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# Assessment of the DRT System Based on an Optimal Routing Strategy

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**Abstract:** Demand responsive transport (DRT) is operated according to flexible routes, dispatch intervals, and dynamic demand, is attracting a lot of attention. The biggest characteristic of the DRT service is that the vehicle routes and schedules are operated optimally based on real-time travel requests of using passengers without fixed operating schedules. This study analyzed the feasibility of implementing the DRT service by analyzing the benefits for the users and cost of the operator from the effects of increasing public transportation use and providing personalized mobility service based on DRT implementation by the introduction of DRT using multi-agent transport simulation (MATSim). Through the simulation, the DRT is expected to provide convenient, fast, and cost-effective mobility services to customers; provide an optimal vehicle scale to providers; and, ultimately, achieve a safe and efficient transportation system.

**Keywords:** DRT; MATSim; first mile/last mile; feasibility analysis

## 1. Introduction

Growing population and mobility needs are the problem of today's cities. In order to overcome different challenges, such as accessibility, congestion, pollution, and fuel conception; governments have to explore new forms of sustainable transportation. One of the sustainable transportation forms, is the demand responsive transportation (DRT) modes, which is mainly characterized by its flexibility and door-to-door service. In fact, DRT has appeared since the 1960s in UK, within some rural transport experiments, in form of a dial-a-ride, flexi-route, and community car and bus schemes [1]. Later, many communities developed different forms of DRT services according to their local circumstances and conditions, however, the service was depending of government sponsorship [2].

The concept of DRT itself has a potential to ensure a viable transportation service. The usage has been greatly enhanced through transport telematics and its successful demonstration in a variety of environments in EC-funded R&D projects such as SAMPO (System for Advanced Management of Public Transport Operations) and SAMPLUS (System for Advanced Management of Public Transport Operations Plus) [3].

The transport service that could be considered has a DRT form, has to fulfill the following characteristics [4]:

- The service should be available to the general public, without restriction to any special group (categorized by age, sex, disability, place of employment, etc.);
- The service should be provided by low capacity vehicles (small buses, vans, or taxis);
- The service has to be able to reply to different changes in demand by either altering its route and/or its timetable;
- The system's fare has to be charged per passenger and not a per vehicle basis.

The topic was under investigation under many terminologies, like dial-a-ride [5], ad-hoc ride-sharing [6,7], and paratransit in USA [8,9]. As stated in Ambrosino et al. [10], DRT is considered an “intermediate form of transport, somewhere between the bus and taxi, which covers a wide range of transport services, ranging from less formal community transport through to area-wide service networks”. On the other hand, Bakker [11] defined DRT as the “transportation option that falls between private car and conventional public bus services. It is usually considered to be an option only for less developed countries and for niches like elderly and disabled people”.

This new form of transportation has the ability to fight against social exclusion, for example: of elderly and disabled people [12]. Accordingly, the DRT has promising potential of competing against the increase of private cars, especially in case of short distance and delivery trips within low density urban areas [13].

In fact, DRT is considered a transport mode that could increase accessibility and security with a relatively cheaper cost than taxis [14] while maintaining comparable flexibility. However, there are several socio-economic, demographic, and trip characteristics of both individuals and households, which affect the DRT. Since social impacts are very considered in any transportation mode [2,15], DRT could be successful, if only the new form of transportation could overcome social issues.

Despite the great potential, DRT is believed to not given opportunity to be fully exploited, as it still suffers from existing institutional barriers that weaken its growth. Moreover, it faces a big challenge regarding the realistic prediction of travel demand in order to plan adequate supply, as well as the enhancement of the financial viability of the service. The indirect competition with private vehicle modes, and sometimes taxis, worsen the DRT situation and tied its success to other external factors such as parking spaces and tolls. However, it has been acknowledged as an advantageous tool that can efficiently contribute to expand and strengthen public transport schemes [16,17].

Nonetheless, with the recent development in information technologies and telecommunications [18], and in optimization methods, DRT is believed to have a better growth and prosper environment to achieve its fully potential. In fact, exploiting new technologies offers ways to reduce the costs, and even increase profitability in some restricted markets. IT development technology induced progress regarding enabling real-time or ad-hoc DRT [7].

