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Hybrid Smart Demand Responsive Public Transport System for Conventional Public Transport in City Metropolitan Area

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ABSTRACT

Providing quality public transportation is extremely expensive and unpredictable. Passenger demand across a metropolitan area can vary greatly with changes in population density and time of the day. Demand Responsive Transport (DRT) is an intermediate form of public transport that lies between a regular bus service and a personalized taxi service. DTR provides "on demand" transport to commuters with a fleet of vehicles operating in a shared-ride mode between pick-up and drop-off locations. However, DRT has been introduced as an alternative transport service, rather than as a substitute for conventional public transport. In this study, a hybrid smart DRT public-transport system has been proposed for integration into the conventional public-transport system. The proposed system is an intermediate stage to a fully driven DRT service. It combines the flexibility and reliability of DRT services with the fixed routes and time tables of a conventional public transport service, and has been implemented using cutting-edge technologies. Moreover, a simulation demonstrated that the system performed almost as effectively as the conventional public-transport system while passenger demand was at its highest. It outperformed the conventional public-transport system in case of low to moderate passenger demand.

Key Words : Demand Responsive Transport (DRT), Intelligent Transportation System (ITS), Internet of Things (IoT), Public- transport, Task planning

Ⅰ. Introduction

With the increasingly widespread use of private vehicles as a mode of transport in many countries since the 1950s, most metropolitan areas have begun to suffer from serious congestion and environmental quality problems. To overcome these issues, appropriate traffic regulations and pedestrianization of streets in city areas have been applied in numerous cities. Such traffic regulation is effective at suppressing the number of traffic accidents by appropriately controlling the number of vehicles entering the city area. This motivates city authorities to improve public transportation services to compensate for the inconveniences caused by such traffic regulations and to satisfy the commuting needs of the general public[1,2]. It has been argued that the market for urban passenger travel is not homogeneous. This argument claims that there are many markets, each of which have their own requirements in terms of origin, destination, timing, and quality of service. However, if conventional public-transport service

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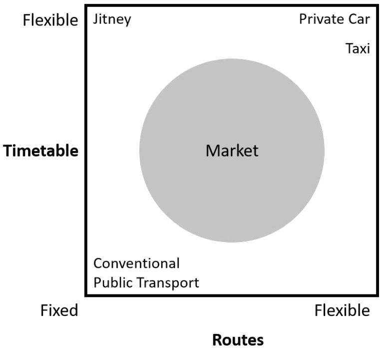

Fig. 1. Public transportation services

options are plotted against the relative flexibility of their routes and timetables, as shown in Fig. 1, it becomes clear that the range of markets is not matched by a similar range of service types. Conventional modes of public transport cater to extremes of route and timetable flexibility, and thus, typically leave a significant gap in the service market. Hence, if public transport is to provide an attractive alternative to private vehicle use and cater to the range of sub-markets that exist in the community, it is no longer sufficient to view public transport in conventional terms as a set of buses, trams, and trains providing fixed-route and fixed-schedule services. Public transport must be varied, flexible, and responsive to the needs of different market niches.

A frequently suggested solution to this growing transport challenge is to enhance existing services through the implementation of demand-responsive transport (DRT) services. DRT is an intermediate form of public transport that lies between a regular bus service and a personalized taxi service. DRT provides "on-demand" transport to commuters according to their needs using a fleet of vehicles operating in shared-ride mode between pick-up and drop-off locations[3,4]. DRT was developed in response to several different mobility problems faced by people living in rural and urban areas, mainly with the intent of improving social inclusion in areas that are difficult to cover using conventional public transport or where it is not economically viable.

However, technological, social, market, economic, and institutional barriers have prevented its widespread adoption. Recently, many local authorities and public transport operator initiatives have been launched in response to developments in information technology (e.g., open data, big data, machine learning, sensor technology, and wireless communications) in the transport sector, and research on intelligent transportation systems (ITSs) has increased. Specifically, three main factors converged to change this lack of widespread use.

1.1 Several[5].

A common issue faced by commuters today is that they are often unable to make informed choices owing to a lack of up-to-date or real-time information. ITSs can help commuters interact with the DRT public transport system more efficiently by collecting various types of data in real time. Examples include data related to one or more of the following types of entities.

- Vehicles: location, occupancy level, vehicle status, presence of on-board staff, etc.
- Commuters: time and location of entering and leaving vehicles, individual preferences and final destination, ticketing data, etc.
- Trip Scheduling: status of transport links, such as congestion, and the number of people in a certain location, such as at a bus stop.

However, challenges are associated with using DRT services. It cannot be claimed that any existing solution eliminates any of the following challenges in all possible situations.

- Business models: Telecommunications operators, sensor data providers, data storage providers, end-user service providers, and different public authorities.
- Privacy and Integrity Issues: movement of individual travelers can be tracked using data from mobile phone operators or RFID tags on travel cards. (Such data are useful for generating origin–destination matrices).
- Security threats such as cyberterrorists and hackers: There are entities that would compete with DRT services directly, such as providers of public transport services. These entities may have a business interest in illegally ensuring suboptimal

system performance.

- Scalability: Data storage, data analysis, and efficient algorithms or heuristics that can be used to solve optimization problems (often in real time).
- Usability: Ease of use of the information and services provided For example, commuters typically access public transport through smartphone applications and interactive webpages, which must be easy to use and learn.
- Data Collection: The type of data to be collected, data quality, and handling situations involving insufficient data.
- Deployment: User acceptance of new technologies and services. In addition to the acquisition of necessary equipment such as smartphones, users may also have to change their behavior patterns.

However, there are technologies that either fully or partially help overcome the challenges identified above. Several general ITS architectures have been proposed to address the various challenges and technological developments. These architectures are currently at a relatively high level of abstraction, meaning that they are technologically independent specifications for components and communication[6]. Thus, some of the interoperability challenges discussed above can be solved using one of the previously proposed ITS architectures. However, there is no single “standard” ITS architecture; different countries and regions have developed their own ITS architectures to fit their needs. The lack of a standard ITS architecture must be addressed to develop a global solution.

