Heuristic Approach for Solving Demand Responsive Transport Scheduling Problems

H. S. Park[a], S. H. Cho[a], D. H. Shin[b], S. H. Park[a,*]

[a] < Department of Transportation Engineering, University of Seoul >, < Seoulsiripdaero 163, Dongdaemun-gu, Seoul >, < Republic of Korea 02504>
hyunspark@uos.ac.kr, shcho@uos.ac.kr, shinhpark@uos.ac.kr
[b] < Department of Computer Information Engineering, KwangWoon University >, < Gwangun-ro 20, Nowon-gu, Seoul >, < Republic of Korea 01897>
dhshin@kw.ac.kr
* Corresponding author

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1 INTRODUCTION

Recently, DRT systems have been able to effectively handle dynamic travel demands with lower costs owing to advancements in information and communication technology (ICT) (Angelelli et al., 2022). Accordingly, various studies have been underway to explore the feasibility of operating flexible and sustainable DRT systems in rural and urban areas (Franco et al., 2020). As the scope of DRT services has expanded, various types of DRT have been operated. The traditional dial-a-ride is a service in which passengers request trips via phone reservations. This service is generally provided to residents living in low-demand areas that are not accessible by conventional public transit services (Cordeau and Laporte, 2003). However, use of the service is restricted to those with reservations. Another type of DRT is a customized bus (CB), which plans and operates routes by aggregating similar travel demand patterns using online information platforms such as the Internet and cellphones (Liu and Ceder, 2015). However, CB plans routes based on existing demand patterns, making it difficult to accommodate new requests that deviate from these established patterns. The other type of DRT is demand responsive feeder service (DRFS). DRFS primarily serves passengers residing in low-demand areas, commuters during peak hours, and individuals who utilize specific stops or transfer hubs to reach their destinations. However, DRFS is a concept of first- or last-mile service exclusively provided to passengers with the same specific travel purpose, making it less attractive than other types of DRT services.

Existing DRT services face limitations or unavailability of route changes during operations, as routes are planned based on information collected through in-advance reservations or subscriptions (Chen et al., 2021; Montenegro et al., 2021). This study proposes the development of a DRT service system with fully flexible routes, unrestricted by specific passengers, and devoid of fixed stops or predetermined origins and destinations for passenger requests. It employs an insertion heuristic (IH) to effectively address DRT scheduling problems, while the proposed services handle unknown demand on a first-come-first-served (FCFS) basis without requiring advance reservation information. This approach focuses on utilizing an objective function to minimize travel costs while considering constraints such as vehicle capacity and the passenger's desired pick-up and drop-off times. Subsequently, a case study is conducted using randomly generated passenger requests within the Sioux Falls network to assess the developed DRT system.

2 METHODOLGY

2.1 Objective Function and Constraints

The objective of this study is minimizing the operating cost of a DRT system, which is calculated as the sum of the link travel times for all DRTs. The operating costs include the time required for the DRT to pick up passengers and deliver them to their destinations, excluding idle times. The objective function is represented as Equation 1.

$$min\ T = \sum_{k \in K} \sum_{i \in V_p} \sum_{j \in V_d} (t_{i,j} \times y_{i,j}^k), \tag{1}$$

where $t_{i,j}$ represents the travel time from vertex i to vertex j, and $y_{i,j}^k$ is a binary variable indicating whether DRT k travels from vertex i to vertex j.

