A FEASIBILITY ANALYSIS OF INTRODUCTION OF SMALL CAPACITY PUBLIC TRANSPORT SYSTEM IN AN AREA WITH SPARSE PUBLIC TRANSPORT DEMAND

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ABSTRACT

This study aims to provide highlights for selection of cost-efficient and user-convenient public transport services to sparse demand in rural areas in Japan. As an effective way, smaller capacity public transport systems including demand responsive transport (DRT) are discussed.

The estimation system is applied to case study area and several results are got: 1) for passengers, increasing fares are more effective than frequencies and connections of route for residents. 2) Operation costs may be reduced until a certain level of passengers. However for higher demand, necessity for more vehicles may increase the total cost.

Keywords: Demand Responsive Transport (DRT), Bus, Local Public Transport Service, Rural Area

INTRODUCTION

Local bus services in Japan are experiencing rapid declines in passenger numbers. Private bus operators are struggling to provide sustainable bus services, particularly in rural areas where private cars generally provide mobility.

While many bus routes currently receive government subsidies, Japan's financial and economic difficulties are making these subsidies more difficult to maintain.

On the other hand, transport systems have been expanding their roles to encompass the increasing number of people who are "mobility handicapped," namely the elderly and disabled. Therefore, providing cost-efficient public transport services in these areas is important. In this context, smaller capacity public transport services are currently drawing greater attention in Japan.

This paper provides guidelines for selecting cost-efficient and user-convenient public transport services in rural areas of Japan, where user demand has declined significantly. Such systems, which include smaller capacity buses and demand responsive transport (DRT) systems, are alternatives to current public transport systems in rural areas.

CHARACTERISTICS OF SMALLER CAPACITY PUBLIC TRANSPORT SYSTEMS AND LITERATURE REVIEW

Characteristics of Smaller Capacity Public Transport Systems

Smaller capacity public transport systems have the following characteristics:
1. They use smaller capacity vehicles. (In Japan, such vehicles generally carry nine passengers.)
2. They provide share-ride services that do not limit the number of passengers.
3. They include both fixed route and/or time-schedule bus services as well as demand responsive transport (DRT) systems

Smaller capacity public transport systems help reduces operating costs. In this context, DRT systems are a very important alternative to conventional bus systems, as DRT systems easily meet the public transport needs of residents in rural areas.

Literature Review

Existing research into alternative smaller capacity public transport services have focused mainly on DRT systems. For example, Takeuchi *et al.*, 2003, analyzed the operating costs of DRT systems and evaluated the changes in costs when conventional bus services are replaced by DRT systems. Diana and Dessouky, 2003, examined the Dial-a-ride problem

and solution and the efficient allocation and control of vehicles in DRT systems. Noda *et al.*, 2008, used computer simulations to analyze the relationship between user convenience and profitability for both DRT systems and fixed-route bus systems. Ueshima *et al.*, 2004, considered the level of service in DRT systems by applying an algorithm for allocating vehicles when the number of vehicles is constrained. Yoshida *et al.*, 2006, used a computer simulation with real data to analyze the possible results of implementing DRT systems in urban areas.

Hara *et al.*, 2005, categorized past and current implementations of DRT systems and underlined the issues that require consideration when planning DRT systems. Takeuchi and Yoshida, 2006, examined the integration of DRT systems with other means of transport.

Some countries of the European Union consider DRT systems to be excellent and efficient alternative systems and have developed various systems for allocating vehicles. (Relevant reports exist; for example, FAMS Consortium, 2005.).

This study aims to contribute to the literature by evaluating the results of a mathematical simulation that we developed to examine the efficiency of smaller capacity public transport services that may be alternatives to ordinary bus systems.

SIMULATION OF SMALLER CAPACITY PUBLIC TRANSPORT SERVICES

Mathematical Simulation of Smaller Capacity Public Transport Services

Framework for mathematical simulation

The results of a questionnaire were used to estimate the modal shift of public transport users to a smaller capacity system from a current bus service on fixed routes.

The parameters for different levels of service are estimated and then used to estimate demand. Difficulties and constrains arising from modal integration over the entire network, as well as telephone reservations, are incorporated into the models so that the demand analysis of DRT systems can account for the simultaneous impacts of these two important issues.

The total operating cost of a DRT system is estimated from the unit operating cost and the total number of vehicles and services, which are determined from the estimated demand for the DRT system. Figure 1 shows the framework for the mathematical simulation.

a) Scenario settings for implementing smaller-capacity public transport services

b) Estimation of parameters for demand analysis

c) Total passenger demand

d) Control of vehicle allocation
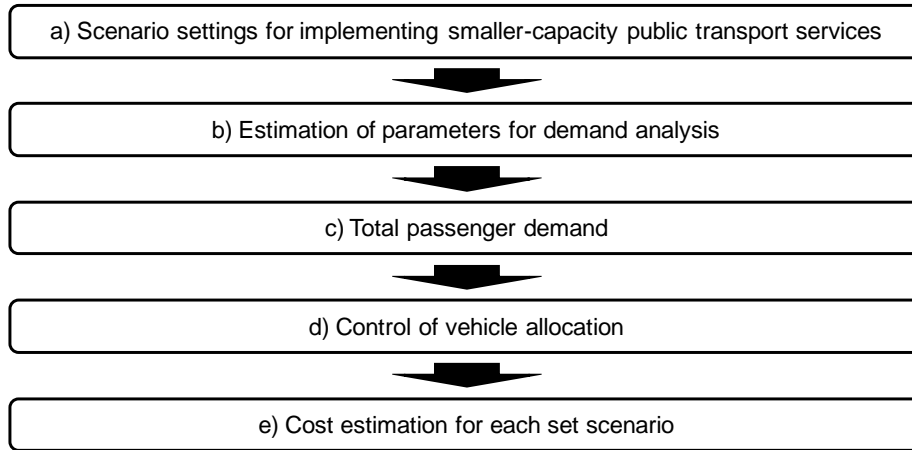
e) Cost estimation for each set scenario