Currently, DRT systems exist in many cities around the world, under several forms and using many types of vehicles, but generally it offers a trip for fixed origins or destinations, or fixed routes, or with some form of pre-booking.

This study aims to analyze the effect of operating a DRT that satisfies real-time travel demands. If the DRT service is implemented additionally in the conventional public transportation system, it will affect the transportation system. In other words, if DRT, which provides door-to-door service of the first mile/last mile concept considered in this study, is implemented, private car users will switch to public transportation, thus leading to a socioeconomic benefit. Therefore, to evaluate the DRT service that provides personalized mobility service by corresponding to user requests instead of using fixed routes such as public transportation does, it is crucial to perform simulation-based evaluation of the DRT routing method by reflecting real-time travel behaviors, rather than using a conventional static stochastic model-based optimization method. Therefore, this study analyzed the simulation-based DRT implementation effect by using the activity-based model for transportation planning so that the operation of individual vehicles with no fixed route can reflect the travel behaviors of users. This study aims to establish a socioeconomic benefit maximization strategy according to DRT implementation by applying a DRT routing algorithm that can minimize DRT users' cost and providers' operation cost based on a dynamic vehicle routing problem (DVRP) that reflects specific and diverse travel behaviors. In a usual DVRP, one vehicle accepts only one request at a time, but the proposed algorithm is devised based on a dispatch algorithm so that pickup, drop, and boarding can all be performed at once [19]. DRT vehicles are dispatched to minimize total travel time of passengers after operating on attractive routes such as the DVRP does, and this is implemented through the multi-agent transport simulation

(MATSim). Furthermore, various effects such as the optimal DRT fare system, number and capacity of vehicles, and transportation modal shift are analyzed through simulation-based evaluation.

## 2. Simulation Framework of DRT

To evaluate the effects of large-scale introduction of DRT, we decided to carry out a microscopic simulation of a typical weekday in Seoul. The simulation runs in this study were made with MATSim. The software is open-source and jointly co-developed by TU Berlin and ETH Zurich. MATSim allows a microscopic simulation of agent behavior at high computational speeds. Thus, it is suitable for large-scale scenarios and has been used worldwide. It combines a traffic-flow simulation with a sophisticated scoring model for agents as well as provides co-evolutionary algorithms that can alter the daily routines (“plans”) of agents. Specifically, in line with Kim and Lee [20], individuals’ trips were aggregated from a clean data set according to the trip start time and OD(Origin-Destination), and the plan data were generated by using trip-chain analysis and smartcard data.

To prepare a network to use as input data in MATSim, the following two processes were performed. First, Seoul City’s network was extracted from a program called JOSM. In this study, the link attributes were input by using the original Korea Transport DataBase network. Then, using a program called the NetworkCleanser, the network was organized to satisfy the input data requirements of MATSim. This enabled each link on the network to reach another link. The links not tied to other links were deleted from the network. Nodes that do not have incoming or outgoing links were also deleted from the network.

For the simulation of DRT, door-to-door service should be analyzed; therefore, the starting and terminating points of the DRT mode should be set up to facilitate any place in the service area, even if they are bus stops or taxi stands. In this simulation, a location where the demand occurs or the DRT arrives is expressed as a point. In other words, in most transport-planning models, the TAZ is created as a polygon shape, but this study reflected it in the form of points. Specifically, by using the MATSim Converter program, trip plans of initial individual agents were composed from the cleaned data set, and the locations where the demands occur were assigned coordinates. An arbitrary coordinate pair  $(x, y)$  was based on an activity occurring in an administrative sub-district (dong) area of an existing zone unit, and this study selected activity locations where the individual users’ demands occurred by using activity coordinates, similar to Rieser et al. [21].