The constraints of the proposed DRT system include time windows, capacity, and flow conservation. First, the time window constraints are represented by Equations 2–3. The passenger's actual pick-up time ($t_i^{r,\acute{p}}$) must be within the passenger's desired pick-up request time plus the maximum waiting time (WT), and the passenger's actual drop-off time ($t_j^{r,\acute{d}}$) must be within the passenger's desired drop-off time plus the maximum detour time (DT). In this study, each request was subject to a maximum waiting time and detour time of 10 minutes (Boesch et al., 2016; Oh et al., 2020). The capacity (Cap) constraint of the DRT is represented in Equation 4. This study assumes a DRT with a 6-seater minivan, adopting a conservative approach due to the unknown passenger demand. Where x_r^k represents the request-to-vehicle assignment, the variable equals 1 if request r is assigned to DRT k, and 0 otherwise. The flow conservation constraint states that each DRT vehicle entering and exiting a node is equal. This ensures a balanced flow of vehicles through the network. The flow conservation constraint is represented in Equation 5.

$$t_{\square}^{r,p} \leq t_{\square}^{r,\acute{p}} \leq t_i^{r,p} + WT \ \ \forall v_i \in V_p, \tag{2}$$

$$t_{\square}^{r,d} \leq t_j^{r,\acute{d}} \leq t_j^{r,d} + DT \ \ \forall v_j \in V_d, \tag{3}$$

$$\sum_{r \in R} x_r^k \leq Cap \ \ \forall k \in K, \tag{4}$$

$$\sum_{i \in V, i \neq j} y_{i,j}^k = \sum_{i \in V, i \neq j} y_{j,i}^k \ \ \forall j \in V, k \in K \tag{5}$$

