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The Quantitative Evaluation for Pick-Up Transportation Services Considering Spatio-Temporal Activity Diagram

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Abstract: In Japan, an aging society has come. The inhabitants of middle mountainous areas use cars as a daily transportation mode. On the other hand, most elders who cannot drive by themselves tend to depend on pick-up services by their household members. However, the pick-up service constrains both driver's and passenger's activities. In addition, household members will face more frequent pick-up needs from elders in the future, because some of pick-up service providers would be a consumer of pick-up service, by their aging. In order to tackle this problem, this study quantitatively demonstrates the hybrid transportation service such as "pick-up for feeding to bus" which combines the pick-up transportation with feeding to the regular bus services, by all the drivers in the community. The purpose of this study is to evaluate the above pick-up service according to the waiting time of pick-up and achievement rate of elder's activities.

Key Words: *middle mountainous areas, sustainability, monte-calro simulation*

1. INTRODUCTION

In Japan, an aging society has comes. Most of middle mountainous areas have few facilities for shopping, medical services and leisure activity, due to the few demand caused by the regional depopulation and aging. In other words, now inhabitants have to travel with long distance to go to commodity shops and hospitals. Most inhabitants living in these areas use cars as the daily transportation mode because public transportation services such as a regular bus are poor. Thus, the elders who cannot drive by themselves tend to depend on pick-up service provided by the household members, when they want to go out. However, the pick-up service strongly constrains both the activities of drivers and passengers, in temporal and spatial dimension (Konno *et al*., 1994). In addition, the drivers who provide the pick-up transportation to the elders will also become old, so not only the current elders but the "future" elders will also face the lack in the transportation mode to go out. Therefore, it is not sustainable for the elders to depend on pick-up transportation services by the household members.

In order to tackle this problem, new public transportation services such as community bus and DRT (Demand Responsive Transport) have been introduced in the middle mountainous communities. Many studies evaluate these services by various viewpoints (Inoi *et al*., 2004; Kishi and Satoh, 2006; Marco *et al*., 2006; Takeuchi *et al*., 2003; Yamazaki *et al*., 2005). New transportation services provide the opportunities to the elders to go out with less access distance to the pick-up station, instead of rapid transportation time and relative higher frequency. However, such the services often suffer from sustainability once they had initiated, mainly due to the low demand and high operation costs comparing to the prior forecasting. Therefore, in the middle mountainous areas with a poor public transportation, it is necessary to consider a cooperative transportation services by the community members, as to meet the needs of individual inhabitants.

In order to refine the community transportation system, Acker *et al*. (2010) insists to go back the activity-based approach for analyzing people's daily travel behavior, and discuss that people's activity pattern under their spatio-temporal constraint. Omori *et al*. (2000) apply a spatio-temporal prism constraint to an analysis of elder's travel behavior, specifically pick-up service. They describe the activity pattern using spatio-temporal paths, and try to match the elder's activity pattern with the driver's. Douglas (2006) proposes a procedure to control the round-trip route of transportation service, in order to tackle the pick-up and delivery problem. Liping (2002) also shows a simulation system for a dial-a-ride paratransit system. These studies cover the schedule matching between the provider of the pick-up transportation service and the passenger. Therefore, in order to consider the transportation service at the middle mountainous area, we should also consider the scheduling of inhabitant's daily activity and the drivers. This study proposes a "pick-up for feeding to bus" which combines the pick-up transportation provided by community members with the regular bus services operated in the trunk lines. In order to quantitatively evaluate the pick-up transportation, the possibility to match the activities of elders to go out with the activities of community members is simulated by using indices such as waiting time and the achievement rate of the round trip within a day.

2. SUMMARY OF DATA

2.1 Activity Diary and Questionnaire Survey

An activity diary and questionnaire survey were conducted in the Omach-Kujima area of Hatsukaichi City in Japan, located at the fringe of Hatsukaichi-city area, from November 19th through December 4th, in 2009. Both surveys were conducted for all inhabitants including the elders and the drivers. The items of the questionnaire were the daily living activities including pick-ups, and the hypothetical questions about the intention to use the pick-up service. As discussed in sec. 1, the pick-up service would be provided not only by household members but also by the drivers in other households. The activity diary survey was designed to record their activities per 15 minutes for 3 successive days, with activity types, day of time, and the location. Activity type classification was travel, shopping, hospital visit, leisure activity, and so on.

