A research on the new Demand Responsive Transit service in Japan

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Abstract

This paper proposes practical Demand Responsive Transit (DRT) system with a new reservation processing called "Insured Announced Time Reservation System (IATRS)".

DRT service has been expected as an alternative mode in public transportation which aims to improve mobility in a city. However, it was initially impractical because the routing system cannot assure reserved passengers that vehicles will arrive at the passengers' destination by the announced arrival time. The developed IATRS for this new DRT service intends to ensure the announced arrival time by employing a slack time variable and a new proposed algorithm. The program composes of vehicle-choosing and routing algorithms. The vehicle-choosing algorithm decides which vehicle will accept the new reservation, while the routing algorithm designs the new route and schedule for the vehicle chosen to serve the new reservation. The system calculates and updates the route of the vehicle and returns the pick-up time to the customers immediately during reservation. Moreover, the vehicle will not delay the announced arrival time of passengers who have reserved already even if new passengers are added and the schedule of the vehicle is updated.

In order to validate the proposed DRT service, one experiment was conducted in Kashiwa City, Japan in 2008. In the experiment in Kashiwa City, which is recognized as a commuters' town of Tokyo metropolitan area, 3851 passengers used the about five DRT vehicles in 40 days (480 hours). It was shown that the characteristics of this system worked very well, and more than 44.7 percent of passengers were satisfied with the DRT service because they can make a reservation via personal computers and they were able to specify dependable arrival time or pick-up time. And 36.1 percent of passengers answered that their chances of going out increased by the introduction of DRT service. The result of Willingness To Pay (WTP) analysis is more than twice of fixed bus (353 yen / ride). In conclusion, the result of experiment showed the developed DRT service is a practical alternative mode for public transportation.

Introduction

In Japan, Demand Responsive Transit (DRT) service is expected as new transportation mode which aims to improve mobility in a city. Passengers ride the DRT after they reserve their seat and the DRT vehicles run as schedule. Schedule consists of passengers' reservation and it changes dynamically by new reservation. The conventional DRT service is very impractical because of the rack of assurance of arrival time. Since the DRT vehicle has to turn around when new reservation is inserted, DRT system cannot assure the arrival time to passengers.

This paper describes practical DRT system with a new reservation processing called "Insured Announced Time Reservation System (IATRS)". The system calculates and updates the route of the vehicle and returns the pick-up time to the customers immediately during reservation. Moreover, the vehicle will not delay the announced arrival time of passengers who have reserved already even if new passengers are added and the schedule of the vehicle is updated.

The objective of this paper is to explain the detail of developed DRT system especially on IATRS and to evaluate the developed DRT system in field experiments.

Developed DRT system

Overview of the system

Figure 1 shows the overview of suggested reservation system for DRT users.

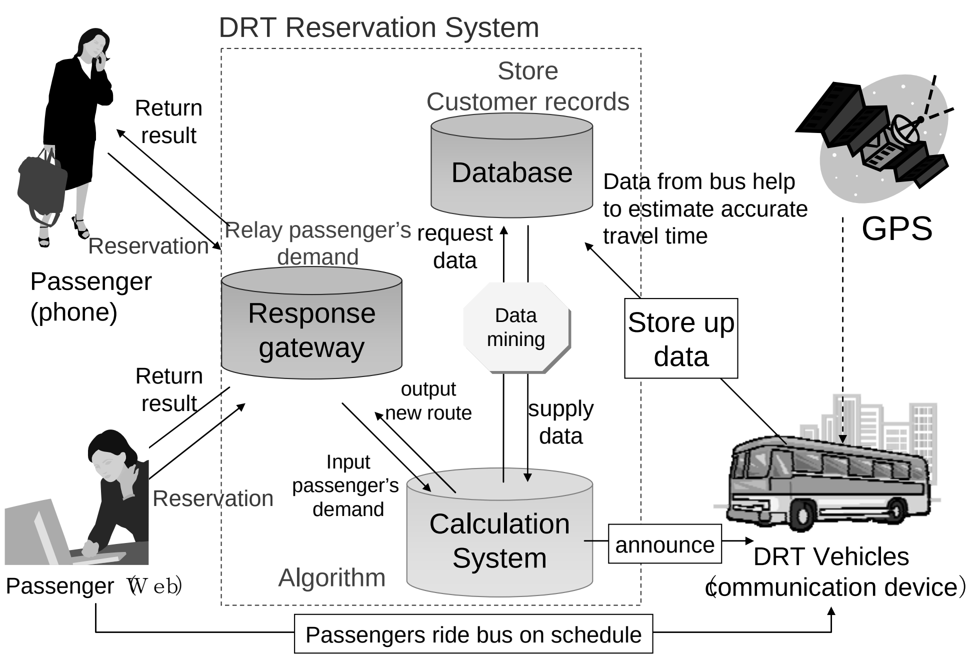

Figure 1 Overview of the new Demand Responsive Transit system

First of all, passengers access response gateway in reservation via phone or web. Response gateway relays passengers’ demand to calculation system that the original algorithm is implemented and the algorithm updates the route. After updating route, system announces new route to communication device. The software for communication device is implemented on the commercial Personal Digital Assistant (PDA). This is very simple software only which reads the server and gets the newest schedule of each DRT vehicle. And the communication device stores up actual moving time into the database. Passengers can confirm the location or the situation of the bus via web because of Bus Location system.