The fundamental question facing DRT operators is how to design an advanced, attractive, and viable DRT service that makes conventional public transport users feel that using the transit service is accessible, reliable, and as easy as using a private vehicle, and convince private car users to give up the use of their cars. Two further questions emerge to address this issue.

- How should the “success” of a system be defined based on its initial objectives and other potential alternatives?
- What are the (operational) features that differentiate DRT from conventional public transport? These characteristics should be defined in terms of flexibility, capacity, and how they are translated into service networks.

Moreover, replacing conventional public transport services with DRT services in metropolitan areas poses extremely difficult and complex problems. Although the most critical factors and prerequisites for implementing viable DRT systems have been widely discussed and studied in numerous cases, particularly in rural areas, the underlying assumptions used in specific case studies restrict the generalization and transferability of the resultant conclusions to a certain extent. This is also a major reason for the absence of a robust and clear-cut methodological framework capable of indicating whether DRT investment in metropolitan areas is feasible for a given set of economic, social, and environmental criteria.

Considering these issues, a hybrid smart DRT public transport system was proposed. Based on public demand, the system varies the flexibility of the routes and timetables of a conventional public transport system throughout the trip cycle, considering their initial timetables, as shown in Fig. 2.

The hybrid smart DRT system proposed in this study differs from previous DRT systems in two ways. First, the proposed system is an intermediate stage in the integration of a full DRT service, which combines the flexibility and reliability of DRT systems with the fixed routes and timetables of conventional public transport services. The system allows for better trip scheduling, higher occupancy rates, and fewer access and window times per user. It also maximizes the number of trip cycles per day, guaranteeing commuter

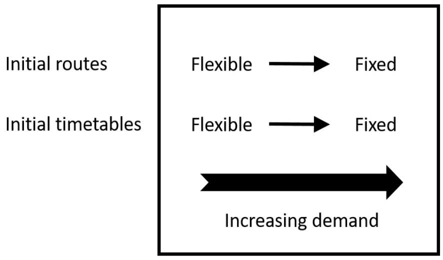

Fig. 2. Proposed system routes and timetables flexibility

satisfaction and reducing passenger inconvenience.

Second, the proposed system will be implemented using cutting-edge technologies, such as Android applications, real-time vehicle tracking, and cloud computing. The system keeps track of vehicle stop coordinates, vehicle current location indicators, possible routes, and traffic congestion, which greatly enhances scheduling capability. In order to utilize the system, an Android application package will be offered to passengers for use on smartphones or on passenger-stop's electronic panel devices. The application package allows users to view a map showing their nearest stop and query vehicle schedules based on the desired pick-up or drop-off stop. A different Android application package has been developed for vehicle drivers, allowing them to view their vehicle schedule and commuter booking requests, update or alter trip schedules dynamically, and notify commuters of changes in real-time. Moreover, the system collects booking request frequencies at stops throughout the day, which facilitates better trip planning for operators and city authorities.

The remainder of this paper is organized as follows: In Section II, the DRT service background is presented. In Section III, the details of the proposed system architecture and algorithms are described. In Section IV, the implementation of the proposed method is described. In Section V, the evaluation parameters, environment, and performance of the proposed system are outlined. Finally, the paper is concluded, and open issues and future work are described in Section VII.

Ⅱ. Demand Responsive Transport (DRT) Services Overview

DRT services are offered using a variety of transportation modes such as buses, coaches, taxis, adapted taxis, and minibuses, and can be supplied by a variety of service providers including bus, taxi, private hire operators, community transport, local authority, and even ambulance vehicles. However, it is known in its broadest form to be a more flexible form of bus service and matches its level of service to the particular needs of the commuters. This can in some cases extend to other forms of transport, but bus is the most common form of DRT vehicle. Furthermore, DRT services can be freestanding or integrated between different modes, for example as feeder services for bus, tram, and rail services. In an integrated DRT system, the fixed-route transit network is leveraged to decrease the operating costs of the DRT vehicles[7,8]. Often the role of the DRT vehicles in such a system is to provide the first mile of transportation to a high-speed rail or bus line[9,10].

In general, a mode of public-transport can be categorized as a DRT service if:

- The service is available to the public and it is not restricted to particular groups of commuters according to age or disability criteria.
- The service responds to changes in demand by either altering its route and/or its timetable.
- The fare is charged on a per passenger and not a per vehicle basis.

George *et al.*[11], defined DRT systems using parameters such as usage type, area characteristics, and trip characteristics. Niitani *et al.*[12], classified DRT systems using numbers of passengers and trip length. Ambrosino *et al.*[13], classified DRTs using demand characteristics, usage type, and technologies.

Table 1. Classification categories of DRTs

Category	Contents
Service supplier	Public/Private company.
Service	Routes and timetables are defined responding to each user's reservation.
Trip Form	Trips with different origins and destination are combined, moreover, many-to-one or many-to-many service can be provided.
Trip Length	Short-haul - Middle-haul in a district.
Area/Demand Density	In low-medium density area, where no or poor public transport systems exists, or low demand density.
Users	Residents living in areas where no or poor public transport system exists or, elderly or disabled people.
Advanced Operation Techniques	By using advanced telecommunication techniques, operators accept each . user's reservation and manage vehicles

In Table 1, the various DRT classification methods are described.

The demand responsiveness of any public-transport system can be described using six aspects. Responsiveness is defined by the length of time from a commuter's booking to the confirmation of the booking, as well as by the length of time between time of travel and route determination. The shorter these times are, the more responsive the system is. A vehicle that is available for a longer period of time is more responsive, whilst a greater choice of vehicle specifications is also more likely to include a vehicle that satisfies capacity and accessibility requirements as shown in Fig. 3.

