# Study on Service Characteristics of Demand Responsive Transport Using Sequential Demand Assignment Algorithm

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Through recent developments in information and communication technologies, dynamic monitoring and control of transport systems are technically possible. These technologies enable constructing more flexible and cost-effective transport services which may vary based on demand. This study proposes an introduction of demand responsive transport (DRT) services as unlimited public transport services. To explore the effectiveness of DRT systems, a sequential passenger assignment algorithm for DRT is created. The algorithm is applied to the test network, and the service performance of DRT is discussed.

*Keywords: Demand Responsive Transport, Service Evaluation, Demand Assignment Algorithm*

## 1. Introduction

Mobility is often a vital problem for older and disabled citizens. If the transport services available to them are not adequate these groups might become socially excluded. Avoiding social exclusion is one of the key policies in developed countries. On the other hand, as the needs and preferences for mobility have been diversified, it has become difficult to maintain the high level of service of the public transport system necessary to satisfy all types of users. In recent years, therefore, the usage of private cars is increasing, and the number of passengers using public transport is decreasing. In order to change this situation, the public transport service should be made more attractive and convenient.

Through recent developments in information and communication technologies, dynamic monitoring and control of transport systems are technically possible. These technologies would enable constructing more flexible and cost-effective transport services which may vary based on booking requests. Such transport systems are often called demand responsive transport (DRT) services and DRT has been developed as special transport services (STS), especially in European countries. Since the demand is quite low if DRT is used as STS, demand is often assigned manually. But this study attempts to introduce DRT as unlimited public transport services. For this purpose, the service characteristics of DRT services such as; how much demand is affordable with specific demand patterns, or how many vehicles with how much size are needed for

sufficient service for the specific demand levels, should be identified. To explore the effectiveness of DRT services, a passenger assignment algorithm for DRT transport is needed.

Based upon the background explained so far, this study attempts to develop demand assignment algorithms, and using the proposed algorithm the service characteristics of DRT are explored. In Section 2, earlier studies about DRT services and assignment algorithms are briefly reviewed. Then, a new demand assignment algorithm is developed and the solution algorithm is explained in Section 3. We assume in this study that the demand is assigned when the system receives the request and report the pickup time to passengers at the stage of booking (First-Request-First-Assign protocol). This booking type is realistic and also simplifies the assignment problem. Then in Section 4, the hypothetical demand created based on demand patterns obtained in the Keihanna ITS project are assigned to the vehicles by the proposed assignment algorithm, and service level of the DRT is explored. Finally, in Section 5, the contribution of this study is summarised.

## 2. DRT and related researches

### 2.1. DRT all over the world

First, we shall summarise DRT services in the real world. One of the most popular DRT services is Flexline in Gothenburg, Sweden, which has been in operation since 1996[1]. Flexline is originally introduced as special transport, but is now available to everyone to

reduce unit costs of the existing shared taxi service (FareService) for disabled and elderly people. Booking requests was assigned manually at first but later an automated booking system has been introduced. The assignment criterion is not clearly explained but the algorithm considers time constraints and spatial availability. Though its origin, destination and departure time is predetermined, the route of the vehicle is fully flexible in between origin and destination. In 2002, about 25,000 trips are made by FlexLine.

One of the largest DRT services in the world can be found in London [2]. The service started in 1980 and more than 1.5 million trips are made annually by disabled/elderly citizens with more than 300 mini/micro buses. A trip should be booked by noon of the previous day, and the demand is assigned manually when the operation centre receives the request. The fare varies from 60p to 2GBP (1GBP = 100p = about 200 yen) according to the distance. Through the conversation with one of the dial-a-ride operators, it was found that demand is assigned manually by inserting one demand into every 30-minute slot and sharing trips rarely happens. Consequently, only 2-3% of running costs are covered by the user payment [3]. Booking and scheduling system is expected to be launched in 2005 [2].

There are also several cities in Japan where DRT system has been practically implemented or experimentally introduced. In Odaka town, Fukushima, a shared taxi service (Odaka e-machi taxi) has been introduced in 2001 [4]. Everybody can use this service if his/her origin and destination are inside Odaka town. The vehicle will depart the depot on the scheduled time but runs any route in the city to pickup and deliver passengers. 4 vehicles are used for services and 90-100 trips are daily made. Almost half of the running costs are covered by the user payment. Similarly, a dial-a-ride bus service called 'D-Bus' is introduced in the Keihannna district as a three-year social experiment for merged public transport systems. Keihannna district is a newly developed suburban area in 1980s locating among Kyoto, Nara and Osaka. The size of the district is about 15,000ha and 400,000 people are living there. Also there are many research institutes. The area consists of several clusters the objective of the social experiment is to provide transport services among the clusters. 2 normal-size buses are used for this project and 70-100 passengers per day use this service. Fully flexible service is introduced in this project and a demand assignment algorithm developed by a private company is used [5]. Nowadays DRT is getting popular in Japan, but most of the services aim at either providing special transport services or providing minimum mobility in rural areas.