Figure 1 - Framework of simulation

a) Scenarios for implementing smaller capacity public transport services

This study considered the following three scenarios.
1) A smaller bus, rather than an ordinary-size bus, is used at the terminal point
2) DRT service is introduced at the terminal point for connecting bus routes
3) DRT service is introduced and operated in parallel with conventional bus services.

b) Estimation of parameters for demand analysis

The total volume of public transport demand and the destinations in the area considered in this case study are calculated using the number of passengers and the origin-destination data from buses on the current routes. The number of passengers by destination is estimated from the ratio of total public transport demand to the population at the end points in the study area. The parameters are estimated using the results of a questionnaire.

c) Total passenger demand

The total passenger demand is calculated using the estimated parameters from step b) and the population in the vicinity of the bus stops. Basically, two estimates are made. The variations in the number of passengers in the study area are the same as those observed for buses on current routes, and the induced demand, if any, caused by the implementation of the DRT system is not considered.

d) Control of vehicle allocation

DRT vehicle allocation is based on a single service per hour rather than on a time schedule. The vehicles travel the shortest route from the origin to the destination and pick up

passengers. In the case of a fixed-route and time-schedule system, vehicles are allocated in a manner similar to that for bus services on current routes.

e) Cost estimation for each set scenario

The total operation cost is the total length of vehicle travel calculated from simulations multiplied by the cost per kilometer. The number of vehicles required is calculated at the same time.

Model for Estimating Passenger Demand

Basic case

Figure 2 shows the basic case. The bus route from city center C to end point E through sub-center S is given. The frequency of service f (one-way services per hour) changes at sub-center S. The fare is defined by φ (JPY). Passenger demand is given by transport volume D (persons traveling one-way per day). D has two forms; along a bus route to C ($D_{\to C}$), and along a bus route to S ($D_{\to S}$). These two types of demand are expressed by formulas (1) and (2) below.

$$\Delta D_{i \to C} = \alpha \cdot P_i \cdot (L(f_i, \varphi_i))^{\beta} \quad (1)$$

$$\Delta D_{i \to S} = \lambda \alpha \cdot P_i \cdot (L(f_i, \varphi_i))^{\beta} \quad (2)$$

ΔD_i: number of passengers from bus stop i (persons)
P_i: population in the vicinity of bus stop i (persons)
$L(f_i, \varphi_i)$: level of service (defined by frequency f (services per hour) and fare φ (JPY))
α, λ: parameters estimated by the demand to C and S by bus (λ: ratio of demand from i to S to i to C)
β: constant ($\beta > 0$)

Formulas (1) and (2) indicate that the number of passengers in a population increases when the level of service L increases. Frequency f and fare φ are the only explanatory variables of L that are considered. β is a parameter that shows the increase in demand caused by an increase in L. The total operating time per day H_1 (hour) and the total operating cost C_1 (JPY) are described by formulas (3) and (4), given below.

$$H_1 = T(2f_l)(t_m + t_l + \tau) + T\{2(f_m - f_l)\}(t_m + \tau)$$
$$= 2T\{f_m(t_m + \tau) + f_l t_l\} \quad (3)$$

$$C_1 = c_b \cdot V \cdot H \quad (4)$$

T: operating hours (h)

τ: waiting time per service (h)

c_b: basic operating cost (operated bus (b)) (JPY per kilometer)

V: travelling speed (km per hour)

m: main line

l: feeder lines

The number of vehicles N (vehicles) is equal to the total number of services per hour when the frequency is f_m and to f_l when the frequency is constant. (Formula (5) does not consider spare vehicles.)

$$N_1 = 2f_l(t_m + t_l + \tau) + 2(f_m - f_l)(t_m + \tau) \qquad (5)$$

This formula rounds up the results of H/T in order to ensure that the number of vehicles will meet total demand.
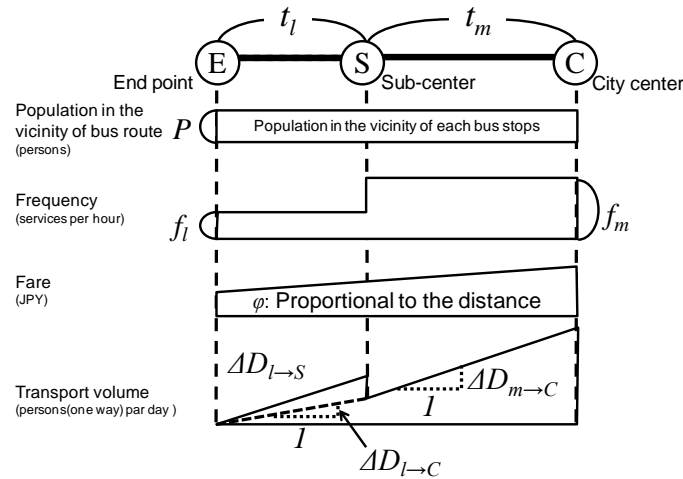
Figure 2 - Basic case