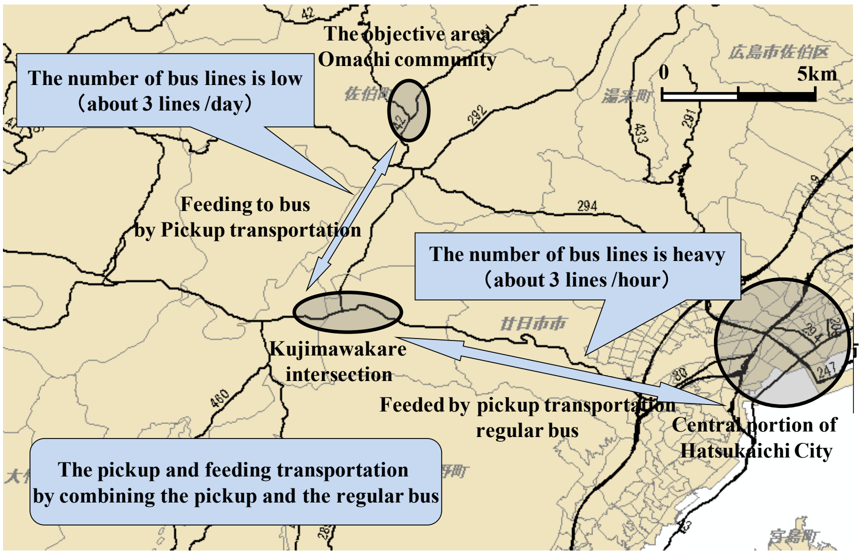

Figure 1 Location of surveyed area and range to adapt the pick-up and feeding transportation

2.2 Geographical Characteristics of the Surveyed Area

Figure 1 shows the location of surveyed area, and the target areas to adapt the pick-up and feeding transportation. Omachi community has 122 inhabitants (49 households) in 2009. The share of elders in Kujima area is 34.9 % in 2009. Omachi community and the surrounding area are depopulated regions that face problems about transportation modes and facilities. On figure 1, most facilities are located around the Kujimawakare intersection, 5 kilometers far from Omachi. Inhabitants in Omachi community have to go to Kujimawakare intersection, or to further areas in the cases of shopping, hospital visiting, and leisure activities. In addition, the inhabitants in Omachi community face the difficulties to travel to the Kujimawakare intersection due to a low frequent bus from Omachi to Kujimawakare, while the frequent bus along the trunk road going through Kujimawakare to Hatsukaichi City is provided. In other words, the inhabitants in Omachi community have to take long distances for daily activities. Therefore the inhabitants in Omachi community often could get access to Kujimawakare intersection, in order to achieve their purpose around there, or to go farther area. They can use bus services in the trunk load between Kujimawakare intersection and the central area of Hatsukaichi city. Considering those characteristics in transportation, the pick-up service between Omachi and Kujimawakare to feed into the trunk line bus service between Kujimawakare and Hatsukaichi City would improve the convenience for the inhabitants, especially for the elders who cannot drive a car.

2.3 Summary of data

We visited all 49 households in Omachi community. Consequently, we could obtain the data from 18 households. In this data, the number of driver's sample is 17, and the number of non-driving elder's sample is 12. In the activity dairy survey, the number of driver is 18, and the number of non-driving elders is 12. Note that the samples are categorized according to the individual attributes such as age, license and occupation. In this analysis, we call "drivers" who can drive a car for a pick-up service provision, except for full-time employees, while we call "elders" who are 60 or older, and cannot drive a car.
About the obtained data, following two features of daily behaviors were observed. One is that

most of the elders do not drive, and almost always depend on pick-up by household members, and do not use the bus (figure 2). The other is that all the households tend to visit around the Kujimawakare intersection, and around the central area of Hatsukaichi City. Figure 3 shows the definition of division area, and figure 4 shows the distribution of the destination zones. Such the characteristics of the daily activities of inhabitants in Omachi area would help them by providing the pick-up and feeding transportation between Omachi and Kujimawakare intersection to Hatsukaichi (figure 1).

The hypothetical question about the possibility of participating in the pick-up service is made. We assumed that this pick-up service is provided by the community members with no fare, and the elders can use this service when they go out. Figure 5 shows the intention of elders to use the pick-up service, and figure 6 shows the intention of drivers to participate in the service on these figures, if the conditions are fulfilled, more than 80% of elders answered to use the pick-up service, and more than 75% of drivers answered that they can participate in the service. Consequently, the pick-up service by the community members would work in terms of the demand (i.e., elders) and the supply (i.e., drivers).