DRT service implementations can be categorized as four types based on function:

- Interchange DRTs: providing feeder services to conventional public-transport.
- Network DRTs: providing additional services or replacing uneconomic services.
- Destination-specific DRTs: serving destinations.
- Substitute DRTs: which totally or substantially replace conventional bus services.

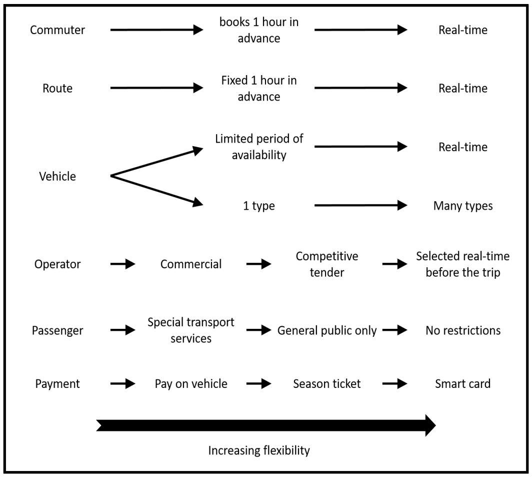

Fig. 3. The demand responsiveness of public-transport

In a survey of DRT providers in Europe, several authorities with significantly rural hinterlands have replaced subsidized bus services with DRT and Community Transport alternatives in recent years[14]. In the case of the United Kingdom, the government pledged to remove or at least relax constraints on the development of flexibly routed bus services, as DRT was identified by some respondents as the most cost-effective way of serving rural communities without access to conventional bus services[15,16]. Furthermore, in North America, survey results revealed that DRT was most often used in small and difficult-to-serve locations, although there were also examples where DRT operated in large (e.g., rural) areas, or else offered services at times of low demand [17,18]. With the rapid development of information and telecommunication technology, Chinese decision-makers have begun to shift some of their budgets from conventional public-transport to an innovative mode of DRT[19]. DRT was first introduced and implemented in Qingdao in August 2013 – although there is little associated, extent literature[20]. However, it has spread rapidly through China since

Table 2. DRT systems in the U.S., Europe, Japan, and Southeast Asia

Region	Era	Name	Notes
North America	1900s-	Jitney	Operated along fixed routes responding to each user's demand.
	1960s	Dial-A-Ride	Motilities for elderly and disabled person. Users need to make reservations when using.
	1970s-	Shared-Ride Taxi	Operated from residential areas to airport/stations.
		Charter Bus	To manage traffic congestion in peak hours, ridesharing programs for commuters have been promoted.
		Car Pool, Van Pool	
Europe	1990s-	DRT	By using advanced information and telecommunication technologies, route and timetable is defined responding.
Japan	1970s-	Demand Bus	Route and timetable is defined responding to each user's demand.
Southeast Asia		Paratransit	Operated along fixed routes with some deviations. Users hail calls along the route when using.

its introduction in Qingdao. Several other adaptations of DRT services in various global locations are shown in Table 2 along with their attendant region and area.

2.1 Disadvantages of Existing DRT Services:

There have been several challenges facing the implementation of DRT services in city metropolitan areas. Davison *et al.*[21] pointed out that there appeared to be numerous reasons for these failures. However, one recurring feature appeared to be that the type and/or scale of the introduced DRT operation was often not appropriate for the market being served. Most proposed DRT systems were not appropriately designed for serving an entire transport network. Instead, they were designed more as complementary/niche solutions for existing networks such as feeder services for bus, tram, and rail services. DRT was first introduced as an alternative transport service rather than a substitute for conventional public transport. One common application of DRT is door-to-door transportation of elderly or handicapped people, known as paratransit, a service mainly encountered in the US[22].

Moreover, in the past DRT has struggled to make a significant mark on the public transport sector because of the complexity involved in scheduling and route-building for large numbers of trips spread over a range of locations and at various times. A review of the SAMPLUS[23] sites in Europe showed in almost all cases that as service usage increased, the dispatcher became the real bottleneck in the process.

Furthermore, several adaptation failures of the technology have resulted in low-tech DRT system being introduced, thus reducing the capability of the service. In a survey of DRT services in the UK, a little over half of the DRT services in rural areas in England did not use any specialized software for booking and routing, instead relying on pencil and paper booking or taxi software[24]. Most of the services offered phone booking, often with hailing at bus-stops. Text message and internet booking were not common. However, a portion of the services did have websites featuring timetables and information. These low-tech DRT systems will not effectively meet commuter needs. Not incorporating sufficiently high levels of technology when providing a complex service was a key factor influencing the failure of several implementations, such as the Adelaide Dial a Bus service in South Australia and the Kutusplus in Helsinki, Finland.

Ⅲ. Hybrid Smart DRT System Design

In previous studies, problems associated with designing and operating DRT services are closely related to the Vehicle Routing Problem (VRP). In particular it is classified as a Dial-a-Ride Problem (DARP)[25,26], that can balance the quality and efficiency level of the service. The DARP involves designing vehicle routes and schedules for n passengers who specify pick-up and drop-off requests between the origin and destination stops. Very often the same passenger will have two requests in the same day: an outbound request from home to a destination such as a hospital, and an inbound request for their return trip[27-29]. The main contribution of this work is that the proposed system doesn't replace the existing traditional public transportation system, instead it upgrades the system to be feasible when the demand gets low so the access-time window for the user improves and they arrive earlier buy skipping the stops that has no demand.

3.1 Problem formulation

In order to solve the DARP in the proposed system, a new hybrid DRT service route concept is introduced that takes the following parameters as inputs:

1) Initial set of vehicles together with their conventional public-transport timetables. 2) Initial road network map.