There are three characteristics of IATRS for improving on punctuality in this system. The first one is the routing algorithm which updates the bus route without delaying. The second one is unique time constraint on the route called as slack time. And the last one is storing up actual moving time so as to estimate accurate travelling time.

Calculation System

When the new customer reserves their seats, they input their demands to the calculation system through the response gateway. The information of “demand” consists of five information, origin, destination, expected arrival time (or expected pick-up time), date and the number of reserving seat. The system calculates the best route which new customer’s demand is satisfied without violating a set of constraint that is reflected the already planed customers’ demands. The calculation time should be shortened because the customer waits for finishing the calculating process over response gateway.

The quality of calculation and the speed are decided by the way of calculation. In operational research field, this problem is classified in Dial-a-Ride Problem (DARP), especially On-line Capacitated Dial-a-Ride Problem with Time Windows (On-line C-DARPTW). “On-line” means route can change as the new customer reserves, “Capacitated” means there is a volume constraint in the car, and “with Time Windows” shows problem have some constraints of time windows. On-line C-DARP is proven to have NP-hard constraint.

Considering from the requirement, routing algorithm should be a heuristic algorithm to insert the new customer's pick-up and get-off event into the planed route in a second. Jaw[1986] and Li[2003] also solve On-line DARP by Insertion method, they took a lot of calculation time. So, it becomes infeasible when the number of customer or number of bus increase. Fabri[2006] shortened the calculation time by assuming the first founded feasible solution semi-optimal. In developed solution, the Fabri’s idea is modified to be able to select the better vehicle to insert by comparing each bus moving locus.

The computer executes two main algorithms which are vehicle-choosing algorithm and routing algorithm. Using the vehicle-choosing algorithm was used for decision about which vehicle will accept the new request. And the routing algorithm was used to design the new route and schedule for the vehicle chosen to serve the new request. After calculation, the system will report to the customer whether the request is accepted or not. If it is accepted, the vehicle will pick up and deliver him to his destination within a guaranteed time – not later than the desired delivery time (or not earlier than pick-up time). We also carried out an experiment to evaluate the developed algorithm worked as we designed.

Slack Time

The routing algorithm used the existing DRT being introduced in the previous DRT system also inserts the new reservation, but the delaying often occurs in every insertion because the new customer's reservation lengthens the travel time of the bus. The developed routing algorithm doesn't allow the bus not to arrive at the bus stops in time though it allows the bus to go roundabout.

It is necessary to permit the schedule some latitude in order to be able to insert the new customer's reservation. The suggested system has a time window called 'Slack Time' as latitude of the schedule. The Slack Time is a unique time window about the announced arrival time and it assures that the bus will arrive at the bus stop in a time window. For example, in the case that the announced arrival time is 9:00 a.m. and Slack Time is 15 minutes, the bus will arrive at the bus stop between 8:45 a.m. and 9:00 a.m. Thanks to the introduction of new insertion algorithm and slack time, the bus will not delay on announced arrival time and the bus can transport lots of diversified customers to their destination together.

Estimation of accurate travelling time

Suggested algorithm makes the bus possible to travel without any delaying on announced arrival time. However the problem of delaying caused by traffic jams remains. The learning database helps the system to estimate accurate travelling time. The actual travelling time sent from the bus is stored in the database, and system get accurate travelling time according to the learning algorithm in Figure 2, where *T(a,b,hour)* shows travelling time from bus stop a to bus stop b in hour o'clock and T_{New} and T_{Old} show the updated and before updated travelling time. N shows the update times and T_{Data} means the actual travelling time sent from the bus. Lastly, the value of p means the permissible limit of updating the database.

And this system can be improved by adding diversified metadata such as weather and day of week.

$$T_{New}(a,b,hour) = \frac{T_{Data}(a,b,hour) + T_{old}(a,b,hour) \times N}{N+1}$$

$$in \quad case \quad when \frac{1}{p} \leq \frac{T_{Data}(a,b,hour)}{T_{Old}(a,b,hour)} \leq \quad p$$

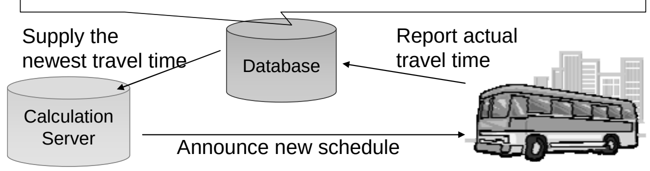

Figure 2 Estimation accurate traveling time

Mathematical Problem Formulation

This chapter describes mathematical problem formulation of On-line DARP for the developed DRT service with IATRS. In order to ensure passengers' arrival time, the problem is formulated with the some type of time windows as constraints. The reservation system can assure the informed time to passengers not by violating the time windows.