When the feeder line is separate from the main line

$$C_2 = 2T \cdot V \cdot \{c_b \cdot f_m'(t_m + \tau) + c_s \cdot f_l'(t_l + \tau)\} \qquad (6)$$

Figure 3 presents the case of a current bus route divided into a main line (C to S) and a feeder line (S to E) at sub-center S. Bus operations on the main line use the same schedule and vehicle fleet as the current service. However, bus operations on the feeder line use smaller vehicles with a more economical basic cost (c_s). The frequency changes to f_m' and f_l'. The total operating cost C_2 is expressed by formula (6).

$C_1 \geq C_2$ is calculated from formulas (4) and (6).

$$\frac{c_s}{c_b} \leq \frac{f_l \cdot t_l - (f_m' - f_m)(t_m + \tau)}{f_l'(t_l + \tau)} \qquad (7)$$

Formula (7) can be used to examine the extent of an increase in f_m or f_l for a fixed operating cost ($C_1=C_2$).

The number of vehicles N_2 is expressed by formula (8).

$$N_2 = N_2{}^b + N_2{}^s$$
$$= 2f_m{}'(t_m + \tau) + 2f_l{}'(t_l + \tau) \qquad (8)$$

In this case, the same vehicle fleet cannot be used on both the main and feeder lines. The route is divided at sub-center S, and the number of passengers from the surrounding areas traveling to C is likely to decrease. This is expressed by formula (9).

$$\Delta D_{i \to C} = r \cdot \alpha \cdot P_i \cdot \left(L'(f_i, \varphi_i)\right)^\beta \qquad (9)$$

r: ratio of change in demand resulting from need to make a transfer
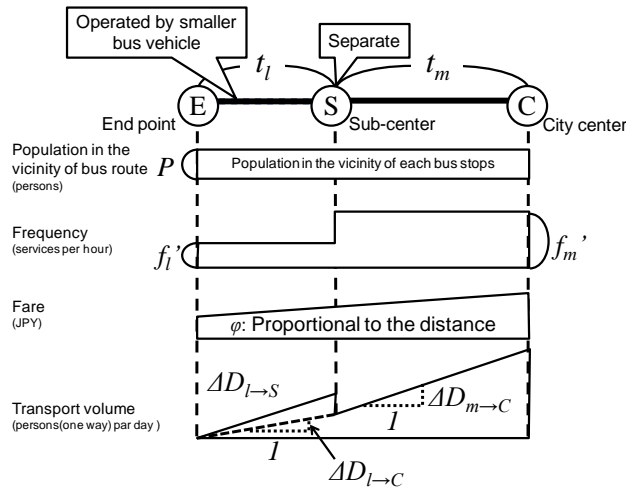
Figure 3 - Feeder line is separate from main line

DRT systems as feeder lines

Figure 4 shows that the current bus route is divided at sub-center S, with a DRT system serving the surrounding areas. The number of passengers travelling from the surrounding areas to city center C is likely to decline because the passengers must transfer at sub-center S to the main bus line. The number of passengers may increase after a DRT system is introduced because they can board DRT vehicles at their homes rather than walk to a bus stop. However, the number of passengers is likely to decline because a reservation must be made, which may be perceived as an inconvenient way of using a public transport system. Passenger demand is expressed by formulas (10) and (11).

$$(\Delta D_{i \to C})^D = d \cdot r \cdot \alpha(sP_i) \cdot (L(f_i, \varphi_i))^\beta \qquad (10)$$

$$(\Delta D_{i \to S})^D = d \cdot \lambda \cdot \alpha(sP_i) \cdot (L(f_i, \varphi_i))^\beta \tag{11}$$

d: ratio of change in demand resulting from the need to make a reservation

r: ratio of change in demand resulting from the need to make a transfer

s: constant for the improved user-convenience resulting from the convenience of boarding vehicles at the home

d·r·s=1, in formula (10) and *d·s=1* in formula (11) are equal to formulas (1) and (2). This indicates that the increase in the number of passengers is covered by any decrease resulting from the needs to make transfers and reservations.

The operating cost is calculated using formula (4). In DRT systems, t_l is arbitrary. If the number of passengers increases, the operating cost and t_l also will increase. In this case, the DRT capacity is constrained at sub-center S because the vehicles must wait for passengers connecting to and from the main bus line.
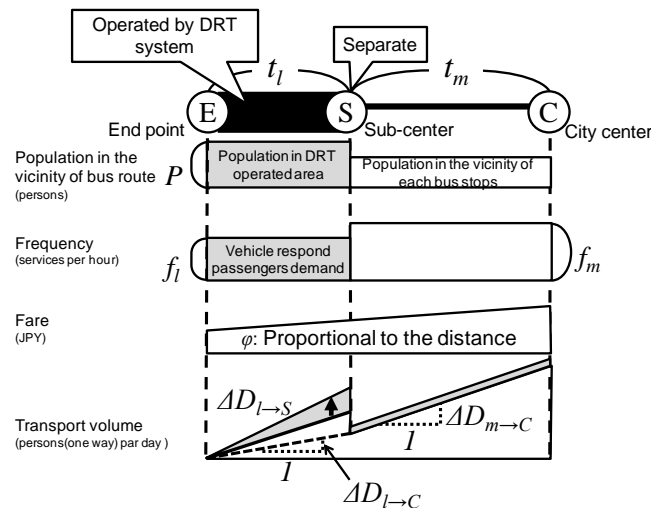

Figure 4 - DRT system introduced in feeder line

OUTLINE OF CASE STUDY AREA AND QUESTIONNAIRE

Case Study Area

This case study examines an area in the western part of Tahara City, which is located in Aichi prefecture, Japan. The major industry in this area is large-scale farming and the population density is very low. The number of bus passengers also is very low because of the extensive use of private cars. Figure 5 shows the available data and the public transport system for the area.