## 2.2. Demand assignment algorithm

Demand assignment algorithms for DRT can be regarded as a derivative of the TSP (Travelling Salesman Problem, [6]) and are often called as 'Dial-a-Ride Problem (DaRP)'. In general, the objective function can be described as the summation of operator-side cost and passenger-side cost. Many researches have been conducted about the DaRP, and they can be categorised depending on the definition of the objective function, the booking/assignment type, and whether the model considers dynamic assignment.

There are a variety of booking/assignment types. The simplest one is the 'First-Request-First-Serve' protocol. The service will be provided promptly when the request is received, meaning that basically the service will be provided in the same order as the bookings have come in. This protocol makes the problem much simpler but it is difficult to handle many passengers. The most realistic protocol is 'First-Request-First-Assign'. The requests are assigned when the system receives the request, and the assignment result will be informed to the passengers at the time of booking. Since the demand is assigned sequentially, there might be a case when the assignment result is not globally optimal. For example, many trips might be rejected when a trip of long distance has already been assigned. This protocol can also be said to be fair since the trip is guaranteed if the booking request is made earlier. We can obtain the global optimal solution if the all requests are gathered in advance and are assigned simultaneously. However, either all trips should be accepted with their desired departure time or the assignment results should be reported afterwards to the passengers. Also the simultaneous assignment protocol would provide unfair solutions if not all trips are guaranteed since for the operator unpopular long-distance trips are likely to be rejected.

The definition of 'Dynamic assignment' in DaRP is that a new trip can be assigned to a vehicle that has already departed. If new trips are accepted after vehicles have started moving, we should continually observe the locations of the vehicles and check the feasibility continually.

One of the earliest and simplest works is carried out by Psaraftis[7], who proposed a method to assign many-to-many trips onto one vehicle. He assumed that the service is provided in the order of requests (First-Request-First-Serve protocol).

Then, Jaw et al.[8] developed an algorithm to solve the advance-request, multi-vehicle, many-to-many DaRP. Advance-request means that booking requests are collected and users can notice the pickup time. A First-Request-First-Assignment protocol is applied and a heuristic solution algorithm is proposed. One of the interesting innovations in this paper is introducing changing weights of cost for the operator and the passengers according to the demand level. Passenger benefit is heavily considered when the demand level is low, and efficiency of operators is pursued when the

demand level is high. Because of recent progress in computer technology, researches for DaRP largely increased in the 90s. The extensions are mainly made to apply efficient heuristic algorithms such as genetic algorithms [9] or Tabu searches [10] or to consider time-varying link travel time by assuming a statistical distribution [11] or by using a simulation approach[12].

The formulation and solution for the DaRP are explored so far and many researches have been made in the field of operations research. It can be said that the tool for evaluating DRT is ready, but not much research has been carried out to evaluate the service level of a DRT system as an alternative to ordinary fixed-route bus services. Only Noda *et. al.* [13] tried evaluating the profitability of a DRT system compared to a fixed-route service. However, the assignment model used in their research does not consider constraints of time window, which discards the main advantage of DRT services.

In conclusion, DRT is getting popular all over the world and many assignment algorithms for DRT have been proposed. It is therefore expected that DRT can be one of the new convenient public transport systems. In this study, a demand assignment algorithm similar to Jaw *et, al.* considering a time window with First-Request-First-Assignment protocol is developed and the service level of DRT will be evaluated by the proposed algorithm. The differences between Jaw *et. al.*'s and our approach are discussed in the following section.

# 3. Algorithm development

## 3.1. Notation

| | |
|---|---|
| $i$ | : Index for passengers |
| $p_i$ | : Desired departure time, |
| $mt_i$ | : Direct travel time between boarding / alighting bus stops |
| $d_i$ | : Time needed for boarding/alighting |
| $t_i$ | : Departure time of passenger $i$ |
| $k$ | : Index for items |
| $i(k)$ | : Passengers corresponding to $k$th item |
| $k(i, \{b\ or\ a\})$ | : Item corresponding to passenger $i$ boarding/alighting |
| $w_k^-, w_k^+$ | : Lower/upper boundary of time window for item $k$ |
| $t_k^{(j)}$ | : Time to arrive at item $k$ at the stage of $j$ |
| $tt_k^{(j)}$ | : Travel time from items $k$ to $k+1$ at the stage of $j$ |
| $\mathbf{t}^{(j)}$ | : Vector representation of $t_k^{(j)}$ |
| $\mathbf{I}^{(j)}$ | : Itinerary defined at the stage of $j$ |
| $N_v$ | : Number of vehicles |
| $N_i$ | : Number of passengers |
| $j$ | : Assignment stage when $j-1$ *passengers have been assigned* |
| $N_k^{(j)}$ | : Number of items at $j$ |
| $N_c^{(j)}$ | : Number of candidates at stage $j$ |
| $C^{(j)}$ | : Set of candidate itineraries at stage $j$, |
| $C_f^{(j)}$ | : Set of feasible itineraries at stage $j$. |
| $n_{vm}^{(j)}$ | : Number of items served by vehicle $v$ in itinerary $m$ at stage $j$ (excluding dummy items) |

## 3.2. Assumption

We set following assumptions for formulating the assignment algorithm,
1. Passengers will get on/off at a bus stop.
2. Trip requests are assigned with first-request-first-assign protocol
3. Passengers accept a certain time window for boarding and alighting.
4. All trip requests are assigned to the vehicles before they start the services,
5. The travel time between bus stops is set to be constant.