The initial model was based on the MATSim-Seoul model for the year 2018. It has been used in several Seoul-related case studies on both public and private transport. The network contains about 18,440 road links and 7248 nodes. This allows the depiction of all major and minor roads within the city boundary as well as all bigger roads in the surroundings. The initial network also contains designated public transit links (used for railway and subway lines). The synthetic population depicts a typical weekday in Seoul [20]. There are many agent activities throughout the day. In the original scenario, agents make use of all relevant transport modes. These also include very short trips made by bikes or walking. Traffic flow in the scenario was characterized by a morning peak, which was followed by a constant amount of traffic flow during the day, leading to a remarkably strong afternoon peak. The split of car and public transit trips (PT) in Seoul was roughly even, with both modes having a share of 35%. This scenario was validated against car counting stations throughout the city.

The simulation of DRT dispatching was carried out by MATSim’s DVRP extension that allows simulation of on-demand transport services. DRTs are coordinated by a dispatcher, who reacts to incoming events (such as new request submissions, vehicle arrivals, and departures) and dynamically re-optimizes DRT routes and schedules to ensure the most efficient execution of DRT orders.

Conventional DRT usually serves requests according to the “first come, first served” rule, because taxi demand is relatively small compared with the supply most of the time. However, in an overloaded system, this strategy is highly inefficient. For instance, when all vehicles are busy, whenever a vehicle turns idle, it is immediately dispatched to the longest waiting open request, regardless of the distance between them. To avoid oversizing of the DRT fleet, the dispatching strategy must be implemented in

a different way considering the demand. This issue was addressed by the demand-supply balancing DRT dispatching strategy proposed by Bischoff and Maciejewski [22]. It classifies the system state into two mutually excluding categories—oversupply, with at least one idle taxi and no open requests, and undersupply, with no idle taxis and at least one open request—and it handles these two situations differently. In the former case, when a new request is placed, the nearest taxi is dispatched toward it; in the latter case, when a vehicle becomes idle, it is dispatched to the nearest open request. Under low demand, the balancing strategy serves requests immediately as they arrive, exactly as in the traditional approach. However, in an overloaded system, the focus is on maximizing vehicle utilization, which results in an increased throughput and, consequently, reduces the amount of time passengers await taxis. Despite its simplicity, this strategy provides solutions that are close to those of more complex methods, such as iteratively solving a taxi assignment problem. Moreover, we used a dispatch strategy based on Bischoff and Maciejewski [22] for adaptation to a large scale.

- A zone-based register of idle vehicles was maintained to quickly select a subset of  $k$  idle vehicles that were nearest to a given location using pre-calculated distances between zone centroids. This registry was used for a request-initiated dispatch, which is when a request is posed during oversupply. Once the  $k$  nearest idle vehicles were selected, the backward shortest path search was run, starting from the submitted request and moving backward until the nearest vehicle was reached.
- A vehicle-initiated dispatch, which takes place when a vehicle becomes idle during undersupply, was handled in a similar way. A zone-based register of open requests was used to pre-select the nearest  $k$  requests, and then a search of the shortest forward path from an idle-vehicle to  $k$ -open-requests was executed to determine the nearest open request and calculate the shortest path to it.

The DVRT algorithm is based on MATSim's ability to replan agents dynamically during the day. The extension contains a framework for scheduling vehicles according to tasks. These are handled by dynamic agents. So far, the DVRP and taxi extensions are only able to serve a single request per vehicle at a time. This needs to be extended for the purpose of DRT, wherein several passengers are onboard a vehicle at the same time. The DRT was hence equipped with the following [21]:

- Taxibus tasks that can serve multiple requests at a time;
- A taxibus scheduler that schedules pickups, drop offs, and rides in accordance with the requests and as calculated by the dispatch algorithm; and
- An abstract dispatch algorithm that provides the typical dispatch infrastructure.

The dispatch algorithm, or optimizer, could then be implemented by extending the abstract dispatch algorithm in accordance with the actual use case. The basic principle of each optimizer, however, is usually the same: a list of requests, which may be pre-booked or not, need to be handled. The optimizer should then return to a dispatch, consisting of a vehicle, the requests it is meant to handle and the paths it is meant to travel between pickups and drop offs. With this approach, a large set of use cases may be implemented with little additional effort. These could include classical dial-a-ride or paratransit approaches as well as shared-taxi algorithms or even parcel deliveries.