Mathematical Notation

N:	the total number of customers requesting service
n:	the indicator of a customer
DPT_n (DDT_n):	the desired pick-up (delivery) time of customer n
EPT_n (EDT_n):	the earliest pick-up (delivery) time of customer n
LPT_n (LDT_n):	the latest pick-up (delivery) time for customer n
APT_n (ADT_n):	the actual (scheduled) pick-up (delivery) time for customer n
$D(x, y)$:	vehicle direct travel time from point x to point y using the shortest route
$+n$ ($-n$):	the event "pick-up (delivery) customer n"; "$+n$" ("$-n$") also denotes the point of origin (destination) of customer n
$TT(x, y, hour)$:	the travel time from point x to point y at a specific time
$p(x)$:	the place where event x occur, i.e. $p(+n)$
Bus_n:	the bus number which serve customer n
DRT_n:	the direct ride time of customer n, i.e. $DRT_n = D(+n, -n)$
MRT_n:	the maximum acceptable ride time for customer n
ST_n:	the slack time of customer n
IPT_n (IDT_n):	the informed pick-up (delivery) time of customer n
V:	the total number of vehicles

The Problem

In this problem, N customers have to be transported by maximum V vehicles. Each customer, customer n, has to specify pick-up bus stop, $p(+n)$, and delivery bus stop, $p(-n)$. He also has to specify either desired pick-up time (DPT_n) or a desired delivery time (DDT_n). Most individuals are constrained in the morning by a desired "delivery" time (e.g. work start time) and select their trip starting time accordingly. Such a Dial-a-Ride customer will be a "DDT-specified" customer and will rely on the system to tell him at what time he will be picked up so that he will be delivered by time DDT. The reserve is true for DPT-specified customers. After system calculation, informed pick-up time (IPT_n) and informed delivery time (IDT_n) will be informed to the customer.

Time Window Setting for the First Time

Given a subscription list of N customers, each specifying either a DPT_i or DDT_i (i = 1, 2… N) and a fleet of V vehicles, find an effective allocation of customers among vehicles and associated time schedule of pick-ups and deliveries such that:

1. for all customer *n*;

$$EPT_n \le APT_n (= IPT_n) \le LPT_n \tag{1}$$

$$EDT_n \le ADT_n \le IDT_n \le LDT_n \tag{2}$$

2. For DPT-specified customers:

$$EPT_n = DPT_n \tag{3}$$

$$LPT_n = EPT_n + ST_n \tag{4}$$

$$DRT_n = TT(p(+n), p(-n), hour(DPT_n)) \tag{5}$$

$$EDT_n = EPT_n + DRT_n \tag{6}$$

$$LDT_n = LPT_n + DRT_n \tag{7}$$

3. For DDT-specified customers:

$$LDT_n = DDT_n \tag{8}$$

$$EDT_n = LDT_n - ST_n \tag{9}$$

$$DRT_n = TT(p(+n), p(-n), hour(DDT_n)) \tag{10}$$

$$EPT_n = EDT_n - DRT_n \tag{11}$$

$$LPT_n = EPT_n + ST_n \tag{12}$$

Time window will be set as shown in Figure 3.

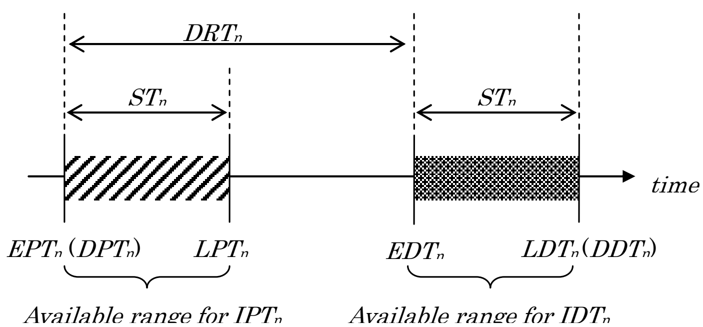

Figure 3 Initial time windows before IPT_n defined

Time Window Setting after Reservation Completion

When one reservation is completed, the time window will be set by the constraints below.

$$IPT_n = APT_n = EPT_n \tag{13}$$

$$LDT_n = IDT_n \tag{14}$$

$$EDT_n \le ADT_n \le LDT_n (= IDT_n) \tag{15}$$

$$LPT_n = LDT_n - DRT_n \tag{16}$$

In order to guarantee that the actual riding time will not exceed the maximum acceptable riding time. The following constraint is also introduced.

$$0 \le ADT_n - APT_n \le MRT_n \tag{17}$$

Time window will be set as shown in Figure 4. Time windows are narrowed by calculation.