The first assumption is made to simplify the problem, but this assumption can easily be relaxed for door-to-door services without any additional computational burden. The second assumption is very important. As is discussed in the previous section, more effective solutions can be obtained if all trip requests are assigned simultaneously, but we need to report results of assignment to all passengers. To avoid this additional load, we adopted the protocol to assign the requests at the time when the algorithm obtained the booking request, and then reply the assignment result instantaneously. Adopting the sequential assignment also contributes to simplify the assignment algorithm, which will be explained later. By the third assumption, the algorithm can assign passengers to share a ride. If trip requests are to be accepted after vehicles have started their journey, we should continually observe the locations of vehicles and check whether the requests can be assigned or not. It would require an additional vehicle tracking model and therefore it is out of scope in this study. This explains the necessity for the fourth assumption. Finally, the fifth assumption removes uncertainty for travel time, which also simplifies the problem.

## 3.3. Formulation

In sequential demand assignment, a trip will be assigned every time the booking request comes. Therefore if the trip requests are ordered in the same way as the booking sequences, the 1st to $j\text{-}1$th requests must have already been assigned to the vehicles (or rejected) when assigning the $j$th request. We shall define that at stage $j$ the sub-optimisation problem $P_j$ is formulated to assign the $j$th request without breaking the time windows of already assigned trips. To formulate this, let us first define an *itinerary*. An *itinerary* contains the information of bus stops to visit in order to pick-up or drop-off a passenger. It is a list of '*item*s' where the
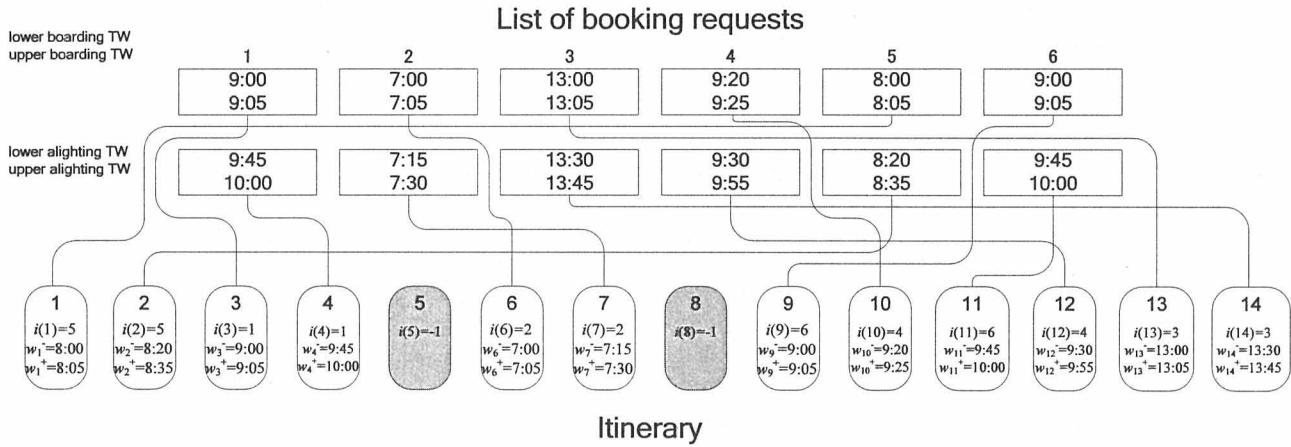
## List of booking requests



Figure 1. Relationship between booking requests and itinerary

$k^{th}$ item contains information of passenger ID; $i(k)$, and upper/lower boundaries of time window, $w_k^-$ and $w_k^+$. Figure 1 shows the relation between booking requests and an itinerary. In this example, 6 trips are assigned onto three vehicles. The $5^{th}$ and $8^{th}$ items are called *dummy* and are inserted so as to distinguish the visit list of vehicles. The $1^{st}$ to $4^{th}$ items are assigned onto the first vehicle, the $6^{th}$ and $7^{th}$ onto the second vehicle, and the $9^{th}$ to $14^{th}$ onto the last vehicle.

At stage $j$, we should have a feasible itinerary containing up to $2(j-1)+(N_v-1)$ items. The former term corresponds to the number of assigned trips whereas the latter one represents the number of dummy items. Boundaries of the time windows concerned with 1 to $j-1$ trips should have been identified at the earlier stages. The idea is to insert the new two items of request $j$ corresponding to the boarding/alighting bus stops of the $j^{th}$ request into certain positions within the itinerary. An objective function determining the positions of the new items as well as the departure time of all items is defined in this study to maximise the total benefit of all passengers. The sub-problem at stage $j$ can be defined as follows.