A private bus company runs a single bus over two bus routes. This case study examined the Irago-honsen route, which is the main bus line.

Figure 6 shows the number of passengers on the Irago-honsen line. Passenger demand between central Tahara (C: City center) and Hobi (S: Sub-center) is much higher than it is between Hobi (S) and Cape Irago (E: End point). The average number of passengers per service is 16.1 between C and S and only 3.0 between S and E. The number of services between S and E is half that between C and S.

For these reasons, this study explores the impacts of replacing an ordinary bus system with a smaller capacity DRT system in the section between S and E and the surrounding area.
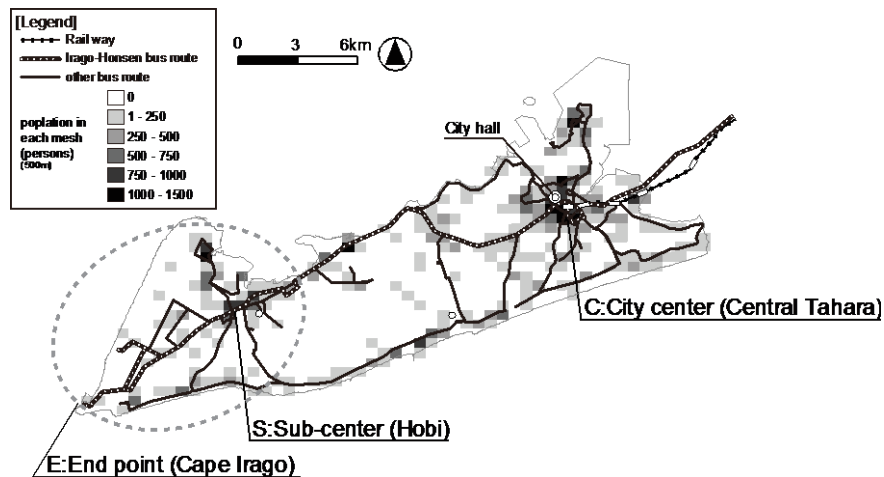
Figure 5 - Population distribution and public transport network in Tahara City
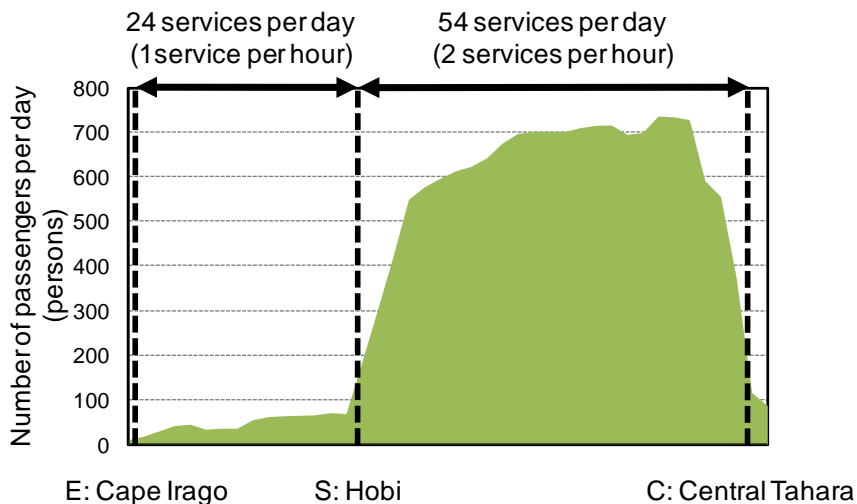
(Circle indicates area of case study)

Figure 6 - Number of passengers on Irago-honsen route

The Questionnaire

Possible changes in passenger demand resulting from replacing the current bus system with a smaller capacity public transport system are estimated using the results of a questionnaire that was conducted to learn passenger preferences. Table 1 is an outline of the questionnaire.

Table 1 - Outline of the questionnaire

Subjects	Bus passengers (without students)
Route	Community bus Nakayama route
Dates conducted	21–23 January 2008 (3 days)
Questionnaire	
Content	Characteristics of current bus use Perceived use (boarding) for each level of service and DRT 　- Changes in the number of passengers (boarding) resulting from increasing the fare from 100 JPY(current fare), to 200 JPY, 300 JPY, and 500 JPY 　- Changes in the number of passengers (boarding) resulting from requiring a transfer at point S for travel to the city center 　- Changes in the number of passengers (boarding) resulting from adding new added bus stops in front of homes and from the requirement to make reservations by telephone
Number of Samples	4

The frequency of ridership is defined by the average of number of boarding per person.