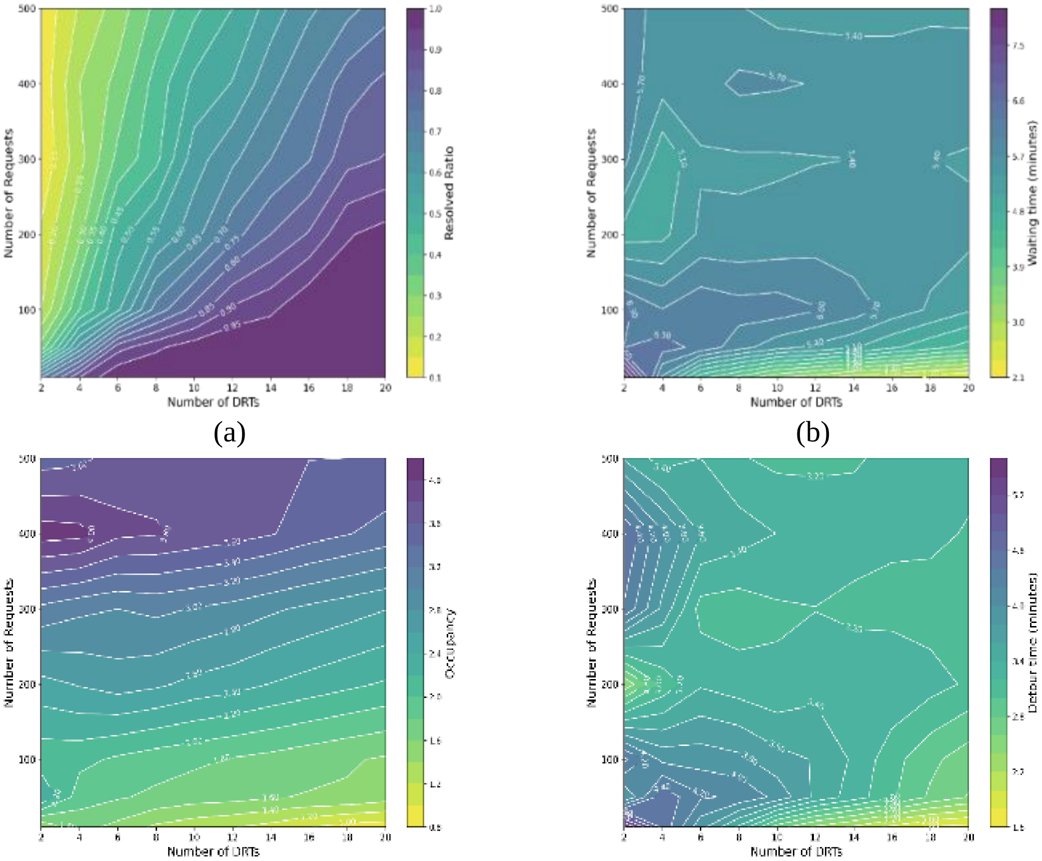
2.2 Insertion Heuristic

The IH is employed to assign passengers to DRTs by identifying routes and schedules that minimize operating costs based on passenger request information. When a new request is received, the system checks whether assigning a new request to each DRT will cause it to exceed capacity. If the capacity is not exceeded, the system identifies potential insertion points. The insertable condition of each DRT is that passengers already onboard or scheduled to board must be picked up within their desired pick-up time plus WT and dropped off within the desired drop-off time plus DT. Once the insertion locations are identified, each DRT can create a list of acceptable schedules based on the pick-up and drop-off insertion positions. The system then utilizes Dijkstra's algorithm, based on a list of acceptable schedules, to calculate the operating costs. Subsequently, passengers are assigned to the DRT schedule and route that offer the lowest operating costs.

3 Case Study

This case study aims to assess the proposed DRT system using four indicators from operational and passenger perspectives. The DRT service operates for 1 hour, and the analysis is conducted in an environment with multiple DRTs and multiple travel demands. Travel demand information is unknown in advance, and requests are handled on an FCFS basis. Unassigned requests are rejected after the maximum wait time, and the time for passengers to board and disembark is disregarded. Initial DRT locations are randomly assigned to the Sioux Falls network.

Figure 1 presents the analysis results, examining the impact of increasing travel demand and DRT numbers, with requests ranging from 10 to 500 and DRTs from 1 to 20, using indicators from both operational and passenger perspectives. From an operational perspective, the resolved ratio (as shown in Figure 1(a)) increases with an increase in the number of DRTs and a decrease in the number of requests. The occupancy shown in Figure 1(c) decreased when the number of requests was significantly lower than the number of DRTs. These results are believed to be due to an increase in individual travel rather than shared travel because the proposed DRT system operates based on minimum travel time. From an passenger perspective, waiting time (Figure 1(b)) is particularly sensitive to the number of DRTs in situations where the number of requests is significantly small. This sensitivity may result from the DRT's initial location being far away from the pick-up location of most passengers or, conversely, being close to the pick-up location of most passengers. As shown in Figure 1(d), the detour time responds sensitively when the number of DRTs is less than the number of requests. This result is believed to be due to the DRTs sharing as many trips as possible. These insights can be utilized to determine the number of DRTs required to maintain a certain level of operator revenues and service quality.



(a) (b) (c) (d)

Figure 1 – *Operational and passenger perspective indicators analysis results by number of requests and vehicles: (a) Resolved ratio; (b) Passenger waiting time; (c) Vehicle occupancy; (d) Passenger detour time*

4 Conclusion

Recently, with the advancement of ICT, various DRT services, including dial-a-ride, CB, and DRFS, have become operational. Nevertheless, these services face limitations or the unavailability of route changes during operations, as routes are planned in advance based on reservations or subscriptions. This study proposes the development of a DRT service system with fully flexible routes, unrestricted by specific passengers and without fixed stops or predetermined origins and destinations. The proposed DRT system was assessed in an environment from the Sioux Falls network, and the results of a comprehensive review of the case study can be summarized as follows: (1) Given that operational indicators react sensitively to the number of DRTs and requests, identifying demand and deploying appropriate number of vehicles is necessary to ensure sustainable services; (2) The waiting time and detour time were found to be less than about 5 minutes, indicating that the system can efficiently share trips among passengers with similar origins and destinations.

This study has some limitations. First, although the random demand generated in the Sioux Falls network environment provides insights into the phenomenon, the resulting numerical values may not be realistic. As a result, it is necessary to analyze the effects of switching to DRT based on actual demand, such as taxi trip data. Second, although this study provided sensitivity analysis for changes in the vehicle size and passenger requests, it was not conducted using a real-world network. Hence, in the future, exploring the applicability of the IH-based DRT system by utilizing various fleet sizes and numbers of requests in a real-world network environment is necessary.

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