=Sub-Problem $P_j$=

$$min \ F_j\left(\mathbf{I}^{(j)},\mathbf{t}^{(j)}\right)$$

$$= \sum_{i=1}^{j}\left|p_i - t_{k(i,b)}^{(j)}\right| + \gamma\left|t_{k(i,a)}^{(j)} - t_{k(i,b)}^{(j)} + d_i - mt_i\right|. \quad (1)$$

*subject to*

$$w_k^- \le t_k^{(j)} \le w_k^+, \ k=1,\ldots,N_k^{(j)} \quad (2)$$

In the objective function, the first term corresponds to the difference between desired departure time and actual departure time, and the second term represents the increase in travel time. $\gamma$ is a parameter explaining the relative weight of delay of travel time compared to shifted a departure time. To identify the time window, we further assume that passengers accept up to $\alpha$ and $\beta$
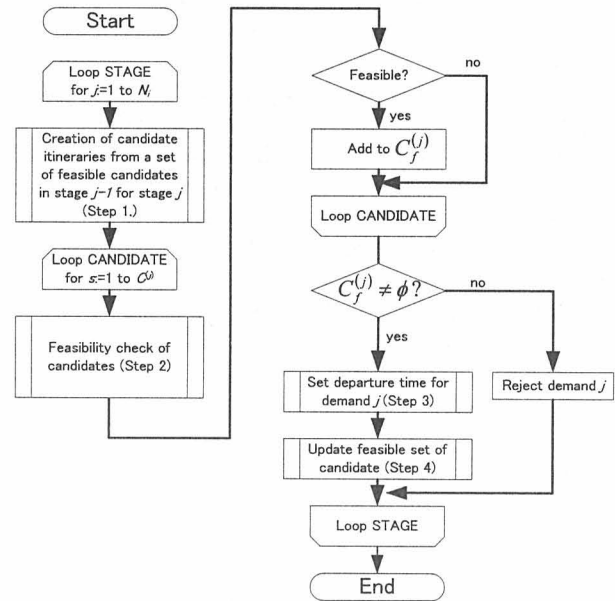


Figure 2. Solution algorithm

minutes of delay for boarding and alighting, respectively. This means that if passenger $i$ requested a trip of $mt_i$ minutes and the system replied with a pick-up time $t_i$, then the vehicle should arrive at the boarding bus stop during $(t_i, t_i+\alpha)$, and should drop off the passenger during $(t_i+mt_i, t_i+mt_i+\beta)$. These constraints are explained by $w_k^-$ and $w_k^+$ in Eq(2), which will be explained in detail in the next section.

### 3.4. Solution algorithm

The optimal itinerary is obtained by the algorithm shown in Figure 2.

Step 1. Creating the candidate itineraries

Since we adopt the sequential assignment, it is impossible to change the sequences of already assigned trips. Therefore, a feasible itinerary for stage $j$ must be created from a feasible itineraries for stage $j-1$. The

number of possible ways to assign a new request can be calculated by the combination operator, and the problem is to pick up 2 items among already assigned items while allowing picking up the same slot twice. Suppose that we have $N_c^{(j-1)}$ feasible itineraries for stage $j$-1 and there are $n_{vm}^{(j-1)}$ items for the $v^{th}$ vehicle in the $m^{th}$ itinerary. Then, the number of candidate itineraries for stage $j$ is expressed as follows.

$$\sum_{m=1}^{N_c^{(j-1)}} \sum_{v=1}^{N_v} \frac{\left(n_{vm}^{(j-1)}+2\right)\left(n_{vm}^{(j-1)}+1\right)}{2}. \qquad (3)$$

For the itinerary shown in Figure 1, we shall have 49 candidates. The number of candidates can be quite large when we have many trip requests. But the number of feasible solutions is much smaller when we consider time constraints, and we solve this problem by enumerating all possible itineraries. By inserting the new two items, the set of candidate itineraries, $C^{(j)}$ is created at this step.

## Step 2. Feasibility check of the $s^{th}$ candidate

For all itineraries in the set of candidates, the feasibility of time constraints for all items as well as the two new items is examined. Following three sub-steps are implemented. Note that the initial time window of the newly assigned request is set to be 0 to infinity. Also note that the index for the candidate, $s$, is omitted in the following explanation to simplify the expression. This procedure should be repeated for all candidate itineraries.

*Sub-Step 2-1. Update of lower boundary of time window*

Time windows of all items are checked for each vehicle individually at this step. Consider the vehicle providing the services for the $m^{th}$ to $n^{th}$ items in the itinerary, and let us assume that it will arrive at the first bus stop at the lower boundary of time window, $w_m^-$. Then, the vehicle will leave the first bus stop at the earliest on $w_m^- + d_{i(m)}$, and the earliest time to arrive at the next bus stop is $w_m^- + d_{i(m)} + tt_m^{(j)}$. However, the vehicle has to wait until the time window becomes open when it arrives earlier than the lower boundary of its time window. In conclusion, the lower boundary of the feasible time window for item $l$, $u_l^{(j)}$ is calculated by the following formula.

$$u_l^{-(j)} = \begin{cases} w_l^- & l=m \\ \max\left(u_{l-1}^{-(j)}+d_{i(l-1)}+tt_{l-1}^{(j)}, w_l^-\right) & l=m+1,\dots,n \end{cases}. \qquad (4)$$