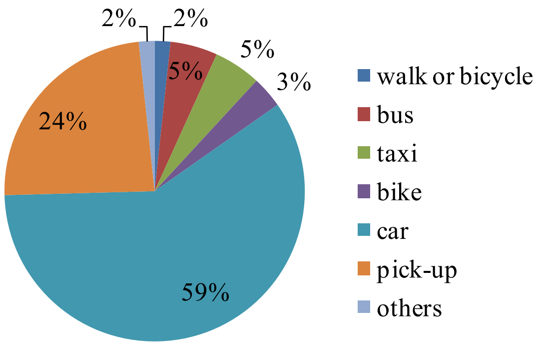

Figure 2 Main transportation mode

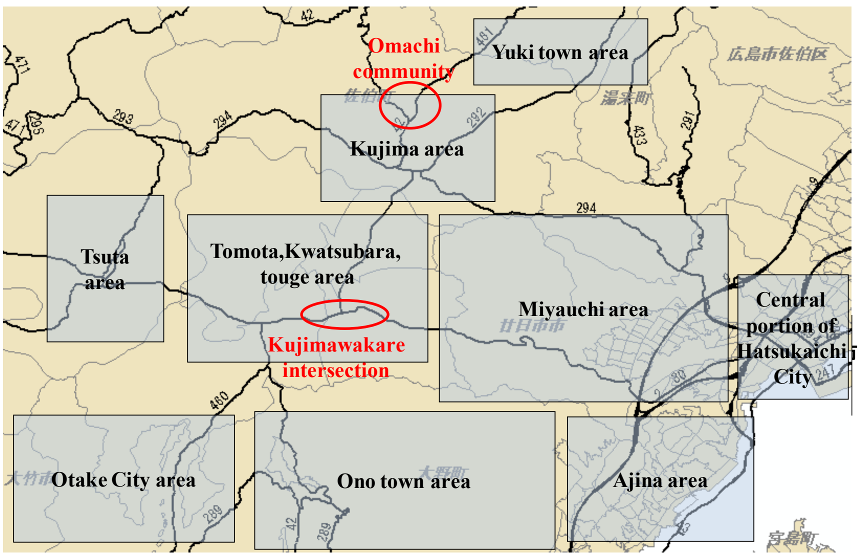

Figure 3 Definition of the division area

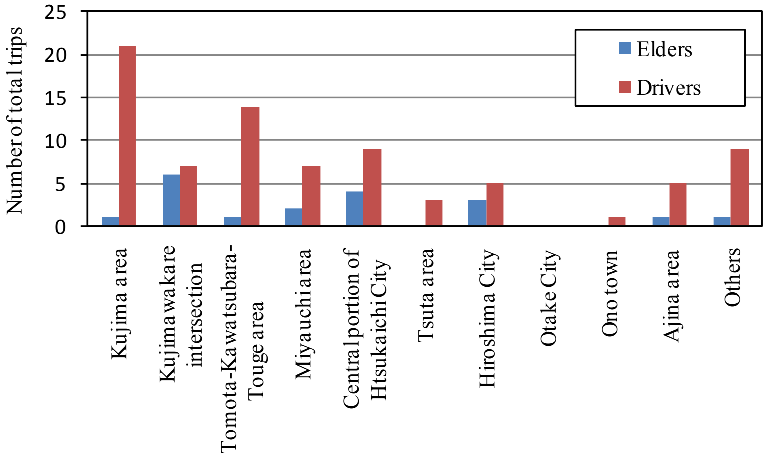

Figure 4 Destination zones of daily activity

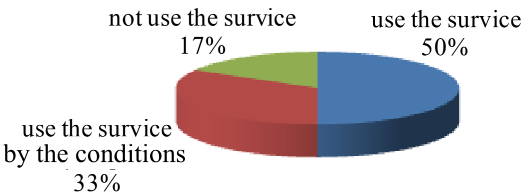

Figure 5 The intention of elders to use the pick-up service

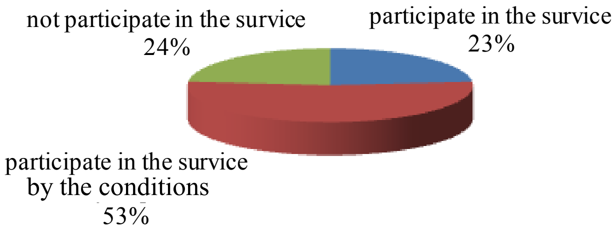

Figure 6 The intention of drivers to participate in the pick-up service

3. SIMULATION PROCEDURE

In order to quantitatively evaluate the effectiveness of the pick-up for feeding into bus, the schedule matching between the driver's trips for out-of-home activity departing from Omachi in a day and the elder's trip is simulated. The driver's round trip chain from home via destination to home can be described by spatiotemporal activity diagram. When an elder goes out by using other driver's car, he/she moves along the driver's activity diagram. Here, we assume that the elder can change the accompanied driver on a way of the round-trip. In other words, elders have a possibility to use a pick-up service provided by multiple drivers during their trip, rather than a single driver. Therefore, the driver's activity diagram consists of a set of driver's activity paths in a day, departing from Omachi to other areas via Kujimawakare.

3.1 Building an Activity Diagram of Drivers

The spatiotemporal activities of drivers are made up as follows. The time period is set at each 15 minutes-period, from 5:00 to 21:15, thus totally 65 periods in a day. Figure 7 shows the definition of staying zones between Omachi and Hatsukaichi, including Kujimawakare. If the trip is end up within 15 minutes, the zone of that time period is the zone staying with the longest minutes within the 15 minutes. Note that the input data for the activity