the row indicates the detailed results. Regarding the number of detour passengers and detour time, the proposed method is inferior to Majima’s method. That is because, the number of stranded passengers reduced by the proposed method is added as the number of detour passengers. The increase in detour time is the result of the increase in the number of detour passengers. What is important point here is, regarding

Table 3 Parameters of the route optimization.

Evaluation equation	Equation (3)
w2	0.5

Table 4 Result comparison to Majima’s method.

	Majima	Proposed (Ave)	Proposed (typical)
#Bus	77	78	79
Total time (hr)	3225	3283	3326
#Stranded passenger	154	98	44
#Detoured passenger	379	328	338
Detour time (hr)	3.4	3.4	2.3
#Influenced buses	23	18	16

Table 5 Robustness Comparison of Majima’s method with the proposed method.

Cases	Two roads broken		Three roads broken	
	Proposed	Majima	Proposed	Majima
#Stranded passenger	125	397	252	670
#Detoured passenger	552	496	650	464
Detour time (hr)	5.3	4.5	7.9	4.1
#Influenced buses	30	41	43	58

the sum of the number of stranded passengers and detoured passengers, the result of the proposed method is superior to the result of the conventional method. This result revealed that the route network generated by the proposed method has a high robustness even if the multiple links are broken.

6. Discussion

6.1 Experiment in Non-damaged Case

In discussion, Majima’s and the proposed route network are compared in detail. Figures 13 and 14 respectively show the route network optimized by Majima’s method and the proposed method in the non-damaged case. In these figure, the arrows indicate the generated routes.

From these figures and the experimental result shown in Table 2, the proposed method can generate the effective route network as compared with the conventional method. However, the proposed route network which only applies bus stop clustering includes a few of the long-distance routes unexpectedly. That is because short-distance routes are generally deleted. More specifically, in the situation where the route (agent) only considers to minimize the passenger’s transportation time and the number of buses, the short-distance routes are easily to deleted because the passengers have to transfer many times in a route network consisting of short-distance routes. From this relationship, it is necessary to combine the bus stops clustering with the evaluation function extended to consider the network robustness, in order to generate sustainable route networks.

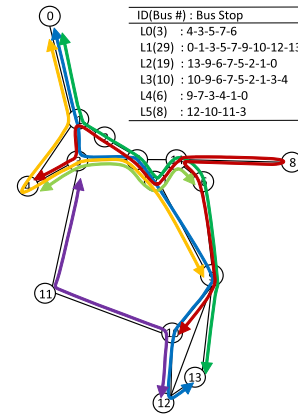


Fig. 13 Routes by Majima’s method.

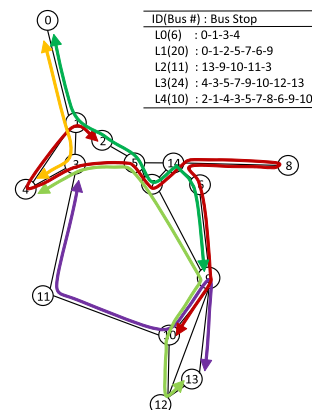


Fig. 14 Routes by cluster-extension method.

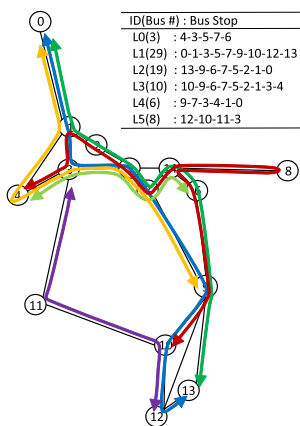


Fig. 15 Routes by conventional method.

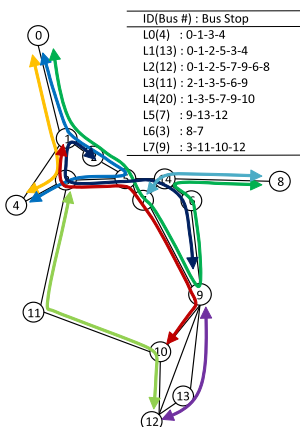


Fig. 16 Routes by cluster-extension method.

From Figs. 13 and 14, as the other issue, Majima’s route network has overlapped on many links, while the proposed route network has only three overlapped routes on a link between St. 5 and 7. Since the link between St.5 and 7 has the highest passengers’ demand, many routes tend to be generated and overlapped with each other on that link. From this fact, the proposed method generates the routes in order to not increase the number of overlapped routes.

Regarding the average length of the routes, Majima’s route network consists of 6 routes and their average of length is 10.8 km, while the proposed route network consists 5 routes and their average length is 9 km. Even in the shorter average length of the routes, the proposed route network has covered most of the links with a few routes. These results suggest that (1) the proposed method can suppress the number of the overlapped routes but (2) can cover the links by few routes, which contributes to generating a sustainable route network.