*Sub-Step 2-2. Update of upper boundary of time window*

Similarly, we can calculate the time when the vehicle should leave the bus stop at the latest. Suppose again that the vehicle will provide the services for the $m^{th}$ to $n^{th}$ items in the itinerary, and will arrive at the last bus stop on the upper boundary of time window, $w_m^+$. To achieve

this, the vehicle should leave the previous bus stop at the latest at $w_m^+ + d_{i(n-1)} - tt_{n-1}^{(j)}$. However, the vehicle has to arrive at the previous node before the upper bound of the time interval of this item. In conclusion, the upper boundary of a feasible time window for item $l$, $u_l^{+(j)}$ can be calculated as follows.

$$u_l^{+(j)} = \begin{cases} \min\left(u_{l+1}^{+(j)}-d_{i(l)}-tt_l^{(j)}, w_l^+\right) & l=m,\dots,n-1 \\ w_l^+ & l=n \end{cases}. \qquad (5)$$

Finally, the candidate itinerary is feasible if the following condition satisfies.

$$u_k^{-(j)} \le u_k^{+(j)}, \text{ for all } k=m,\dots,n. \qquad (6)$$

*Sub-Step 2-3. Feasibility check for the new trip*

To ensure that the new request is served within the required travel time, the following condition is checked.

$$u_{k(j,a)}^- - \left(u_{k(j,b)}^- + mt_j + \beta\right) \le 0. \qquad (7)$$

If the candidate itinerary satisfies the inequality constraints of both (6) and (7), it is feasible and therefore is added to $C_f^{(j)}$. If $C_f^{(j)}=\phi$, it is impossible to assign the request $j$ without breaking the time windows of already assigned requests and so this request is rejected.

## Step 3. Set departure time

For all itineraries contained in $C_f^{(j)}$, we will calculate the value of the objective function. The values of the objective function when the vehicle departs at the earliest and the latest in the feasible time window are calculated, and the one providing the smaller value is set to be the value of the objective function for this itinerary. Then, the minimum value of objective function among all feasible itineraries is selected, and the departure time of item $k(j, b)$, $t_{k(j, b)}^{(j)}$ is reported as a pick-up time to this itinerary;. The time windows of the two new items corresponding with the boarding/alighting bus stops of the $j^{th}$ trip request are set as follows:

$$w_{k(j,b)}^- = t_{k(j,b)}^{(j)}, \qquad (8)$$

$$w_{k(j,b)}^+ = t_{k(j,b)}^{(j)} + \alpha, \qquad (9)$$

$$w_{k(j,a)}^- = 0, \qquad (10)$$

$$w_{k(j,a)}^+ = t_{k(j,b)}^{(j)} + mt_j + \beta. \qquad (11)$$

Note that $w_{k(j,a)}^-$ is always set to be 0 since arriving at the destination at any time earlier than the upper boundary is assumed to be fine for the passengers.

## Step 4. Update feasible set of candidates

So far we have selected the optimal itinerary and set the pick-up time and time windows of the new passenger. But there may be other itineraries which are feasible to provide the service while satisfying time window constraints. To increase the flexibility of the assignment, all the feasible itineraries are used to create the candidate itineraries at the next stage. For this, sub-steps 2-1 and 2-2 are repeated to check the time window constraints.

Steps 1 to 4 will be repeated until the model handles all trip requests, and the evaluation statistics are calculated based on the assignment results. The statistics discussed in this paper are summarised in Table 1.

## 3.5. Characteristics and limitation of the model

The proposed method is similar to the one proposed by Jaw *et al.*[8]. However, there are two major differences in the proposed algorithm:
1. the proposed algorithm will carry over all feasible itineraries to the next stage whereas Jaw et al.'s algorithm keeps only the optimal itinerary,
2. The time windows of passengers are fixed in advance in Jaw *et al.*'s approach while we try to minimise the differences between desired departure time and assigned departure time.

The idea of keeping all feasible itineraries may decrease the efficiency of the algorithm but a better solution might be obtained at the subsequent stage. For the second point, the service capacity of DRT might be underestimated by Jaw *et al.*'s approach since there must be some passengers who do not care about shifting their departure time. Conversely, our approach may overestimate the ridership since there must be some passengers who give up using DRT if they have to shift their departure time. Since our main objective is to evaluate the service capacity of the DRT service, it is sufficient to assume that passengers will obey our recommended departure time. However, of course, the reality must lie somewhere between *Jaw et al.*'s and our assumption.