Transport is supplied using a fixed size fleet of m vehicles based at the same depot. For each vehicle, the scheduling module of the system decides the next stop to approach, by skipping s stops of its timetable. The aim of this approach is to maximize the number of requests that can be served, while planning a set of minimum-cost vehicle-routes capable of accommodating as many requests as possible, for a set of constraints such as passenger window-time and access-time sizes. It will also maximize the number

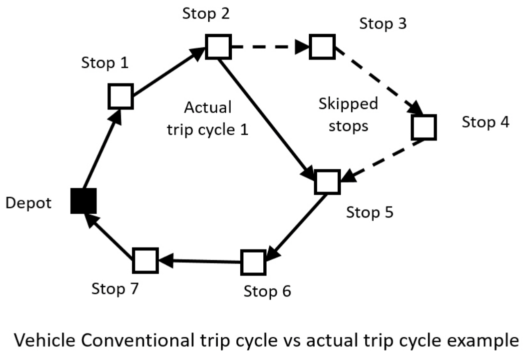

Fig. 4. Proposed service route concept.

of trip cycles per day, which guarantees commuter satisfaction and the reduction of passenger window-time size, Fig. 4 depicts the proposed hybrid smart DRT service.

3.2 System architecture

The proposed hybrid smart DRT system architecture consists of four technologies:

- A responsive gateway.
- A scheduling module.
- A communication device.
- A database.

Fig. 5 shows the overview of the proposed system architecture. Passengers access the response gateway that runs on the cloud for vehicle booking via Android-enabled smart phones or passenger-stop electronic panel devices. The response gateway relays the passengers' demand information to the scheduling module where the routing and scheduling algorithms are implemented. The scheduling module of the system selects the best path for each vehicle, after which the system announces its route to the passenger smart phones and passenger-stop electronic panel devices. Finally, the communication device installed in each vehicle enters the actual moving time and location into the database.

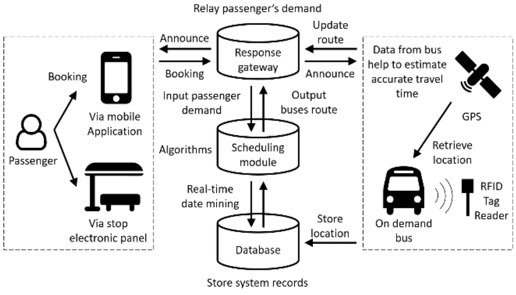

Fig. 5. Proposed system overview.

3.3 Vehicle behavior

Each vehicle is introduced into the network with an initial route and timetable together with other parameters such as vehicle capacity, vehicle status, and vehicle type. The system provides the estimated time of arrival (ETA) at each stop, the number of booking requests at the stop, and the number of commuters to be picked up or dropped off to the driver in real-time. During the trip, various random events can arise that might modify the desired plan. The vehicle's trip performance can be modeled by dividing it into different phases. These are described below and depicted in Fig. 6.

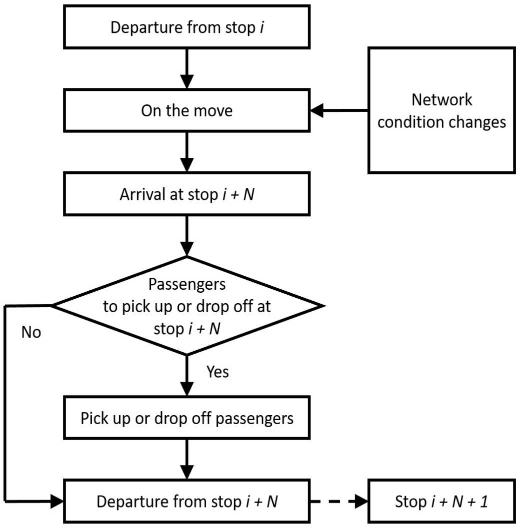

Fig. 6. Scheme of vehicle behavior.

3.3.1 Departure from The Depot

The actual time of departure from the depot is fixed based on the initial timetable of the conventional public-transport system. In the proposed system a random distribution is assumed for the simulation of the time difference between the actual departure time and the estimated one for each vehicle, in the range 0 to 20 seconds to model the random nature of the starting event.

3.3.2 Running

During the vehicle's trip, several parameters may affect its speed such as road speed limits, traffic congestion, and delays at intersections. The path of the vehicle is traced out by the system in real-time. A typical approach in selecting the best path for a vehicle involves the following two phases: route construction and route improvement phase. Thus, in addition to an improvement procedure designed for the route improvement phase, a local improvement procedure is also considered during the route construction. Moreover, the vehicle is free to follow the best path suggested by the simulator based on a Dynamic Route Guidance (DRG) algorithm to arrive at the next stop.

In the route improvement phase, and based on the initial schedule of each vehicle, the scheduling module of the system decides the next stop to approach by calculating the variable *N* as shown in Fig. 6. In order to skip a certain number of stops, altering and updating the vehicle path, the scheduling system must satisfy several constraints. Fig. 7 depicts the process of calculating the variable *N*. This allows the system to enhance the window-time size for commuters, and it also increases the number of trip cycles per vehicle per day, thus improving the quality of the service.

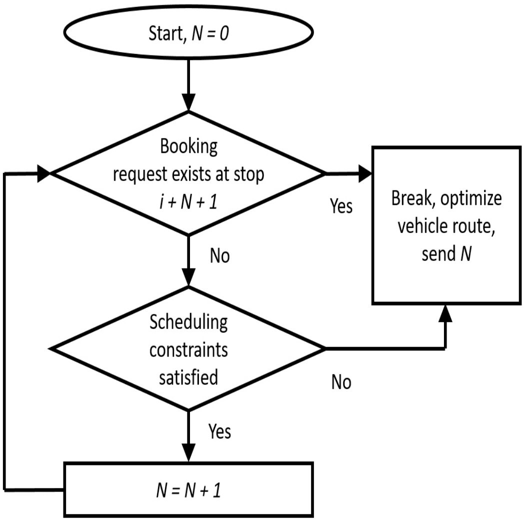

Fig. 7. Calculating the variable N.