6.2 Experiment in Damaged Case

Figures 15 and 16 respectively show the route network optimized by Majima’s method and the proposed method, in the damaged case. The arrows indicate the generated route. The characteristic point of the network by the proposed method is the emergence of detour routes. In fact, the route passing St. 5 and 14 is emerged. If the road between St. 5 and 7 is broken, route 3 (L3) in the network of the proposed method can transport passengers, while most of routes are influenced and the passengers

Table 6 Detailed analysis about each route network.

	Majima	Proposed
#Route	6	8
Route length Ave. (km)	11	7
Ave. # routes on one road	1.8	1.5
Transportation Time In non-damaged area (hr)	33.9	32.7

must be transported passing St.10, St.11 and St.3 in the network of the conventional method. If the road between St. 7 and 14 is broken as in the route passing St. 5 and 14, the route 2 (L2), 4 (L4) and 6 (L6) can transport passengers effectively in the network of the proposed method, while many routes are influenced and the passengers cannot be transported effectively in the network of the conventional method. Since the passengers’ demand concentrates the link between St.5 and 7, the routes which pass through the link between St.5 and 7 also concentrate in order to transport the passengers effectively. In spite of such a hard situation, our proposed method can generate a sustainable route network by generating a detour route in advance, which has a high robustness to destruction of roads. Such features are very useful in a disaster.

Finally, we discuss how to increase the route network robustness. Table 6 shows the detailed analysis on both route networks. The transportation time in the non-damaged area indicates the sum of the transportation time in the OD pair except for the OD pair in the damaged area (i.e., without influence of destruction of roads). Note that the non-damaged case is different from the non-damaged area in the experiments in this paper. The former means the situation without any damaged area, while the latter means the non-damaged area in the damaged area (i.e., the safe area in the disaster situation). From this table, the proposed route network contains a few overlapping routes and is composed of short-distance routes. In fact, Fig. 15 shows that the five routes are overlapped between St.5 and 7, while Fig. 16 shows that only two routes are overlapped. If the roads where many routes are overlapped have broken links, many passengers are influenced. Such results indicate that the cluster-extension method has great potential for controlling the route’s redundant evolution and the extended evaluation function (Eq. (3)) contributes to reducing the route’s overlapping to minimize the damage of the road destruction.

7. Conclusion

This paper proposed a multiagent-based route optimization method as a next-generation transportation system to generate a sustainable route network which can transport stranded persons effectively even if the road conditions are changed in a disaster situation. For this purpose, we applied a multiagent approach into the route optimization method where an agent corresponds to one route. Such an approach is very useful in the disaster situation because it is easy to add/delete the routes and modify their routes according to the dynamic condition change and constraints. Towards a sustainable route network by multiagent approach, our route optimization method (1) employed the

bus stop clustering method to generate clustered routes, (2) introduced the cluster-extension method to connect routes in different clusters and (3) adopted the evaluation function in consideration of damage by road condition change. Through the intensive simulations on Mandl's urban transport benchmark problem, we have revealed the following implications: (1) the proposed method succeeded in reducing the number of stranded persons, detour persons, detour time, all of which are caused by road condition change; (2) detour routes have emerged, which contribute to increasing network sustainability. In detail, (2-a) the proposed method generated the short-distance route network by combining bus stop clustering with the extended evaluation function (i.e., the only route which is close to other clusters can be connected to the route in other clusters in the network modification procedure); and (2-b) the proposed method generated fewer overlapping route networks by the extended evaluation function, because much overlapping of route networks has a high risk of destruction to roads. From these results, it is clear that the proposed method has a great potential for generating sustainable route networks as the next-generation transportation system which can cope with the change of road conditions in a disaster. In fact, we succeeded in reducing 40% of the number of stranded passengers, 10% of the number of detour passengers 11% of their detour time, and 30% of the number of influenced buses, respectively. Furthermore, our proposed method succeeded in the reduction of both the passenger's transportation time and the number of buses in the non-damaged case. What should be noticed here is that these results have only been obtained from one case, i.e., Mandl's urban transport benchmark problem. Therefore, further careful qualifications and justifications, such as an analysis of results using other transport networks or large-scale networks, are needed to generalize our results. Such important directions must be pursued in the near future in addition to the following future research: (1) applying our method into actual route networks such as Tokyo; and (2) tackling a dynamic change of passengers' demand and roads' state (e.g., car accident, traffic jam, road repair).

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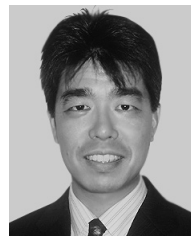
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