Also we shall summarise here the advantages and limitations of the proposed approach in applying the model into the real world operation. First, the idea of defining vehicle movement by itineraries and items helps considering the various types of DRT services. We can even define the ordinary route bus service within the same framework by inserting items representing sequences of bus stops. However, there are limitations with our model in terms of implemention to the real world. The biggest problem is that it is not capable of assigning passengers onto already running vehicles, which is indispensable for practical use. Therefore, the current model can only be applied at the planning stage for a decision whether or not to introduce DRT within the specific area. Also, we only assign trip requests to the vehicles and do not assign drivers. Driver assignment

Table 1. Evaluation statistics

|  | Unit | Definition |
| --- | --- | --- |
| *AD* | demand | The number of requests assigned to the vehicles |
| *TD* | min./demand | Sum of differences between desired and actual departure time for all passengers (value of objective function defined in Eq (1)) |
| *BT* | min/veh./demand | Bus travel time per trip and vehicle (total bus travel time divided by the number of passengers) |
| *DD* | demand/veh./min. | Demand density (number of passengers on board for each simulation minute) |
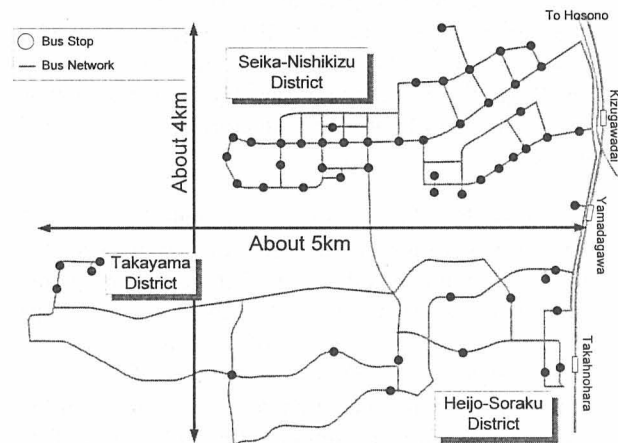


Figure 3. Keihanna network

is one of the largest factors identifying the operation cost, and is sited as a further study.

## 4. Case study

### 4.1 Test network

The proposed algorithm is verified by using data obtained from the Keihanna-ITS project[14]. In this project, a dial-a-ride bus service called D-Bus is provided as well as a car sharing service called C-Car. Figure 3 illustrates the network where the D-Bus service was provided. There are 55 bus stops in the network.

Since the service performance of DRT heavily depends on the booking patterns, it is adequate to carry out the service performance evaluation with the actual patterns. The findings obtained here might be limited to the network and demand pattern, but we think it is more informative to discuss the service performance of DRT with this data than by applying the model to a fictive network.

A pattern of booking requests are created based on the requests collected from July to November, 2003.

From the booking request data, we obtained following findings:

- At morning peak hours, there are many trip requests with origin or destination Takanohara Station (northeast end in Figure 3). Because there are many research institutes in the Keihanna area with bus stops in front of the buildings, many commuters use the D-Bus service.
- During daytime, there are many requests with origin or destination 'Al-Plaza', the large shopping centre in this area located beside Yamadagawa Station. D-Bus was mainly used for shopping at this time of the day. Trip requests mainly concentrated to Al-Plaza in the morning and disperse from Al-Plaza during the afternoon period.
- During evening peak hours, up to 40% of the requests are destined to Takanohara Station. Most of their origins lie in the Seika-Nishikizu District. There is no regular bus service between this District and Takanohara Station.

We have found that the demand pattern changes by the time of day. To make our analysis more realistic, we decided to divide the whole service interval into four, and different demand patterns are calculated based on the booking requests of the Keihanna-ITS project. The D-Bus service starts at 8.30 and continues until 19.30, and the four intervals are set to be 8.30-11.30, 11.30-14.30, 14.30-17.30 and 17.30-19.30. The number of requests for each time interval was almost equal. The requests are created randomly from the pattern, and the booking sequences are also identified randomly.

We should mention here that the demand pattern obtained in the project does not reflect the whole demand within the area since ordinary bus services were also provided during the project. Therefore, most of the DRT booking requests were to receive a ride between bus stops where no direct services exist. Especially in rural areas where the bus service is poor, people are likely to fit their schedule according to the schedule of the bus service. This suggests considering the passenger activities is important for the evaluation of rural bus services. The demand pattern must change according to the service performance, and the performance changes with variations in the demand pattern. In this paper we only evaluate the system capacity of DRT without considering the effect of demand changes in response to the supplied service.

The bus can run on any link shown in Figure 3. Other settings are summarised in Table 2. Note that 20 demand patterns are created to eliminate the effect of randomness.

## 4.2 Results

*a) Evaluation from passenger side statistics*

Figure 4 illustrates the relationship between the accepted demand (AD) and the number of vehicles in operation. In Figures 4, 5 and 6, the larger

Table 2. Parameter settings

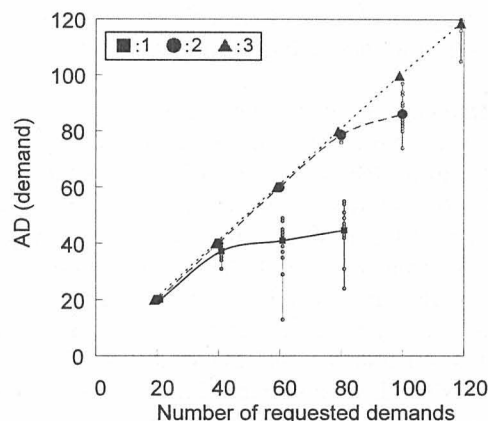| | |
|---|---|
| $\alpha$ | 5 min. |
| $\beta$ | 20 min |
| $\gamma$ | 1 |
| $N_v$ | Up to 3 veh. |
| $d_j$ | 1 min for all passengers |
| *Number of demands* | 20 – 120 |