3.3.3 Arriving/Leaving Stops

When a vehicle arrives at a stop, the vehicle performs pick-up and/or drop-off operations and waits for these activities to be completed if necessary. The departure from the stop occurs when all of the passengers have already boarded or alighted from the vehicle. In some cases, the vehicle can also leave the stop without picking up any passenger, either because it is running late and passengers have already left the stop, or because the passengers reached the stop too late.

3.4 Passengers behavior

The trip for each passenger is established by the time the passenger initiated a booking request and has to get to their pick-up stop. The moment the passenger actually boards the vehicle is considered a random event in the simulator for a number of reasons: passengers may arrive late at that stop or at the previous stop. The booking process and the trip performance of passengers can be modeled by dividing it into different phases, which are described and depicted in Fig. 8.

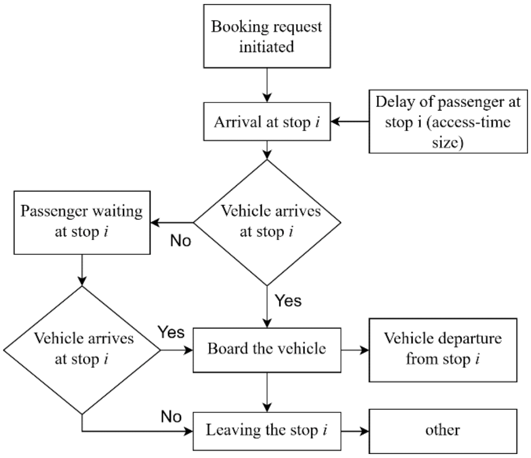

Fig. 8. Scheme of the passenger behavior at stops.

3.4.1 Booking/Arriving at a Stop

Passengers send their demand to the response gateway of the system either via Android-enabled smart phone or passenger stop electronic panel devices. This demand information consists of eight elements: passenger identification number, origin

User GUID	Date	Sorting option	Pick-up stop	Drop-off stop	Vehicle	Seats count	Other preferences

Fig. 9. JSON booking request packet.

stop, destination stop, earliest pick-up (fixed departure) or latest drop-off (fixed arrival) in terms of sorting vehicles, date, vehicle identification number, number of seats for the reservation, and other generic preferences such as wheelchair/stroller access. Fig. 9 depicts the structure of the booking request JavaScript Object Notation (JSON) packet sent to the response gateway. After booking for a specific vehicle, the passengers are introduced to the scheduling module of the system, providing them with access to information about the position of their vehicle in real-time.

3.4.2 Waiting at Stop

In the scheduling phase of the system, passengers at stops wait for vehicles. However, traffic congestion or other factors can delay the arrival of the vehicle, so the passenger may have to decide whether to continue waiting for the vehicle, cancel the booking request, or leave the passenger-stop. For example, if the vehicle has already left the stop before the passengers' arrival, passengers will most likely leave the stop to adopt another means of transport.

The access-time size ATS at each and every stop is continuously calculated and maintained as small a value as possible, but not more than the vehicle's average trip duration.

ATD, taking vehicle route change updates into account using (1). Total skippable stops is donated as N where (i = 1,2,3,...,N), a route change distance difference as ΔD, and vehicle average velocity as AV.

$$ATS \leq ATD - \sum_{i=0}^{N} \frac{\Delta D}{AV} \tag{1}$$

3.4.3 Boarding The Vehicle

When the vehicle arrives at a passenger-stop and any commuters wishing to alight have done so, waiting passengers can board. To guarantee time reliability for boarded passengers using (2), a window-time size WTS, that is the difference between the latest drop-off LDO and earliest pickup EPU, is set. Namely, the flexible parameter is set by the scheduling module of the system in a way that allows the window-time size to be maintained as minimum a value as possible without violating a set of constraints that reflect the details of the other commuters' previously planned trips.

$$WTS = LDO - EPU \tag{2}$$

3.5 Road network

In order to analyze the proposed system simulation, a road network model was built and generated in the server which consisted of nodes N and edges E. Each road or edge E was defined by several parameters such as road speed limits, traffic congestion, and delays at intersections, while each stop or node N, was defined by parameters such as booking frequency. The vehicles V departure from the depot was based on the initial timetable of the conventional public transport system. Considering variability associated with the number of stops along the route, the scheduling module of the system calculated the best route from a set of possible routes in real-time that satisfied the system constraints.

3.6 Vehicles tracking

The current prototype of the proposed system takes advantage of two technologies for real-time vehicle tracking. The first of these is, using the Radio Frequency Identification (RFID) technology. A tag might be embedded in the vehicle with readers for this tag affixed to stops or traffic lights sending electromagnetic signals to the tag. The tags draw the power from the electromagnetic signal and return vehicle information to the reader. In turn, the reader registers the presence of a vehicle and sends this information along with the reader location, comprised of latitude, longitude, and reading timestamp to the underlying system.

A Global Positioning System (GPS) receiver mounted in each bus has also been considered as a modern and complementary approach to real-time vehicle tracking. An Android enabled device is assumed to be running the vehicle driver application and is used for obtaining the continuously streamed GPS data of the vehicle. This information would then enable the scheduling system to either inform passengers of the ETA of the vehicle through the response gateway or dynamically schedule a vehicle trip based on the proposed scheduling algorithm.

Ⅳ. Hybrid Smart Drt System Implementation

The hybrid smart DRT system differs from existing DRT systems in terms of cloud computing technology. The back-end server is deployed on a remote Amazon Web Services (AWS) server and the operators and city authorities can introduce the service without the need for local server systems. The back-end server software was developed using JavaScript scripting language running on top of NodeJS, and the API was built using the ExpressJS framework. System data was stored using MongoDB a NoSQL data storage technology.