The questionnaire offered six possible answers. The answers are converted into an average number of boarding. Table 2 lists the possible answers and the results for the boarding frequency.

Table 2 - Options for boarding frequency question

Answer	Average of number of boarding per person
Every day	1.00
2 or 3 times per week	0.36
Once per week	0.14
2 or 3 times per month	0.10
Once per month	0.03
Not used	0.00

Figures 7 to 9 show the results for the stated preferences of the questioned residents. Each parameter is expressed as a ratio of increase or decrease in the average number of boarding per person in comparison to the current number of boarding per person.

Residents tend to use fewer buses in the case of an increase in fares from 100 JPY (current situation) to 200 JPY (Figure 7). In contrast, increase in the number of services does not have a significant impact on the residents' preferences for bus use (Figure 8).

These values directly describe the residents' preferences for public transport use resulting from any change in the level of services L. Therefore, β in Formulas 9 through 11 need not be considered.

The ratio r, showing the change in the number of boarding resulting from the need to transfer to other lines, could not be determined because the questioned passengers were not O/D users and, therefore, did not require such a transfer.

In the case of a DRT system, d, which is the ratio representing the difficulties caused by the need to make a reservation, is 0.76. The ratio s for the changes in the residents' preferences when using a DRT system, which allows the passengers to board the vehicles at their homes, is 1.22 (Figure 9). This proves that, under both negative and positive conditions, the total number of passengers before a DRT system is introduced tends to differ little from the total number after the system is introduced.

The parameter α represents the ratio of demand from E and S to the city center C and is calculated by dividing the total number of passengers per day travelling from E and S to the city center C (38 passengers per day) by the population of area (13,928). Similarly, λ is the ratio representing the demand variation, and it is the ratio of demand from E and S to the city center C to the demand to S (2 passengers per day). Table 3 lists the results.
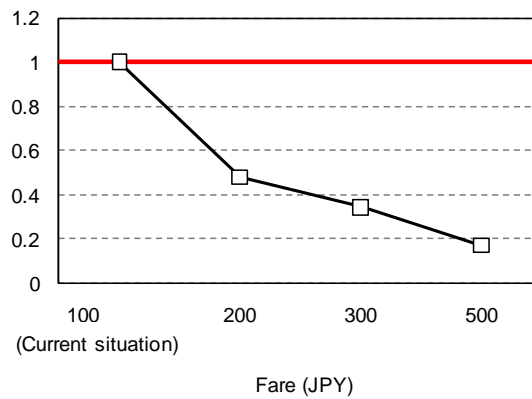

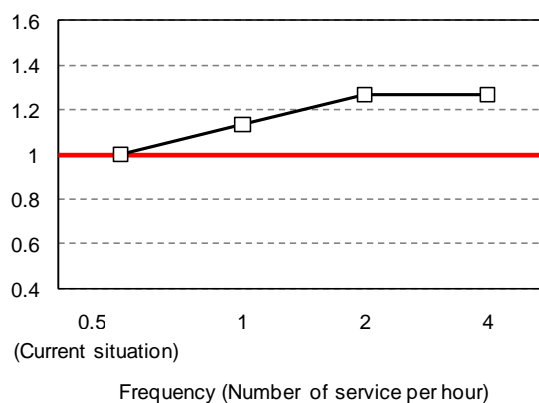Figure 7 - Changes resulting from adjusting the fare

Figure 8 - Changes resulting from adjusting the service frequency
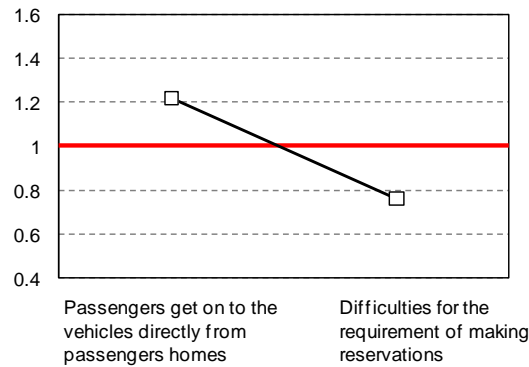
Figure 9 - Changes resulting from introducing a DRT system

Table 3 – Estimations of Parameter

α: parameter for public transport demand in surrounding areas from E and S to city center C	0.0024
λ: ratio representing the demand variation. It is the ratio of demand from E and S to the city center C to the demand to S	0.075
d: Difficulties resulting from the need to make reservations	0.76
s: ratio for the changes of residents' preferences in the case o using DRT system which allows the passengers to board the vehicles at their homes	1.22

CASE STUDY FOR SMALLER CAPACITY PUBLIC TRANSPORT SERVICES IN AREAS WITH SCANT DEMAND

Scenarios

The main point of this case study is to examine the development of smaller capacity public transport services and the introduction of a DRT system on a route between Hobi (S) and Cape Irago (E). The level of service on the main line between Central Tahara (C) and Hobi (S) is assumed to be the same as the current level. Accordingly, three scenarios were created to test the new services and the DRT system over a simulated period of 30 days using a mathematical model.

Scenario 1

This scenario divides the Irago-Honsen route at S and introduces a smaller capacity bus in E at S. Schedules and fares remain unchanged. This scenario verifies that smaller capacity public transport services may reduce costs in areas with few public transport passengers.