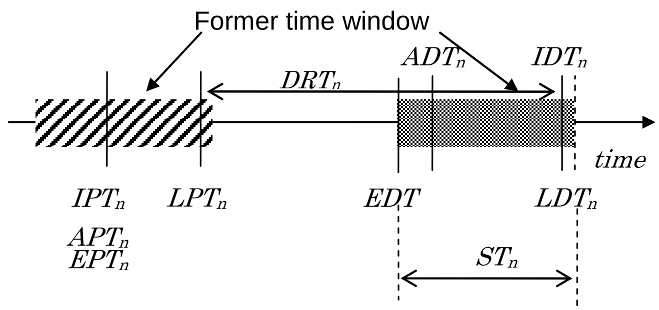

Figure 4 Time windows after IPT_n defined

Scheduling Algorithm of IATRS

In developed DRT system, two algorithm combined together as shown in the following figure are introduced. Using the first algorithm, Vehicle choosing Algorithm, we make the decision about which vehicle will accept the new request. The second algorithm, Routing Algorithm, was used to design the new route and schedule for the vehicle chosen to serve the new request (Figure 5).

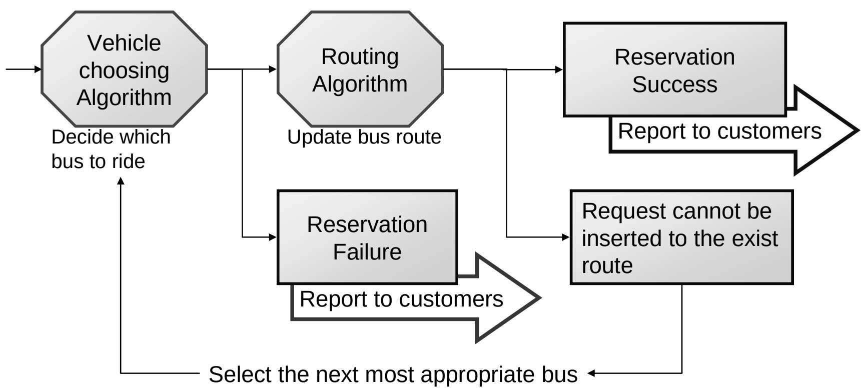

Figure 5 Algorithm Outline

Vehicle Choosing Algorithm

In the Vehicle choosing Algorithm, we try to introduce an effective algorithm with less calculation time, especially when solving big problems. We proposed the direction variable as a decision criterion.

First, we define direction vector (A_n) of customer n as

$$\overrightarrow{A_n} = \overrightarrow{p(-n)} - \overrightarrow{p(+n)} \tag{17}$$

On the other hand, we define bus direction vector (B_i) as

$$\overrightarrow{B_i} = \overrightarrow{p(s_i^*)} - \overrightarrow{p(t_i^*)} \tag{18}$$

In this case, $p(s_i)$ and $p(t_i)$ are the nearest place to the LPT_n and LDT_n, respectively.

Then we define the direction decision variable (θ_i) as

$$\cos\theta_i = \frac{\overrightarrow{A_n} \cdot \overrightarrow{B_i}}{\left|\overrightarrow{A_n}\right|\left|\overrightarrow{B_i}\right|} \tag{19}$$

When a new reservation comes into the system, the vehicle-choosing algorithm will be executed for each available bus. Since the bus with the most value of $cos\theta$ is the one with the closest direction to the new demand, that bus will be firstly selected to be executed by the next algorithm, routing algorithm.

Routing Algorithm

Routing Algorithm Outline

For routing algorithm, we developed a heuristic algorithm which can be described as the following figure. In this example, there are *n-1* passengers who have already reserved the bus. Then there is a new reservation from customer *n*. We proposed the "Insertion and time adjustment algorithm", which will insert event *p(+n)* and *p(-n)* into the planned route. After insertion, some passengers' APT_i or ADT_i (i=1,2,3…$n-1$) will be changed within their each time windows.

Variables Declaration

In this "Insertion and time adjustment algorithm", three new variables are defined. *TimeLimit* and *Repeat* define conditions that the calculation will be finished.

S(e):	Feasibility of event e; we will explain in details in the next part
TimeLimit:	Limitation of searching time
Repeat:	Maximum number for iteration

Insertion and time adjustment algorithm

The procedures of the algorithm are shown by the following flowchart. There are completed route for *n-1* customers. Then customer *n* request for a bus. The time windows of all events {*P(+1), P(-1), P(+2), P(-2), … , P(+ n-1), P(- n-1)*} will be calculated. With this algorithm, the APT_n (IPT_n) and ADT_n (IDT_n) will be decided.

First, the algorithm will set APT_n and try insertion. After insertion, the feasibility check will be performed. If all events are feasible, the route will be decided. If there are some infeasible events, the *TimeLimit* and *Repeat* will be checked. If the two variables don't exceed the limitation, the iteration will be executed by adjusting the departure time of infeasible events. However, the processes will stop if one or both of the variables exceed the defined limitation (Figure 6).