diagram is several driver's data, and each data includes whole trip chain in a day. On an activity path of one driver, a node indicates the location at a specific period, and a link indicates the transition of period or location, therefore the link means staying or travel. For the convenience of simulation, each node is numbered with an ascending order along the time axis. When an elder goes out helped by other driver, the elder starts to move along the shortest period after the starting time for the destination on the driver's activity diagram, and go home on the diagram again after staying at the destination with some necessarily periods. Considering the whole community level, many drivers go out and back to the home in a day, and on the most of their trips, the seats of car are available. On a way of elders going out, the waiting time at same locations will occur if there is no available link to move for the destination or for the home, at the occasion when they arrive an intermediate node, or when they finish the activity at the destination. For describing such situation, some nodes are inserted on the periods from the earliest arrival to the latest departure time in each location among the drivers; then, all the nodes placed in between that periods are connected by links. Figure 8 shows the setting of nodes and links.

3.2 Activity Paths of Elders

The activity path of elders is made on the driver's diagram. The desirable activity path is searched by using Dijkstra's algorithm, which can search the tree shaped shortest path group i.e., from the departure node as a root to all other nodes as leafs.

Dijkstra's alogorithm is applied for going way to destination, and returnning way to home, respectively. Since our activity diagram includes unidirectional links along with the time axis,