Scenario 2

This scenario introduces a smaller capacity bus and DRT service between E and S and the surrounding area. The operation schedules differ from the current timetables (C to S to E: one service per hour, C to S: one service per hour) to timetables that allow transfers at S (C to S: two services per hour, S to E: one service per hour). The time limit for controlling DRT vehicle allocation is sixty minutes, which takes into consideration the current scheduled trip length from E to S, which is forty-two minutes. The number of vehicles is increased only when the current number of vehicles cannot meet passenger demand. The fares for the routes between E and S and S and C are 100 JPY and 200 JPY, respectively.

Scenario 3

This scenario introduces a DRT system for the route between E and S. The DRT routes also directly enter the city center C. The time limit for controlling DRT vehicle allocation is the same used in scenario 2. Half of the total number of vehicles between S and C are replaced with smaller capacity vehicles. The fare system also is the same used in scenario 2.

Setting the DRT line

Figure 10 shows the road network in the area examined in this case study. This area has a population of 13,928. The DRT route is defined by fixing the start and end points at S. This is because, in scenarios 1 and 2, passengers travel to the city center C and transfer to buses at S, while in scenario 3, the DRT buses follow the same route taken by conventional buses between S and C.
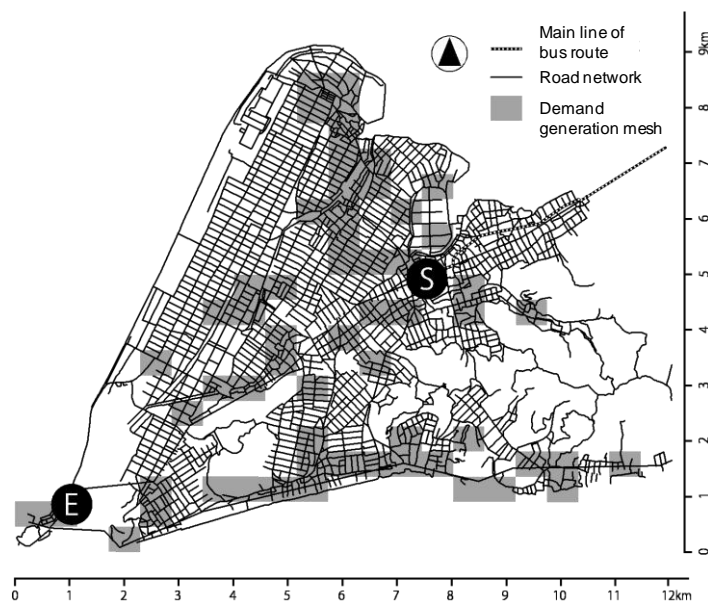

Figure 10 - Road network in the area examined in this case study

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Simulation

Number of trips

The total number of DRT passenger trips from the area of the case study to S and C are estimated using the above parameters α, λ and population P. DRT demand is stochastic, and the total number of DRT passenger trips is distributed among the grids. Trips are generated randomly within each grid, and vehicles are allocated to fully meet the demand. The distribution of trips within each grid is determined proportionately to the population rate. When each passenger uses DRT for a round trip, the number of passenger trips is defined by the number of calls for DRT vehicles. We call this "volume of demand."

The changes in the number of passengers over time are defined by the daily volume of demand distributed hourly on a bus route. Figure 11 shows the hourly fluctuations in the number of passengers on the current bus route from E to S.
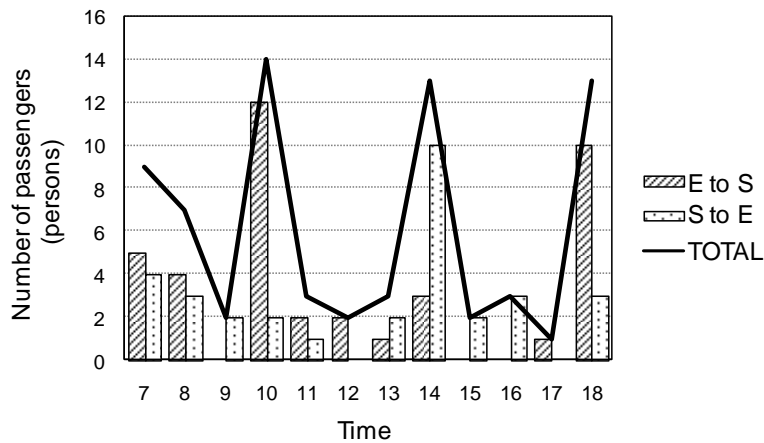

Figure 11 - Hourly fluctuations in the number of passengers for the current bus route from E to S

Table 4 - Total volume of demand per day

Fare	Section	Volume of demand
E to S	E to C	31
100	E to S	3
JPY	TOTAL	34
E to S	E to C	15
200	E to S	2
JPY	TOTAL	17

In scenario 1, the change in the number of passengers does not affect vehicle allocation. In scenarios 2 and 3, the demand by residents for the DRT system is affected by the changes in the fare. Therefore in this case, the number of passengers is calculated by using the results of the questionnaire. (Table 4)

We assume that $r=1$, since r could not be determined from the questionnaire.