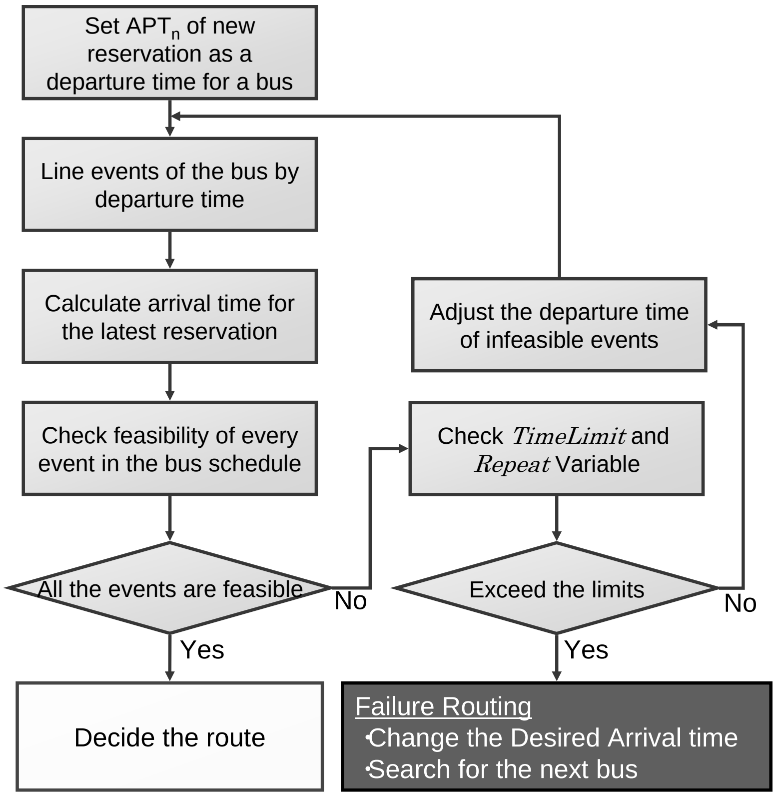

Figure 6 Insertion and time adjustment algorithm

S(e) **Explanation**

S(e) was set up for event's feasibility checking. There are possible value of *S(e)* with different meanings which was shown in the Table 1.

Table 1 *S(e)* Explanation

S(e)	Explanation
0	Event *e* is feasible.
-1	Event *e* is infeasible because of fault events consequence ($APT_e > ADT_e$)
-2	Event e is infeasible because of late delivery time ($ADT_e > LDT_e$)
-3	Event e is infeasible because of early delivery time ($ADT_e < EDT_e$)
-4	Event e is infeasible because of late pick-up time ($APT_e > LPT_e$)
-5	Event e is infeasible because of early pick-up time ($APT_e < EPT_e$)

Time adjustment for infeasible events

When there was an infeasible events and the iteration will not violate the *TimeLimit* and *Repeat* constraints, then the time adjustment will be performed. Table 2 shows that the way of time adjustment by each *S(e)* value.

Table 2 Time adjustment by *S(e)* value

S(e)	Adjustment
0	No adjustment
-1	$APT_e^* = LPT_e$
-2	$ADT_{e-1}^* = ADT_{e-1} - \left(ADT_e - LDT_e\right)$
-3	$ADT_{e-1}^* = ADT_{e-1} + \left(EDT_e - ADT_e\right)$
-4	$APT_e^* = LPT_e$
-5	$APT_e^* = EPT_e$

Conditions to finish calculation

There were two conditions to finish calculation. First, there was feasible route found. Another one was the calculation time exceeds *TimeLimit* or the calculation iteration exceeded *Repeat*.

$$\sum_{e}^{N} S(e) = 0 \tag{25}$$

Validation by Computer Simulation

Computer Simulation

In order to validate the scheduling algorithm, computer simulation is demonstrated. Simulator creates DRT vehicles and passengers in the computer. In virtual world, passengers reserve their seats and vehicles pick up and deliver passengers as schedule. In the simulation, we validate whether the actual pick-up (drop-off) time of each passenger does not delay to their informed pick-up (drop-off) time, that is difference between IPT_n (IDT_n) and APT_n (ADT_n). It is difficult that this validation is conducted not in computer but in real field test because there are many other factors which cause delay such as traffic jam, human error, connection trouble.

Simulation Condition

The personal computer for the simulator has Pentium 4 (3.2GHz), 3.00 GB RAM. We execute the simulation in virtual city. In about 55 km^2 field, 256 bus stops are set. As for variables, ST_n (Slack Time) is set Direct Ride Time (DRT_n) and *Repeat* is 30. We did not set *TimeLimit*. Total number of passenger N=200. The demand information (origin, destination, desired arrival time) of each passengers are created randomly. The service time is 8 hours, and we changed V, from one to six. All vehicles created in computers are eight seats available. The inputted desired arrival time will change when the time adjustment violate time window constraints. ±30 minutes from desired arrival time are set as the maximum search area. It means we define the calculation is successful when the time gap between DPT_n (DDT_n) and IPT_n (IDT_n) is less than 30 minutes.