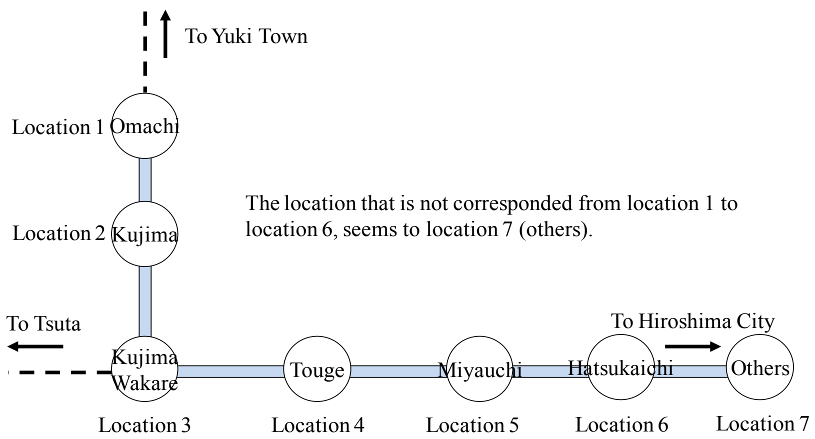

Figure 7 Definition of zones

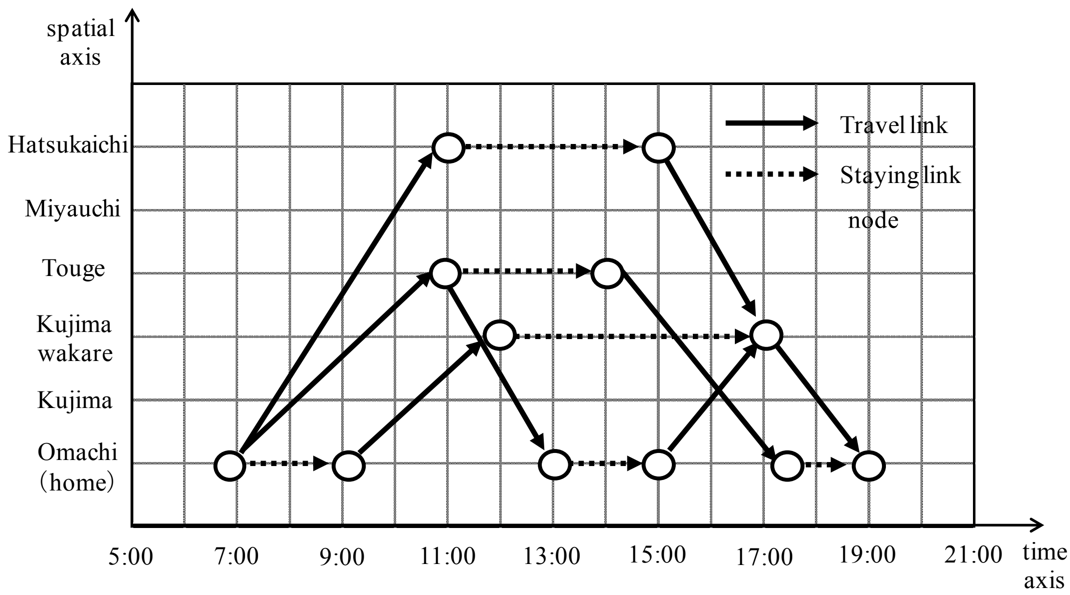

Figure 8 Setting of nodes and links

the shortest path search should be done only to include the links along the time axis. For this purpose, the cost of time-flow direction is set as an unit period (i.e. 15minutes), and the cost of the anti-time flow direction is set as infinite. Among the obtained tree shaped paths, the path to a given destination with the earliest arrival time is selected as the forward path. The elder stays at the destination for required periods, and starts to go back home. The starting node of the backward trip is set by adding the required periods at destination to the arrival time. The calculation procedure of backward path is identical to that of the forward path. For the above calculation, the departure time from Omachi and the required stay at a destination of an elder, and an available activity diagram of drivers should be prepared.

3.3 Calculation of Average Waiting Time

In our study, waiting time can be calculated from the periods on elder's activity paths, except for the required periods at the destination for trips. Figure 9 shows an occurrence of the waiting time. In this figure, the bold path indicates comparing the actual activity path by using household pick-up service, while the dotted path indicates the activity path using an pick-up service of drivers, some waiting periods are generated at home and destination. It is obvious that the waiting time of elder's activity strongly depends on the combination of the pick-up service providers (i.e. drivers). In order to obtain a stable implication, we applied a Monte Carlo simulation over the driver's random combination, and then compute the average waiting time and the achievement rate of the round trip within a day on each driver's diagram. Average waiting time and the achievement rate of elder's activity are calculated as eq. (1), (2) respectively.

$$E[W_{ij}] = \frac{\sum_{n=1}^{N} W_{ij}^{(n)}}{N}, \quad W_{ij}^{(n)} = td_{ij}^{(n)} - ta_{ij}^{(n)} - T_{ij}^{(n)} \tag{1}$$