### 3. Analysis of the Effects of DRT Implementation

#### 3.1. Analysis Scenario

The case study assumed the use of door-to-station service by using the DRT system to use a bus or subway train. In other words, the simulation was configured to analyze the effect of the DRT service for the first mile/last mile concept. The scenario for the simulation was composed by changing the number of DRT vehicles and fares. As for the DRT fare, cases of assigning the service free of charge and at 50% and 100% of the taxi fare were composed. For the number of DRT vehicles, five cases were

composed for the following scenarios: 10%, 30%, 50%, 70%, and 100% of the total number of registered taxis in Seoul. Consequentially, 15 scenarios were composed based on the fare and number of operated vehicles. For the analysis, it was assumed that the capacity of a DRT vehicle was 10 persons. The DRT vehicle started the trip one hour before the arrival time, and the request of other users could be accepted until 15 min before arrival at a destination (public transport stop) of the user who came on board first. On this occasion, the DRT driver decides whether to accept or refuse the request. The public transport users (potential DRT customers) change their request time up to 2 min while performing the first 200 iterations and thereafter they can select one of several possible plans. Furthermore, for the routing, the next customers were only added to the end of the list of accepted customers to be picked up.

### 3.2. Analysis of Results

To analyze the scenario results, this study conducted comparative analysis on the benefits to the users and to the cost of the operator. First, in the case of benefit to the user, the effect of the total transport system's operating hour reduction was analyzed through changes in the number of passengers/public transport users due to DRT service implementation, based on the performance indices proposed by Black [23]. This effect was produced because existing private car users switched their mode use behaviors to public transport because of DRT service implementation. This effect reduced the total travel time of all the modes while reducing the use of conventional private cars due to the overall modal shift. Furthermore, the service quality index (level of service (LOS)) was analyzed to determine the usefulness of the DRT service. When an agent whose private car traveling time is expected to be 10 min switches to using the DRT, if the total sum of DRT waiting time and public transport using time is 30 min, the LOS index is calculated as 3.0. If a relatively lower value is derived for this, it implies better service quality. Regarding the cost of the operator, fixed costs and variable costs are classified according to the vehicles based on DRT implementation (see Table 1). The fixed costs consist of the vehicle depreciation cost, and other administrative costs (insurance fee), and the variable costs consist of fuel cost and vehicle maintenance and management costs. Driver labor costs were not included here, because it was assumed that DRT vehicles were operated on autonomous driving technology.

**Table 1.** Demand responsive transport (DRT) introduction cost.

	Category	Description
Fixed Costs	Vehicle depreciation cost	Vehicle price: 30 million won
	Other administrative cost	Average insurance fee per vehicle: 1918 won/day
Variable Costs	Fuel cost	Fuel economy: 11.4 km/L Fuel cost: 1369 won/L ( <a href="http://www.opinet.co.kr">http://www.opinet.co.kr</a> )
	Vehicle maintenance and management cost	Average maintenance cost and tire cost per vehicle: 1370 won/day

#### 3.2.1. Fixed Costs

Among the fixed costs, the vehicle depreciation cost is calculated as follows by assuming that the residual value of the manufacturer selling price is 35% ( $\alpha$ ) of the purchase price and applying the vehicle age period of the bus (i.e., 9 years) as specified in a relevant law, and in the case of other administrative costs (insurance fee), the average cost per vehicle for the bus company was applied.

$$C_{fixed} = \frac{C_{veh} - C_{veh} \times \alpha}{y}$$

#### 3.2.2. Variable Costs

Among the variable costs, the fuel cost is calculated by using the following equation, whereby the fuel consumption is calculated using the operating distance and fuel economy, and then the fuel price is applied to this. Here, TD is the total operating distance (km) by vehicle,  $\beta$  is the fuel economy (km/L),

and  $C_f$  refers to the unit cost of fuel (won). In addition, for the vehicle maintenance and management costs, the average daily cost per vehicle for the bus company is applied.