Vehicle allocation

Figure 12 is the flow chart for a simulated call to the DRT systems and the resulting vehicle allocation. MicroCity, a GIS software package, was used to create the above flow chart. Vehicles are allocated once per one hour. The shortest route for a DRT vehicle is defined using Ant Colony Optimization. The maximum travel time per service is limited to sixty minutes and the average travel speed is limited to 30 km/h.
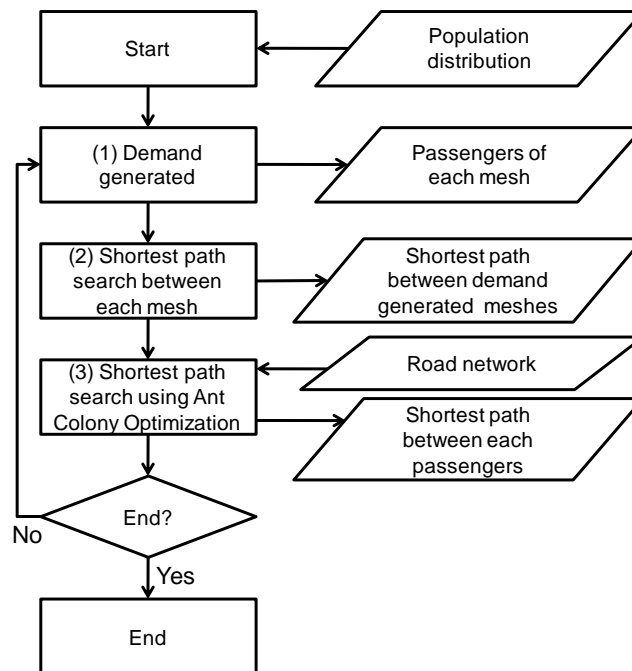

Figure 12 - Flow chart of a call to the DRT system and the vehicle allocation

Figure 13 shows the results of a simulation of the probability of a DRT round trip under different volumes of demand under the above conditions (500 trials).

If the volume of demand is less than three, the DRT vehicle has a greater than 90% probability of being able to return to the starting point and connect to the trunk line. However, the rate of return for a vehicle decreases for volumes of demand greater than four. For this reason, the number of vehicles is increased in the hours when the volume of demand is greater than four.
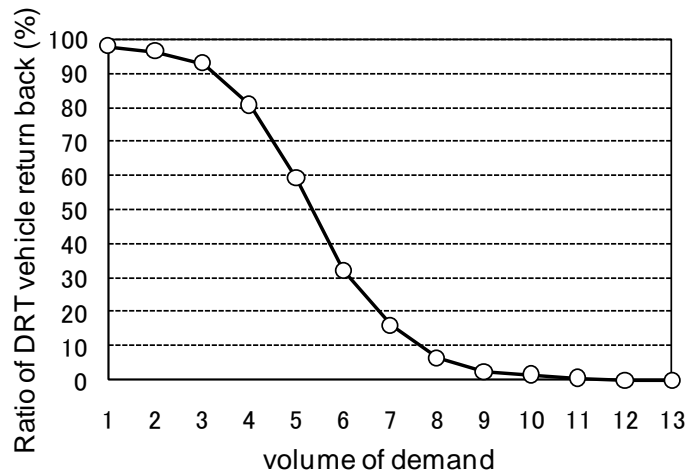
Figure 13 - Results of simulation of probability of a DRT vehicle returning

Cost calculation

The total operating cost is calculated by multiplying the total vehicle distance estimated from the simulation by the cost per kilometer. The cost per kilometer for a smaller capacity bus is considered to be 60% of that for a conventional bus. (Source: press release of the Ministry of Land, Infrastructure, Transport, and Tourism; bus: 333.67 JPY per kilometer)

Comparing the Operating Costs in the Three Scenarios

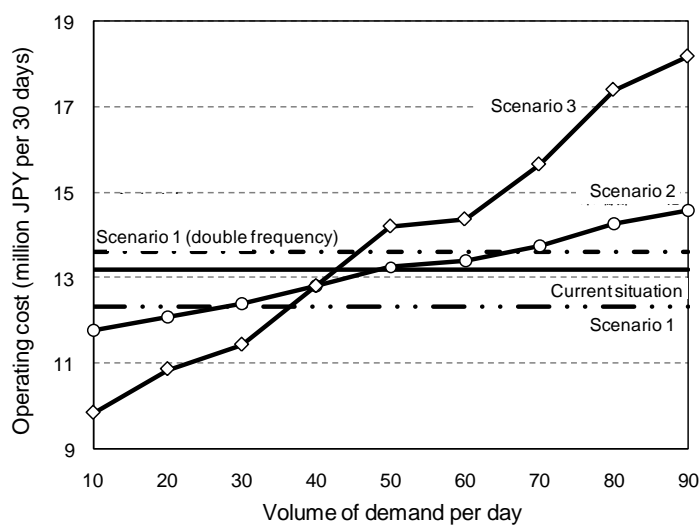Figure 14 shows the operating costs for scenarios 1, 2, and 3 calculated for a 30-day period.

Figure 14 - Operating costs for each scenario 1, 2, and 3

The operating cost for scenario 1 is 870,000 JPY, which is less than the cost for the conventional bus service for a similar level of service (one service per hour). If the number of services is doubled (two services per hour), the operating cost becomes 430,000 JPY, which is higher than that of the cost for the current conventional bus service, but provides an improved level of service.

The operating costs for Scenarios 2 and 3 are compared in order to determine the impacts of introducing a DRT system.

In the case of scenario 2, it is possible to operate the service under the volumes of demand (E to S, 100 JPY: 34, E to S, 200 JPY: 17) estimated from the questionnaire and under volumes of demand less than fifty, for a range of costs similar to the cost for the current conventional bus service .