Simulation Result

APT_n should not be earlier than IPT_n because passengers arrive at the bus stops after the bus leave from the bus stops. On the other hand, ADT_n should not be later than IDT_n because this service ensure the arrival time. Figure 7 shows the distribution of APT_n - IPT_n and positive figure shows APT_n is later than IPT_n. There is no negative figure so the vehicle will not leave from the bus stop before passengers arrive at there.

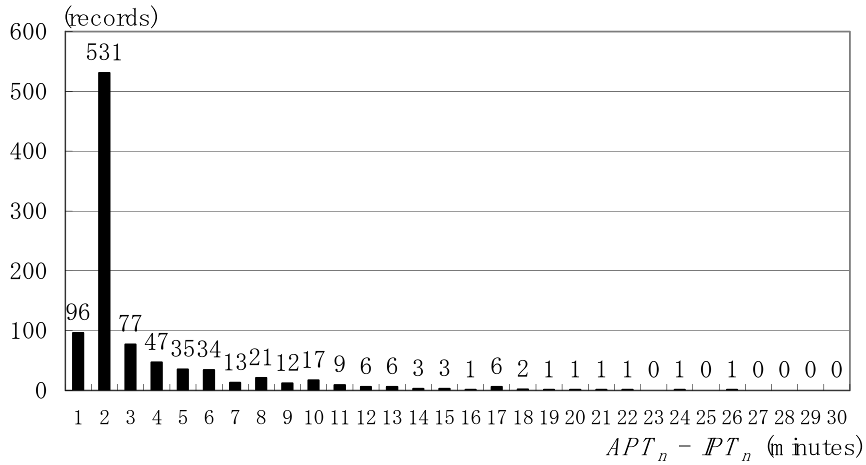

Figure 7 The distribution of APT_n minus IPT_n

Figure 8 shows the distribution of ADT_n - IDT_n and negative figure shows ADT_n is earlier than IDT_n. There is no positive figure so the vehicle will arrive at passengers' destination before the arrival time that system informs to passengers.

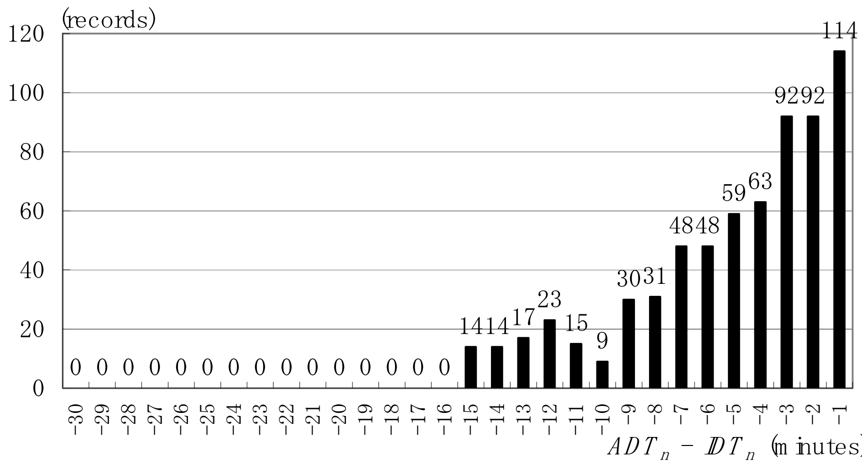

Figure 8 The distribution of ADT_n minus IDT_n

Community tests in Kashiwa

Kashiwa Overview

Kashiwa is located to the northeast to Tokyo, and one of the bed town cities of Tokyo. It has a population of 380,000 and occupies about 110 km^2 area. Those 65 years or older accounted for 16% of Kashiwa population.

The community test site included residential and industrial areas, parks, schools, train stations and hospitals in a 15 km^2 area. The opening of the Tsukuba Express railway in August 2004, expansion of the University of Tokyo's Kashiwa Campus in April 2005, and completion of large commercial facilities in November 2006 and March 2007 greatly changed population traffic and movement.

Most train commuters use Japan Railways' Kashiwa Station, to which fixed bus routes provide important transportation. The aging of the area's population has also introduced new traffic and transportation needs.

DRT Community Test

Table 3 shows the outline of community test. Test were conducted during 22 days in October and 18 days in November 2008 with five 4-passenger vehicles used between 9:00 a.m. - 9:00 p.m. Subjects were divided into Group 1, who commuted to the University of Tokyo's Kashiwa Campus, and Group 2, local residents including older persons. Registered residents who satisfy some condition such as age and the residential area could call for DRT vehicle coming to their homes. Test dates were reported by circulars, emails, HP and blogs. The briefing sessions were held for residents before the test was started.

Services during tests were free and users were registered through telephone or the Internet and received IDs and passwords.