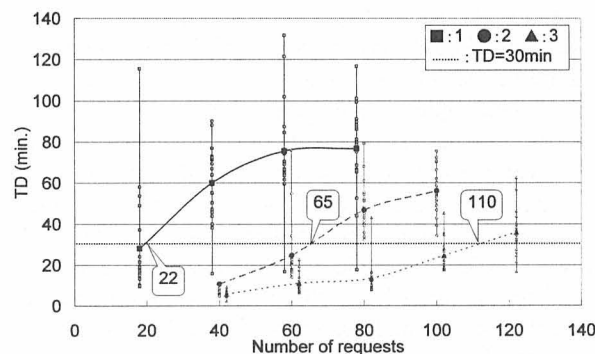Figure 4. Relationship between AD and the number of buses



Figure 5. Relationship between TD and the number of buses

squares/circles/triangles connecting different demand levels with lines represent the average values of accepted demands, whereas the small dots that are dispersing vertically around the average value represent the distribution of the 20 demand patterns. As expected the system can accept more demand when there are more vehicles. Around 45 requests can be accepted if there is only one vehicle, around 90 trip requests can be accepted when we have two vehicles, and more than 120 requests are likely to be assigned to three vehicles. Comparing the dispersion of the calculation results with different demand patterns within the same case, it can be said that the result varies largely when we have only one vehicle. It means that service levels will be more stable if we have more than one vehicle.

Figure 5 represents the relationship between the number of vehicles and the total time difference between desired and actual departure time, called TD. The

horizontal dotted line shows TD = 30 min. Looking at the number of requests where this line crosses for each graph, the number of requests accepted within the service quality of TD=30 are 22, 65 and 110 for 1, 2 and 3 vehicles, respectively. In conclusion, the service quality gets much higher when there is more than 1 vehicle, and more requests can be accepted within certain service quality if we have more requests. The graph suggests that a more efficient service can be carried out if we have a higher demand level.

*b) Evaluation from operator side statistics*

So far we have explored the service quality of DRT services from the viewpoint of passengers. In this section, the service is evaluated from the operators' viewpoint. In Figure 6, the bus travel time per trip (BT) is shown. From this figure we can conclude, that the value of BT gets smaller if more vehicles are in operation. The average direct travel time between OD pairs was 7.5 minutes, and the value of BT is smaller than 7.5 when there are three vehicles. It means that the vehicles are often shared by several passengers. To confirm this, the demand density DD is calculated and the result for a case with 80 requests served by 2 vehicles is shown in Figure 7. Judging from Figure 4, the demand should have been assigned almost up to the capacity of the service. As is expected, the vehicles are shared with other passengers almost all the time. However, the maximum number of passengers together in one vehicle is 5, and the average DD for the whole time interval is 1.2 for vehicle #1, and 1.13 for vehicle #2. In general, a passenger density of around 13 is needed in order to provide a profitable route bus service. Therefore, the fare of the DRT services should be much higher than the normal bus service if we want to provide profitable services with large buses like Keihanna ITS project. Providing services with smaller fleets is more adequate. For evaluating such services, the algorithm should be modified to consider vehicle capacities.

*c) The effect of booking sequences*

As is explained in Section 2, the service efficiency would change if the booking sequence is different. To confirm the effect of the booking sequence, we created the dataset with same origins and destinations but different booking sequences. In Figures 8 (a) and (b), results with 2 vehicles for 40 and 80 trip requests are illustrated. The horizontal axis represents the ID of cases and the cases are ordered by the value of TD. Then, for the worst case (ID=1), medium case (ID=9) and best case (ID=20), another 19 sets of demand with different booking sequences are created and are assigned to the vehicles. The results are shown by the vertical variation in the figure. The effect of OD variation can be evaluated by the variation of best, worst or average values of TD (upper and lower limits are shown with horizontal solid lines in the figure) whereas the effect of
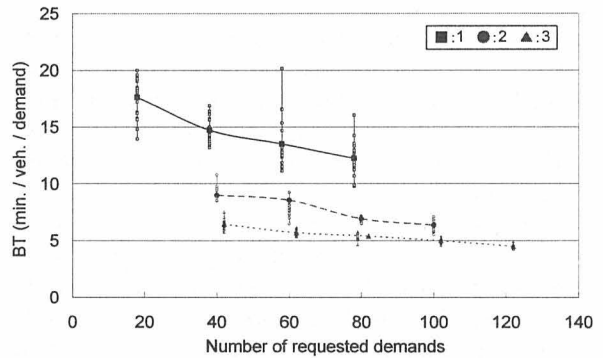