In the case of scenario 3, it is possible to reduce the cost for volumes of demand less than 40 (E to S, 100 JPY: 34, E to S, 200 JPY: 17) to within the range of costs for the cost for the current conventional bus service. However, the operating cost has a greater influence in scenario 3 and, accordingly, the volume of demand changes more. Therefore, Scenario 3 is likely to have a high operating cost when the number of passengers increases.

Required Number of Vehicles

Figure 15 shows the results of a comparative analysis of the number of vehicles required in scenarios 1 and 2 when a smaller capacity bus is used from E to S.

In the case of scenario 1, if the highest number of passengers traveling from E to S is less than the capacity of the smaller bus (nine passengers), then the current number of vehicles can provide the current level of service. Two vehicles are required to maintain the time schedule during the morning peak hour, but it is possible to maintain the same level of service in the off-peak hours using only one vehicle.

Next, the highest number of passengers is considered. Figure 16 shows the number of passengers per service from E to S. In two cases, the number of passengers exceeds the capacity of the smaller bus. Two vehicles can be used in such cases, however, because these cases overlap with the morning peak hour.

In the case of scenario 2, the number of vehicles required is influenced by the volume of demand. Two vehicles are required when the volume of demand is less than thirty. If the volume of demand is less than ten, only one vehicle is required.
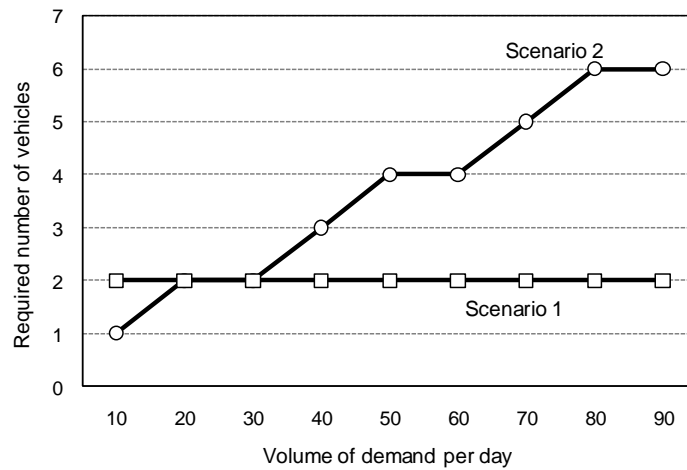
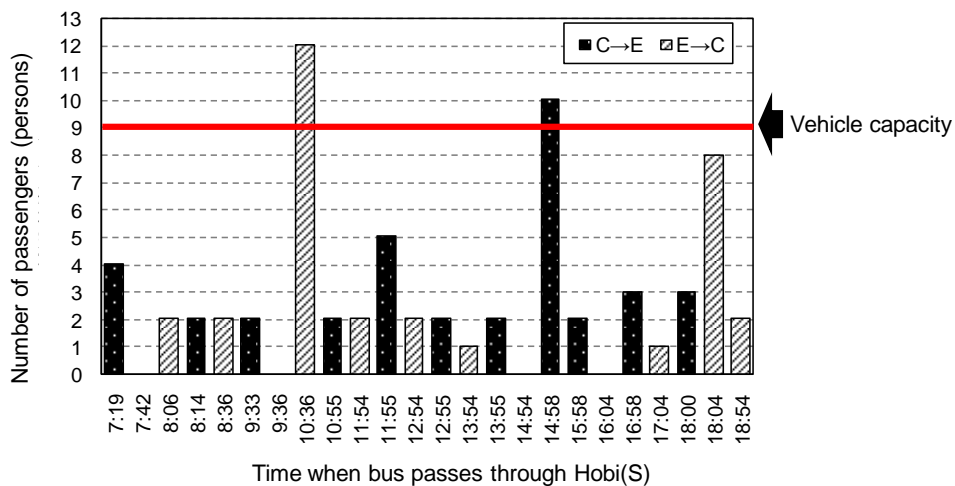Figure 15 - Number of vehicles required in scenarios 1 and 2

Figure 16 - Number of passengers per service from E to S

The maximum volume of demand in scenario 2 is thirty-four (E to S, 100 JPY). Therefore, three vehicles are required. However, more vehicles are required because of the morning peak hours.

One to two vehicles are thought necessary to meet demand in the daytime. Since we do not expect higher demand in the off-peak hours, if a new smaller capacity bus is used, vehicle allocation may be ineffective.

CONCLUSIONS

We have developed a model for examining the re-arrangement of bus routes that considers the possible effects of changes in the bus services, such as: 1) fare, 2) level of service, 3) connection, 4) reservation by telephone, and 5) boarding the bus at home. We

have further applied this model to an area of Tahara City, Aichi Prefecture, in Japan. The results show that user preferences for the bus system are affected by changes in the fare system but not by changes in the level of service or the requirement to make a reservation by telephone.

Our study has illuminated the development of DRT systems by considering the important issues regarding changes in demand (estimated using a mathematical simulation), the associated operating costs, and the user-convenience of DRT systems.

The mathematical simulation of the examined DRT system was developed using the results of a questionnaire. The model's most important conclusion is that user convenience can be improved and operating costs reduced by replacing the current conventional buses and services with smaller capacity public transport systems.

ACKNOWLEDGEMENTS

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