$$A_i = \frac{\sum_{n=1}^{N} s^{(n)}}{N} \tag{2}$$

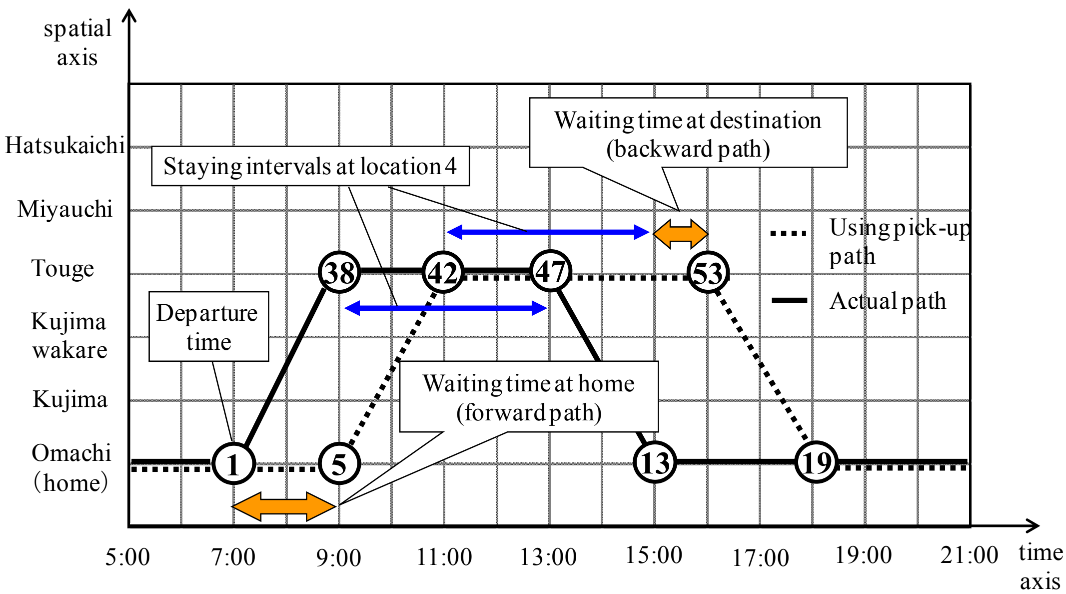

Figure 9 Situation of generated the waiting time

where n is a number of iteration ($n = 1,\ldots,N$), W_{ij} is a waiting time of elder i at a location j, ta_{ij} is an arrival time that elder i arrive to the location j, td_{ij} is a departure time that elder i depart from the location j, T_{ij} is staying period to conduct activity of elder i at the location j, and $E[W_{ij}]$ is the average waiting time of elder i at the location j (eq. (1)). A_i is an achievement rate of elder i, and $s_n = 1$ represent that driver's diagram is available for elder i, while $s_n = 0$ represent that driver's diagram is not available for elder i, within a day (eq. (2)). The waiting time can be calculated for each location or for each period. The former is the staying time at each location to get a ride or buses, except for time of conducting activities. The later is calculated at each time period in the same way. The achievement rate of elder's activity is defined as the share of "success" in the round-trip i.e. able to go back home by 21:00, over the total simulated number N. Figure 10 summarizes the above calculation processes.