Table 3 Overview of Kashiwa experiment

Area	Northern part of Kashiwa City, Chiba Prefecture, Japan
Date, term	Weekday in October, November, 2008 (40days)
Service time	9:00 a.m. – 9:00 p.m.
Passengers	Anyone (free of charge)
Number of vehicle	5 vehicles
Vehicle	Five sedan-typed taxies
Gross number of demands	3005 demands
Gross number of passengers	3851 passengers

Transition of the number of passengers

3,851 passengers used the DRT in 40 days. Figure 9 shows the number of passengers and Figure

10 shows age and sex distribution of passengers. The average number of passengers in the last week (169 passengers) was about 5 times to the average number of passengers in the first week (33 passengers). Moreover, the developed DRT service did not narrow the users because not only elder people and housewives but also time conscious users such as commuters used the DRT service. To collect time-conscious users' opinion is suitable to evaluate the emphasizing point of suggested IATRS.

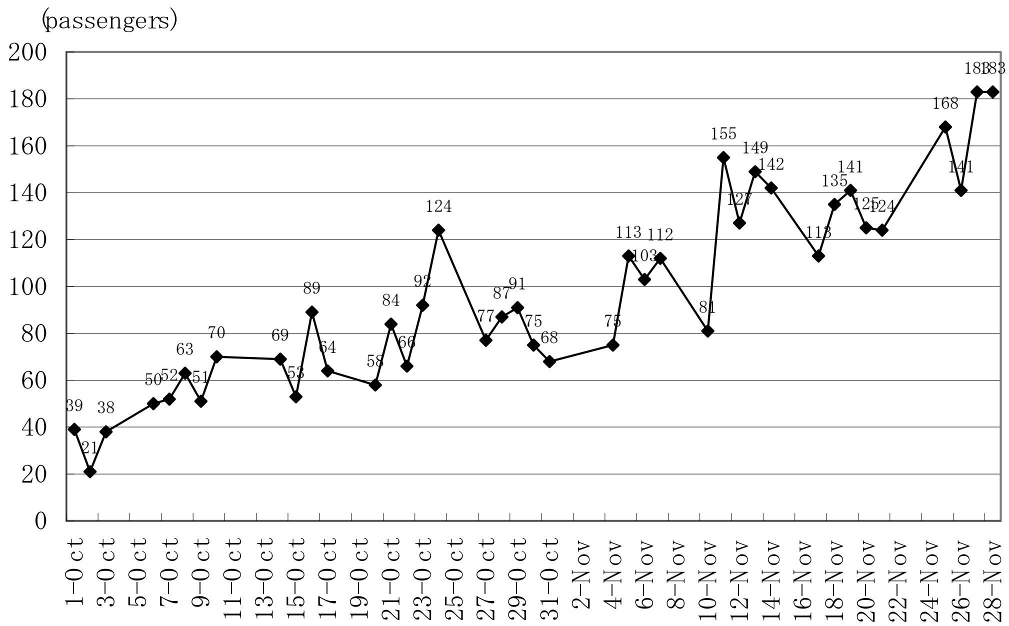

Figure 9 Transition of the number of passengers

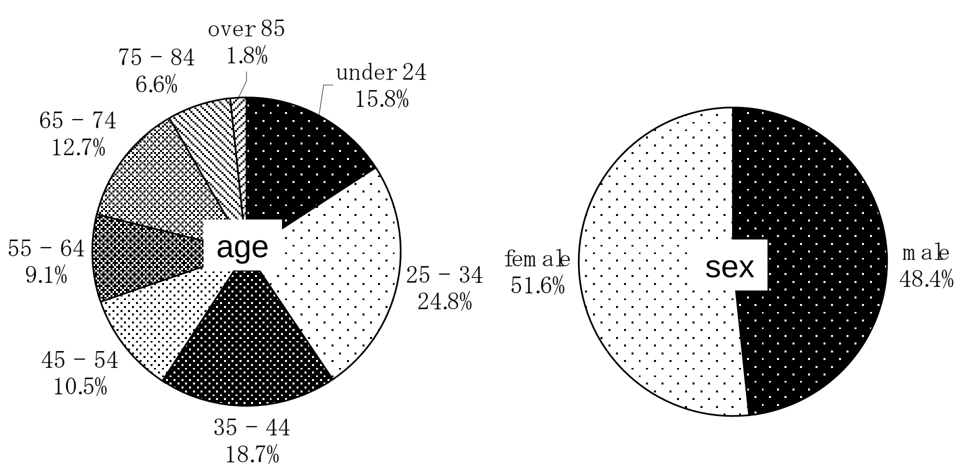

Figure 10 age distribution and sex distribution of passengers

User evaluation

Figure 11, Figure 12 and Figure 13 show the answer from passengers who ride the DRT. Basically, the passengers who use DRT are required to answer the questionnaire. As Figure 11 shows, 44.7% of passengers answer that the most valuable point is to be able to specify the dependable arrival time and pick-up time. This result comes from the IATRS of the developed DRT. Moreover, 21.3% of passengers answer they can reserve the bus easily.