Clients communicate with the back-end server through JSON packets. JSON is a syntax designed to store and move data sent between back-end servers and front-end applications. The road network was implemented utilizing Google Maps Application Programming Interface (API), onto which the coordinates for stops, vehicle's current location indicators, and commuter populations were overlaid, along with possible routes and traffic congestion. The motivations for adopting this approach include: low cost, information security, simpler horizontal scaling to clusters of machines on the cloud, and finer control over availability as shown in Fig. 10.

4.1 User interface (UI)

The User Interface (UI) for both Android-enabled smart phone and the passenger-stop electronic panel, developed for passengers and vehicle drivers were both implemented using Android Studio version 2.3. It has been tested on devices running Android supporting a minimum API 21 (Lollipop). By targeting minimum API 21 and APIs succeeding it, the applications will run on approximately 71.3% of the devices that are active on the Google play store.

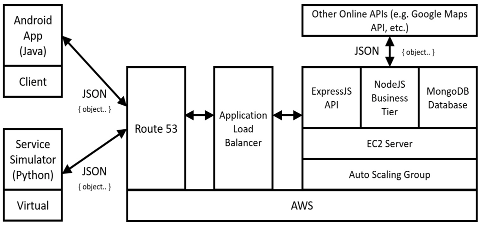

Fig. 10. System implementation design.

Fig. (11 and 12) show the Graphical User Interface (GUI) of the application designed for passengers. It showcases the GUI's ability to query vehicles based on desired pick-up or drop-off times. Passengers are not required to provide personal information; the system keeps track only of the passengers' Globally Unique Identifiers (GUIDs)

The figures also show the GUI of the application designed for vehicle drivers, showcasing its ability to display vehicle schedules, passengers booking requests, and the ability to dynamically update its schedule and notify passengers in real-time. The system requires vehicle drivers to create a profile. Vehicle drivers are able to view the number of booking requests at each stop on their schedule. In addition, vehicle drivers are able to take short breaks, and can order to notify passengers that the vehicle is out of service during their break.

Ⅴ. Performance Analysis

To analyze the performance of the proposed system, a service simulator was built and applied to the city of Gumi in Gyeongsangbuk-do, South Korea. The city's conventional public-transport system, operated by the YesGumi Co., is a suitable service within which to test the proposed hybrid smart DRT service simulator. The Geographic Information System (GIS) exported from Google Maps, which describes the road network by means of 50 stops and multiple route options, was generated in the server, for covering a total approximate area of 12km2 as shown in Fig. 13. The service area included part of the city of Gumi, with a total population of approximately 370,000 inhabitants. It was a small network, but it allows close observation of the service

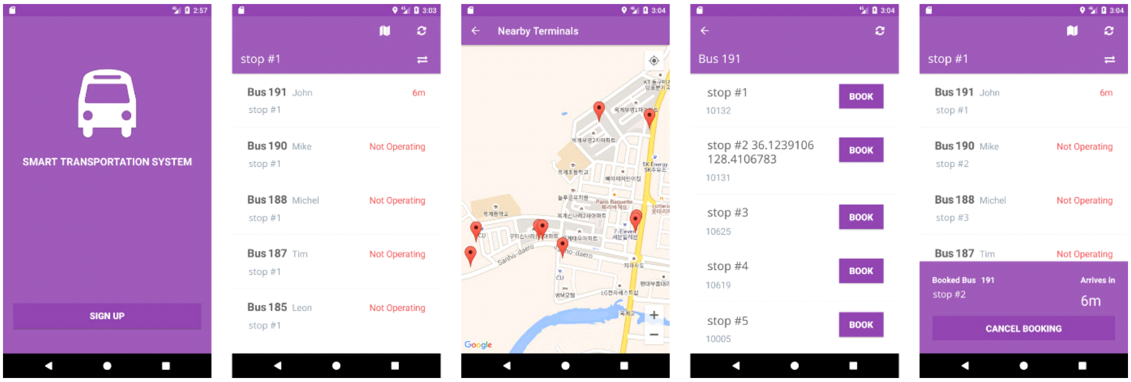

Fig. 11. Passengers smart phone application screenshots.

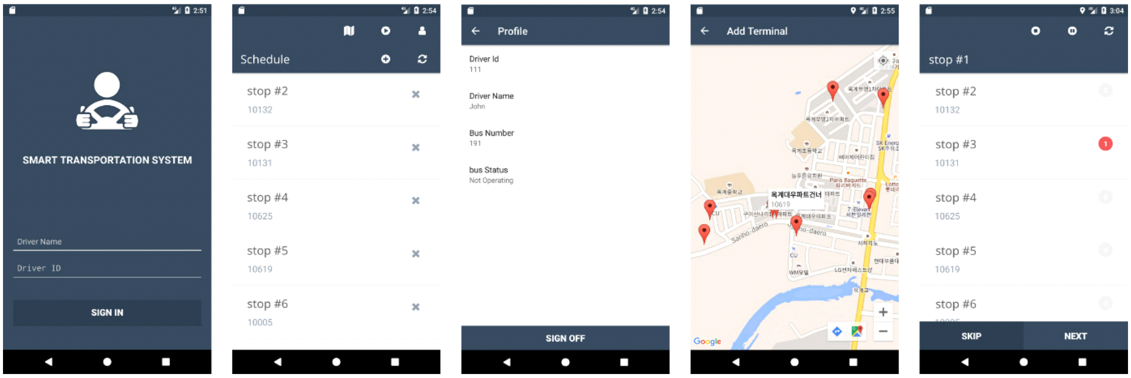

Fig. 12. Vehicles' drivers smart phone application screenshots.

simulator performance.

The vehicle fleet in the service simulator was comprised of 10 vehicles traveling with an average speed of 60 km/h. Initial timetables were set for each vehicle, and the system was simulated for a period of 6 hours. DRT systems have a high dependence on the number of booking requests. Taking this into account, the service simulator generated a set of trip requests with random pick-up and drop-off locations of variable time span, along with the parameter of earliest pick-up time (fixed departure) or latest drop-off time (fixed arrival). The performance of the proposed system was analyzed, specifically in terms of criteria such as the average window-time size per trip cycle, average access-time size, and trip cycle duration.