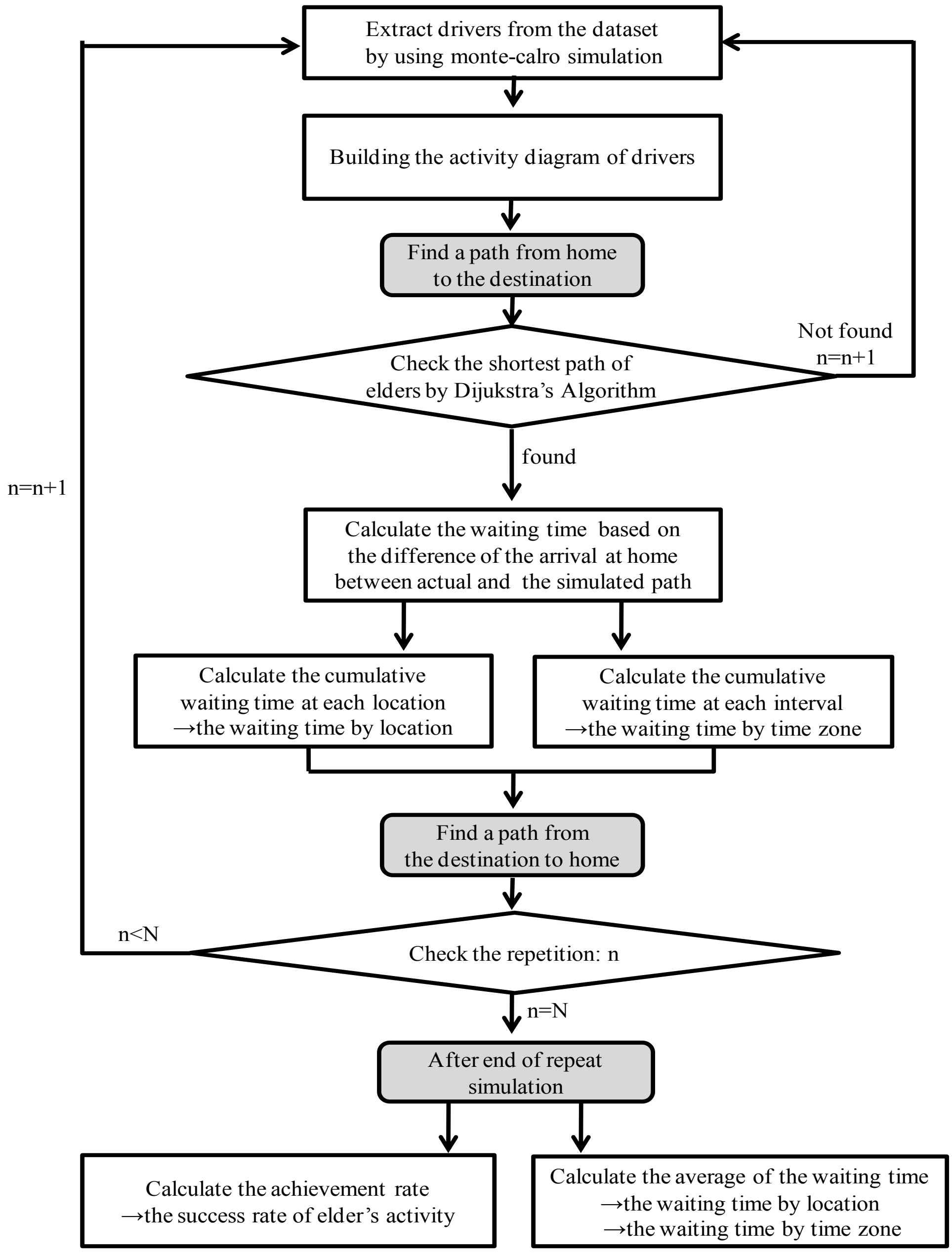

Figure 10 Algorithm to evaluate the elder's going out

4. RESULT OF SIMULATION

Simulation scenarios are set as follows; the case of using the pick-up service by household members (Case 1), the case of the pick-up service (by household members) and the bus service (Case 2), the case of the pick-up (by the community drivers who have the intention to participate in the pick-up service) and the bus service (Case 3), and the case of the pick-up (by all the community drivers) and the bus service (Case 4). Note that in this simulation, the drivers and the elders don't adjust their schedule prior to trip generation. In other words, the elders would not change the departure time even if they have no available activity path of the drivers and, vice versa. The available activity path for the elders is distinguished from the differences in the driver's activity diagram setting. Input data are prepared as follows: the driver's diagram composed of identical household in Case 1, the bus diagram and the driver's diagram composed of identical household in Case 2, the bus diagram and the driver's diagram of respondents at hypothetical question (figure 6) who answered they participate in the pick-up service (including with any requirements) in Case 3, and the bus diagram and all driver's diagram in Case 4. The Monte Carlo simulation over the driver's random combination is applied for these four scenarios from Case 1 to Case 4.

Table 1 show the achievement rate of elder's activities and the expected total waiting time in each case. About the achievement rate of elder's activities, in Case 1 very low achievement rate is often observed because elders would be stuck in their house due to no available pick-up service, and similar results are found in case 2. However, the achievement rate is significantly high in Case 3, Case 4. On the other hand, the total waiting time in Case 3 and Case 4 is less than 90 minutes, especially less than 60 minutes in case4, except for a sample No. 7. So it would be acceptable for the elders to wait at the destination or other out of home location. From these results, we can conclude as follows; when elders depend on pick-up by household members, the elders tend to give up to go out. While the elders use the pick-up service by other household members and bus service, they are easy to go out. There is a little difference between case 3 and case 4, which is different in the member of participating drivers. Even the drivers are limited who have a willingness to participate in the system, the pick-up transportation will large benefit on the elders.

Figure 11 to figure 14 show the waiting time by each location. Note that the departure time in those figures indicates the each elder whose activity schedules are different. In Case 2, a few samples with high achievement rate (sample No. 1, 3) have more than 60 minutes at Kujimawakare and Miyauchi, respectively. In Case 3 and Case 4, various waiting time from 0 minutes to 60 minutes at Kujimawakare (figure 13 and figure 14) is obtained. This probably indicates that elders transfer their travel mode from car to bus at Kujimawakare where frequent bus services are available. At that, it is considered that transfers between car and bus often occur at around Kujimawakare intersection due to the long waiting time. In other words, Kujimawakare intersection is the important hub under the pick-up and feeding transportation.

Consequently, this simulation gave the implications that the pick-up feeding transportation service will significantly improve the achievement rate of elder's activities, and the decreased waiting facility will contribute to lessen the physical fatigue of the elders.