$$C_{fuel} = TD \times \beta \times C_f.$$

In the simulation results based on the DRT fare and number of DRT vehicles, the travel time decreased as the DRT fare decreased and the number of times of the DRT's operation increased. However, as the number of DRT vehicles increased, the decreasing range of travel time reduced to above a certain level (see Table 2). This seems to be because if too many DRT vehicles are operated, the increase in congestion caused by the operating vehicles to pick up users, take users to destinations, or operate on circular routes outweighs the increase in the congestion mitigation effect produced by the decrease in operated private cars due to the modal shift. Based on this result, it is determined that it will be more effective and efficient to operate an appropriate number of DRT vehicles. Based on the result of the simulation analysis, this study used the vehicle's time value by mode, as presented in the "Preliminary Feasibility Study Guide, KDI," to convert the user travel time savings derived from DRT implementation into a monetary amount. Furthermore, when not conducting the business and when conducting the business by vehicle type, the total travel time cost was calculated by applying the different time values, respectively, to the total travel time calculated for each mode; afterwards, the compared difference was calculated as the travel time saving benefit.

$$VOTS = VOT_{before} - VOT_{after},$$

where  $VOT = \sum_l \sum_{k=1}^3 (T_{kl} \times P_k \times Q_{kl} \times 365)$ ,  $T_{kl}$ : each mode travel time of link  $l$ ,  $P_k$ : each mode value of time,  $Q_{kl}$ : each mode traffic volume of link  $l$ , and  $k$  modes (1. passenger car, 2. bus, 3. Truck).

**Table 2.** Benefit of travel time savings derived from DRT introduction.

Category		Demand Responsive Transit (DRT) Fare		
		Free	50% of Taxi Fare	100% of Taxi Fare
No. of DRT vehicles	10%	308.38	266.16	230.32
	30%	1156.92	870.49	924.41
	50%	1951.87	1911.61	1453.70
	70%	2286.60	1798.55	1641.57
	100%	2730.73	2583.40	1925.76

unit: 100 million/year.

When examining the LOS aspect, the LOS varied from 1.006 to 1.537 depending on the DRT fare level and number of operated vehicles (see Table 3). In other words, in the aspect of service quality of DRT implementation, there is no large difference when the DRT fare is expensive or there are many DRT vehicles operated. However, when the number of DRT vehicles is small or the DRT fare is inexpensive, the users have to put up with travel time increase caused by detours because the DRT service provided is not sufficient as compared with the number of users.

**Table 3.** Level of service (LOS) analysis of DRT implementation.

Category		Demand Responsive Transit (DRT) Fare		
		Free	50% of Taxi Fare	100% of Taxi Fare
No. of DRT vehicles	10%	1.507	1.537	1.531
	30%	1.348	1.250	1.318
	50%	1.156	1.221	1.157
	70%	1.097	1.123	1.050
	100%	1.006	1.031	1.077

The required cost calculation results about the operator aspect according to the DRT operating scenarios are shown in the Table 4. In the case of DRT, the vehicle cost (vehicle depreciation cost) occupied the largest proportion, and the fixed costs were larger than the variable costs. Furthermore, the variable costs changed according to the DRT fares, because the variable cost expenditure increased from the operator standpoint as more vehicles were operated due to the DRT service implementation.

**Table 4.** Cost estimation by DRT introduction scenarios.

Category		Demand Responsive Transit (DRT) Fare					
		Free		50% of Taxi Fare		100% of Taxi Fare	
		Fixed Cost	Variable Costs	Fixed Cost	Variable Costs	Fixed Cost	Variable Costs
No. of DRT vehicles	10%	266.4	36.1	266.4	23.9	266.4	17.3
	30%	799.2	108.1	799.2	70.9	799.2	52.5
	50%	1332.0	180.1	1332.0	125.5	1332.0	86.1
	70%	1864.8	252.1	1864.8	171.3	1864.8	126.0
	100%	2664.1	360.1	2664.1	236.6	2664.1	179.4

unit: 100 million/year.