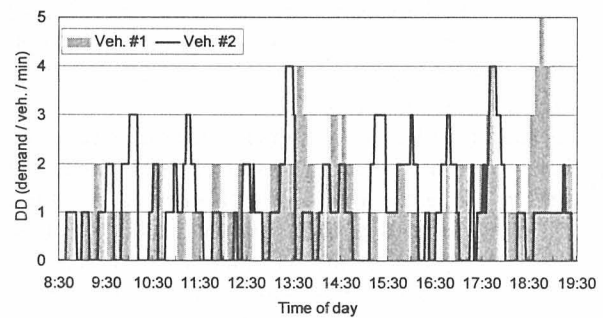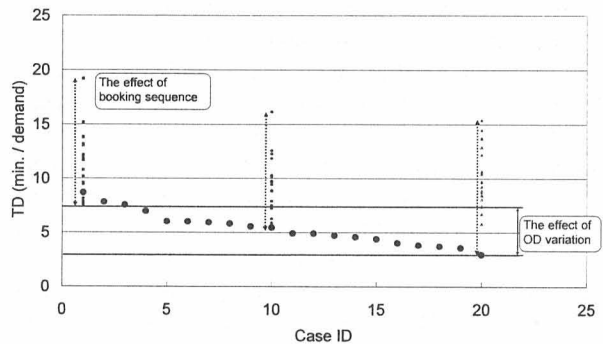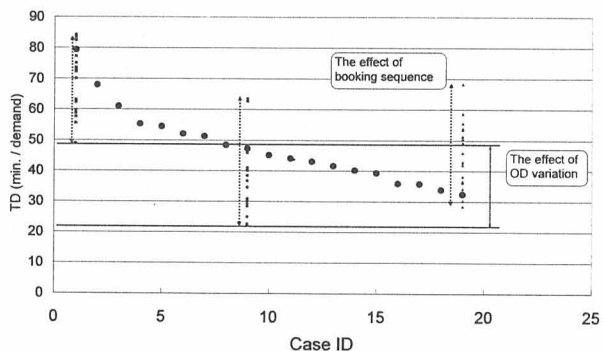Figure 6. Relationship between BT and the number of buses



Figure 7. DD (80 requests, 2 vehicles)



(a) Trip requests=40



(b) Trip requests=80
Figure 8. Effect of booking sequence

booking sequence can be evaluated by the variation shown for the worst, medium and best cases (vertical dotted arrows). The results show that at low demand levels (Figure 8(a)), the effect of the booking sequence is much larger than the effect of OD variation, and the effect of OD variation gets larger when the demand level is higher (Figure 8(b)). In general it can be concluded, that the influence of the booking sequences is quite large.

One might notice that all of the initial 20 cases (larger circles in Figure 8(a)) provided rather better values of TD although their fluctuations should include variations of both booking sequences and OD variation. Evaluating the cases by only 20 patterns might not be sufficient, and the findings here should be confirmed with further calculations.

## 5. Conclusions and recommendations

This study aims at evaluating the service level of DRT, with a new sequential demand assignment. The proposed algorithm minimises the total time difference between desired and actual departure time (TD) and therefore maximise the user benefit. By the proposed algorithm, the service characteristics of DRT are evaluated using the demand pattern obtained by the Keihanna-ITS pilot project. The maximum number of acceptable passengers was around 45 when there is 1 vehicle, and 90 when there are two. Of course these values change according to the demand pattern and size of the network, but at least we can say that it is possible to evaluate the capacity of the service by the proposed algorithm. It is also possible to evaluate how many vehicles should be used for providing a specific service level. In the example, 22, 65 and 110 requests can be accepted in the case of 1, 2 and 3 vehicles respectively when we want to ensure an average service level of TD=30 minutes. The service is more stable if there is more than 1 vehicle, and more a efficient service can be carried out if the demand level is much higher.

From an operators' point of view, the service efficiency improves when the demand level is higher. However, at most 5 passengers can be assigned to one vehicle simultaneously. This means that it is quite difficult to provide a DRT service with normal bus fare. The fare should be much higher to be profitable. It would be preferable to provide DRT services with smaller fleet such as mini-van or micro bus since the running cost is much cheaper. Also the sequence of booking influences the efficiency of services a lot. It is worth discussing the simultaneous demand assignment. In simultaneous assignment, we need to either guarantee the pick up service at the desired departure time or report the assignment result later to the passengers. This additional requirement might be relaxed by the recent penetration rate of mobile phones with SMS or e-mail functions.

In this study, only limited cases are discussed. We should carry out the analysis with more demand patterns to obtain more reliable results, and have only explored the relationship between level of demand and the performance of services. Other studies such as a sensitivity analysis of changing the parameters $\alpha$, $\beta$, and $\gamma$, or comparing the results of different objective functions such as maximising the profit of the operator should be carried out by the proposed algorithms.

In response to the findings of this study, the formulation and construction of a simultaneous assignment algorithm is needed for exploring the further potentials of DRT services. Especially, providing services by smaller fleets such as taxis would be one of the possible solutions to overcome the limitations of DRT found in this study. For this, we should include capacity constraints in the algorithm.

Finally, an important direction for further research would be to implement a resource assignment algorithm to provide efficient vehicle/driver allocation. Also the demand-side analysis forecasting the demand level with a certain level of service should be carried out to discuss profitability of DRT services.

## 6. Acknowledgments

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