Table 1 Achievement rate of elder's activities and total waiting time

Sample No.	Departure time	Destination	Staying intervals	Achievement rate of elder's activity				Total waiting time (minutes)			
				Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
1	6:00	Hatsukaichi	525	0.73%	60.83%	93.82%	96.71%	150	150	45	15
2	7:30	Kujimawakare	150	0.00%	0.00%	100.00%	100.00%	-	-	60	45
3	8:30	Kujimawakare	195	99.99%	100.00%	100.00%	100.00%	15	225	60	60
4	8:45	Kujimawakare	90	0.00%	0.00%	100.00%	100.00%	-	-	30	30
5	10:15	Miyauchi	105	0.00%	0.00%	100.00%	100.00%	-	-	75	0
6	13:45	Miyauchi	75	1.02%	16.88%	96.22%	99.17%	0	30	30	30
7	15:30	Kujimawakare	15	0.00%	0.00%	54.30%	62.48%	-	-	90	90

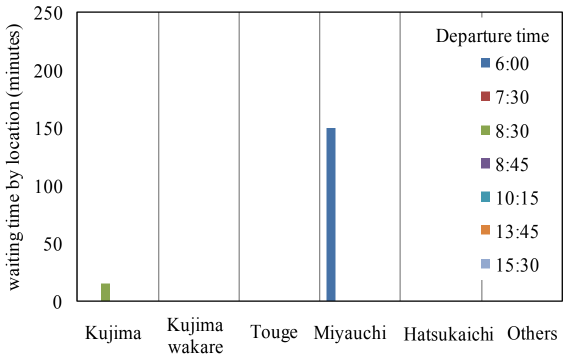

Figure 11 Average waiting at each location (Case 1)

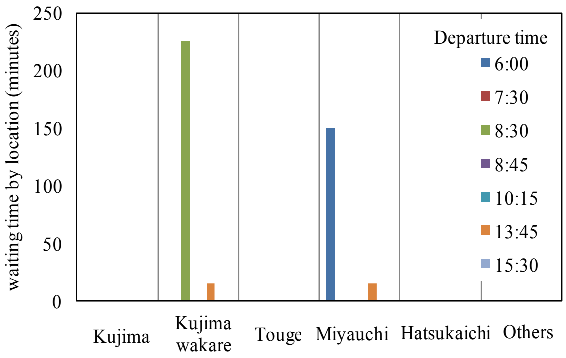

Figure 12 Average waiting at each location (Case 2)

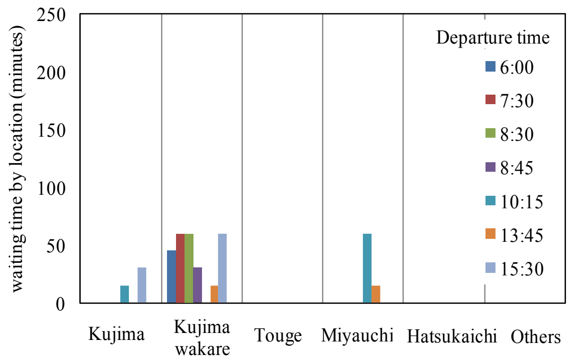

Figure 13 Average waiting at each location (Case 3)

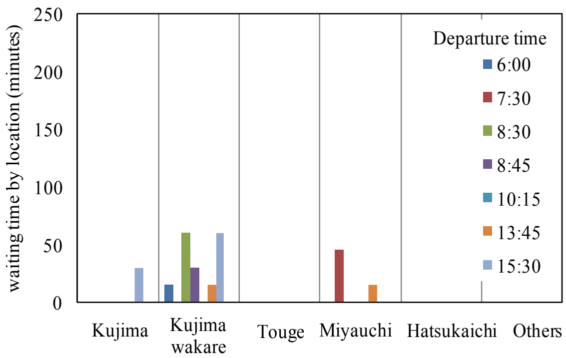

Figure 14 Average waiting at each location (Case 4)

5. CONCLUSIONS

This study proposed a quantitative evaluation procedure of the transportation service, especially in the pick-up transportation service. We proposed the pick-up and feeding transportation service at the relatively small community area, in order to evaluate the feasibility of pick-up service under the several conditions and other pick-up services. In the proposed procedure, we built an activity diagram from the dataset of activity diaries of pick-up service providers, regular bus diagram, and calculated the achievement rate of elder's activities, and the waiting time by each location and by each period. From the result of simulation, it is clarified that the achievement rate of elder's out-of-home activities were significantly improved by introducing the pick-up and feeding system, and the waiting time was also improved. Elders can easily achieve their out-of-home activity when they use the pick-up and feeding transportation, without too long waiting time. The proposed procedure would be useful not only for assisting the planning in pick-up transportation but for supporting low demand public transport system such as DRT or shared taxies.

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