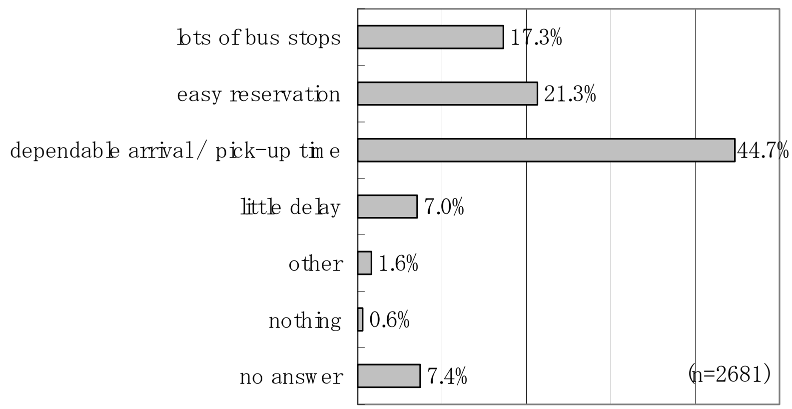

Figure 11 the most satisfying point of DRT

According to Figure 12, 36.1% of passengers answer the chance to go out increase by the developed DRT service. This is caused from the user-friendliness of the DRT service: i.e. passengers can reserve the DRT easily by themselves, the bus will pick up them in front of their houses and go to near the destination, and the informed arrival time is assured. This question is only answered in November, so the total number *n* is about half than other questions.

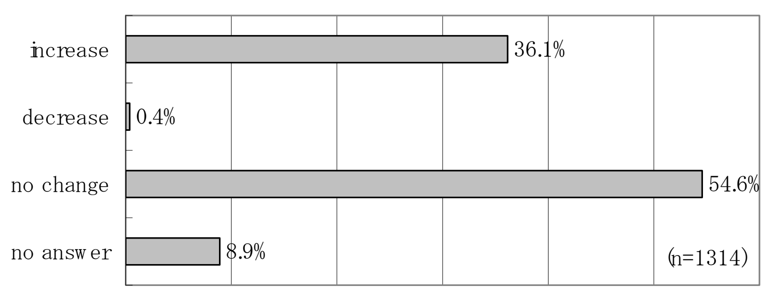

Figure 12 transition of chance to go out

Figure 13 shows that the result of Willingness To Pay (WTP) analysis. According to this, more than half of passengers answer that they can pay more than 300 yen. The average of the WTP is twice of fare of fixed bus in this area (353 yen / ride). It costs 160 yen to move in this area by fixed route bus. And more, the WTP of about 25% of passengers is more than third times of fixed bus.

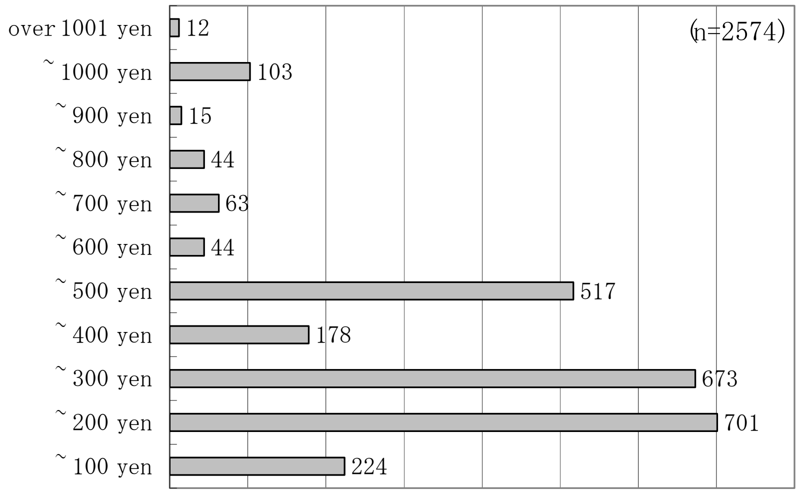

Figure 13 the result of Willingness To Pay analysis

Conclusion

Practical Demand Responsive Transit (DRT) system with a new reservation processing called "Insured Announced Time Reservation System (IATRS)" is developed. The core part of this system is calculation system which updates the schedule of DRT vehicles.

Fundamentally, the problem for this service belongs to Dial-a-ride Problem with Time Window (DARPTW). Authors proposed two heuristic algorithms which are Vehicle choosing Algorithm and "Insertion and time adjustment Algorithm". Using Vehicle choosing Algorithm, the decision about which vehicle will accept the new request can be made. And Insertion and time adjustment Algorithm is used to design the new route and schedule for the vehicle chosen to serve the new request. Computer simulation result shows that the calculation does not violate the time window constraint, because IPT_n does not later than APT_n and ADT_n does not later than IDT_n.

The evaluation of DRT from the field experiments in Kashiwa City showed that not only time unconscious users but time conscious users are well satisfied with the punctual service, which means minimizing overestimation or underestimation of pick-up and arrival time. And 36.1 percent of passengers answered that their chances of going out increased by the introduction of DRT service. The result of Willingness To Pay (WTP) analysis is more than twice of fixed bus (353 yen / ride). In conclusion, the result of experiment showed the developed DRT service is a practical alternative mode for public transportation.

Acknowledgement

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