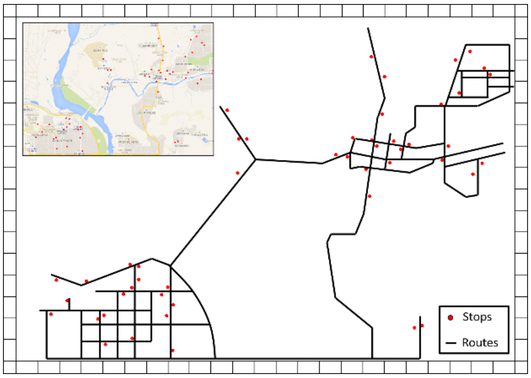

Fig. 13. GIS exported of the city of Gumi road network.

5.1 Simulation parameters

To test the developed service simulator module and its ability to assess the feasibility of the proposed hybrid smart DRT system, various scenarios were investigated. During the simulation the following factors were examined:

- Passenger booking frequency at stops.
- Punctuality of passengers at stops.
- Driver patience in waiting for late passengers at stops.

- Traffic variability (Congestion).

The first two factors involved passenger behavior, whereas the third factor was related to the policy of the service operator. This was based on organizing the service for maximum efficiency. Moreover, the effects of traffic variability over time due to congestion on the network could have been considered in the route planning phase if detailed traffic information was available. Nevertheless, the service operator can also influence the punctuality of passengers. In the proposed hybrid smart DRT system, late passengers may be able to initiate a booking request from their smart phones if they are within a range of 100m from the source stop.

For simplicity, several parameters were set. It was assumed that passengers arrived at stops and waited for a variable length of time, and that vehicles left stops after waiting for late passengers for a variable length of time. Furthermore, booking request frequency was set for every stop in the network, whilst random traffic variability was set for each route, that changed throughout the day on an hourly basis. Such a dataset of demand information to a specific area per stop is not available to our knowledge. Therefore, most of these parameters has been chosen as assumption to investigate the system behavior.

Taking these parameters into account, two different simulation scenarios were investigated:

- A total number of booking requests of 150 and a passenger booking frequency of 10 at passenger-stops.
- A total number of booking requests of 500 and a passenger booking frequency of 30 at passenger-stops.
- Vehicles schedule was collected from the real-life buses timing schedule from Gumi city.
- the demand of service is randomly generated (since there is no dataset for service demand on the analyzed route area)

For all of the cases, a reference scenario was built (S1, S2), to provide a comparison. An elementary scenario (S0) was also built, with the purpose of simulating the performance of the proposed hybrid smart DRT system with as small a demand as possible imposed on the service. The scenarios and the different values of the parameters used in the service simulator are shown in Table 3 and Table 4 below.

Table 3. Parameters used in the simulation.

Parameter	Value	Parameter	Min	Max
Simulation period	6 hours	Punctuality of passengers	0 sec	60 sec
Vehicles count	10 vehicles	Patience of drivers	0 sec	60 sec
Stops count	50 stops	Delay of vehicles (Congestion)	0 sec	5 min
Total booking requests	500 requests	Booking through smart phone distance	0 m	100m

Table 4. Investigated scenarios in the simulation.

Parameters		Scenario S0	Scenario S1	Scenario S2
Total booking requests		50 requests	150 requests	500 requests
Total booking requests	min	0 requests	0 requests	0 requests
	max	5 requests	10 requests	30 requests

5.2 Simulation environment

The service simulator was scripted using Python programming language running in a standalone thread and communicating with the back-end server API. It was executed on a server with the following specifications: 2.40 GHz Intel Xeon E5-2020 processor, with 224 GB DDR3 memory, running a Windows 10 Professional 64 bit OS. The service simulator generated random booking requests, and

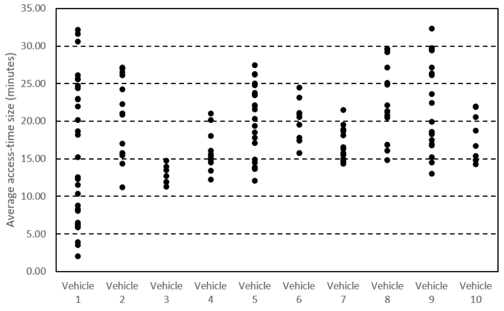

Fig. 14. Scenario S0 average access-time size.

updated vehicle positions taking the parameters in Table 3 into consideration. In the virtual world, passengers reserved their seats and vehicles delivered commuters as scheduled.

5.3 Simulation analysis

In regard to passenger access-time size, Fig. 14 shows the average access-time size for the initial scenario S0. Considering the very low passenger demand level of the initial scenario S0, it can be seen that vehicles arrived at stops way earlier, thus reducing the access-time size for each passenger. It may be assumed that this scenario depicted a small portion of a typical real service day (e.g., late in the evening and very early in the morning). Fig. (15, and 16) show the average access-time size for the system for increasing passenger demand level. A reduction in access time size indicated that the flexibility of vehicle routes or timetables fell drastically, forcing vehicles to avoid skipping stops or changing routes, and instead sticking to the initial conventional public-transport timetables.

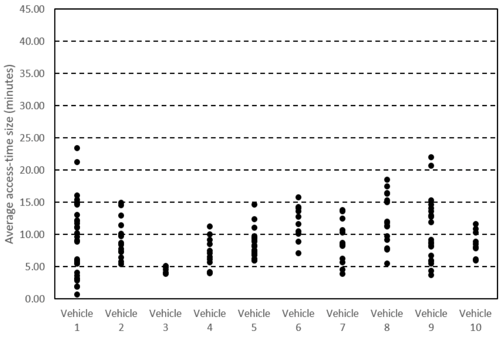

Fig. 15. Scenario S1 average access-time size.