As a result of the cost–benefit analysis based on the simulation results, that economic feasibility was ensured for DRT service implementation when the number of DRT vehicles was at the 30–50% level of the registered number of taxis, or the DRT fare was at 50% of the taxi fare or less (see Table 5). Regarding the number of DRT vehicles, if the number of operated vehicles is too small or too large, the benefit will be small compared with the cost injected for the DRT operation. Moreover, regarding the DRT fare, if the fares are similar to the taxi fares, the users will not feel that the DRT is relatively attractive, and, consequentially, the DRT will be not be economically justifiable.

**Table 5.** The results of benefit/cost analysis of introducing of DRT.

Category		Demand Responsive Transit (DRT) Fare		
		Free	50% of Taxi Fare	100% of Taxi Fare
No. of DRT vehicles	10%	1.02	0.92	0.81
	30%	1.28	1.00	1.09
	50%	1.29	1.31	1.03
	70%	1.08	0.88	0.82
	100%	0.90	0.89	0.68

#### 4. Conclusions

Demand responsive transit can be called a paratransit system that can mitigate the time and space constraints of using transportation to correct the operational problems of the conventional bus system. DRT, which is a transformed form of the conventional public transportation service, is a public transportation system providing a service that is operated freely according to the requests and demands of using passengers, and it corresponds to individuals' travel goals and user intentions. Recently, the DRT, which is operated according to flexible routes, dispatch intervals, and dynamic demand, is attracting a lot of attention. For the traditional public transportation system, which is operated on the usual fixed routes and dispatch intervals, the characteristics of service quality and profitability are high owing to the short dispatch intervals on routes where the demand is high. On routes where the demand is low, however, the characteristics of both quality of passenger service and profitability are low because of inefficient routes and long dispatch intervals. Furthermore, operating vehicles that produce a large amount of exhaust fumes during low-demand hours have been pointed out as a potential environmental problem. In contrast, the DRT is a public transportation service operated without fixed routes according to the dynamic demand without constraints of route and dispatch time. It is also known as a type of paratransit system.

This study analyzed the feasibility of implementing the DRT service by analyzing the benefits for the users and cost of the operator from the effects of increasing public transportation use and

providing personalized mobility service based on DRT implementation. Recently, ahead of the smart city and autonomous vehicle commercialization era, the significant importance of a demand-responsive door-to-door service such as DRT has emerged. Particularly, because the DRT service can solve the first mile/last mile problem, it can contribute to the vitalization of public transportation; moreover, because it can become a foundation of MaaS, it is meaningful to analyze the feasibility of implementing the DRT service. Accordingly, this study reflected the real-time travel behaviors by using the activity-based approach, and it used a DRT routing algorithm through the MATSim-based DVRP to satisfy a variety of user demands. To analyze the DRT implementation effect targeting a large scale based on simulations, this study comparatively analyzed the travel time saving effect of the entire transport system as well as the operator costs incurred by the DRT operation by setting up the DRT fares and number of operated vehicles in various scenarios. The results show that if the DRT service was provided at inexpensive fares, the socioeconomic benefit would outweigh the cost. Furthermore, upon analyzing the quality of the DRT service, the results show that the service quality was relatively good at an appropriate level of the number of operated vehicles and fare system.

This study was significant as it analyzed the effect of DRT implementation that could satisfy various travel demands in a large-scale network by using a simulation method. Particularly, this study analyzed the effect of DRT implementation based on various scenarios, and it quantitatively investigated the implementation feasibility by estimating the costs of the DRT operation. Especially, this method has an advantage as it can assist the decision making of policymakers when implementing the DRT, since the appropriate implementation size (number of operated vehicles) and service fares can be investigated in advance. Moreover, the cost can be calculated, the benefit can be quantified, and the LOS can be derived based on actual performance data similar to that of the DRT service.

The proposed simulation-based approach provides a demand-responsive service such as the DRT in a real large-scale network, and it demonstrates an advantage of performing the cost–benefit analysis based on this approach. However, compared with the conventional microscopic traffic simulation, it has an inherent limitation as it does not consider the movements of vehicles while taking account of the traffic operation and road sign system. Furthermore, a more realistic result will be derived from DRT operation scenarios if a method of inputting more aspects (such as identification of moving patterns of the potential demand by hour, deployment of appropriate types of vehicles, and fare differentiation strategy) are used in the simulation environment.

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