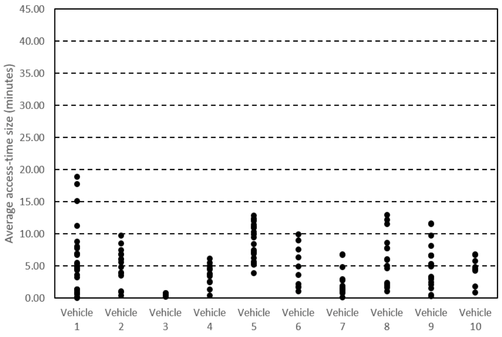

Fig. 16. Scenario S2 average access-time size.

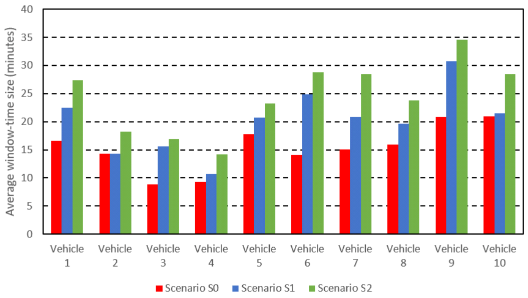

Fig. 17. Average window-time size comparison.

Fig. 17 shows a comparison between the average window-time size of the three assumed scenarios. Commuter trip duration after boarding different vehicles was much lower when the demand on the service was at its minimum, because vehicles' drivers were able to skip multiple stops in favor of a shorter route, thus guaranteeing commuter satisfaction and a reduction in passenger inconvenience. The variation in results in terms of access-time and window-time sizes for the vehicles was inherently affected by the initial timetables of each vehicle.

The results showed that although the proposed hybrid smart DRT system performed almost as well as a conventional public-transport system when the passenger demand was at its highest, the system performance was maximized with low to moderate passenger demand, which enhances the user experience. The fact that DRT services are more efficient than fixed-route conventional public-transport systems does not necessarily mean that the proposed system is best-suited for metropolitan areas. Instead it suggests that the proposed hybrid smart DRT system is more adept at handling the difficulties of servicing low passenger demand levels.

The simulation and comparison also brought to light areas that needed improvement in the proposed hybrid DRT system. For instance, in the simulation, the demand-responsive algorithms consistently reduced the vehicles' travel distance compared to fixed-route conventional public-transport. Unfortunately, the saving to the operator associated with the reduction in travel distance came at a slight

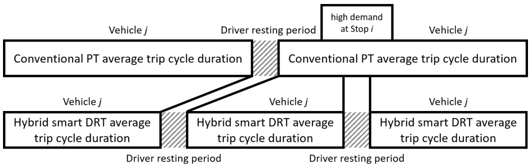

Fig. 18. Vehicles initial timetables shift demonstration.

expense to the passengers in terms of access-time size, as the initial timetables of vehicles may shift throughout the course of the day as shown in Fig. 18. This might make some vehicles unavailable at certain times during the day, creating confusion for some passengers.

Fig. 19 shows the vehicles' trip cycle duration along with the increase in passenger demand in comparison with the initial conventional public-transport trip cycle duration. Adjusting the system algorithms to provide more passenger-friendly timetables with flexible route selection could improve the overall performance of the system.

5.4 Results discussion

The different scenarios that have been studied in this paper have shown that the proposed system works as was intended and expected. Where in S0 the demand was low therefore the system reacted as intended by skipping the regular stops without demand which resulted into lower access-time zone for the passengers, and they were able to arrive to their destination in a shorter period of time. While in S1 the demand increased and as was expected, less stops have been skipped and the access-time window has increased, because in this case the more stops have demand, so the vehicle had no choice of skipping these stops with demand. Finally, in S2 the demand was high since there was 500 requests, the system started behaving as a traditional system in most vehicles. But as have been seen in fig.18, in special cases of skipping some of these stops the vehicle might be not available at some certain timings since skipping some of these stops makes the system has unfixed schedule in case the service line did not have a vehicle showing every now and then. To elaborate, such a system would not work properly if the vehicle is scheduled to initialize the trip every long period of time. Since skipping that stop will leave it unattended for a long period till the next vehicle initialize the trip.

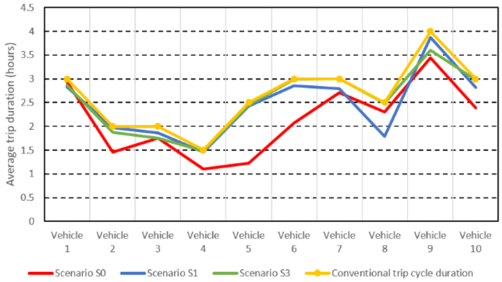

Fig. 19. Average trip duration comparison.

However, the real-time data collection of the passengers' movements and booking frequency at stops throughout the day will facilitate the trip planning phase for operators and city authorities. Instead of relying on statistical data or pencil and paper records for assigning initial timetables to vehicles, machine learning algorithms may be applied to the real-time data collected by the proposed system to design more reliable and efficient timetables that can be updated daily, monthly, or yearly, decreasing the cost per passenger throughout the road network of the city metropolitan area.

Ⅵ. Conclusion

Providing quality public transportation is extremely expensive and unpredictable, as passenger demand across metropolitan areas can vary widely with population density and time of day. DRT services attempt to address this problem by providing an intermediate form of public transport, a service that lies between a regular bus and personalized taxi service, with routes and trip frequencies that may vary according to the actual demand. However, DRT was first introduced as an alternative transport service rather than as a substitute for conventional public transport. Several failures of adaptations of the technology resulted in the introduction of low-tech DRT systems, thus reducing the capability of the service.

In this study, a hybrid smart demand-responsive public transport system was proposed for integration into conventional public transport systems in city metropolitan areas, and it was applied to the city of Gumi in Gyeongsangbuk-do, South Korea. The proposed system differs from previous DRT contributions in two aspects. First, the proposed system is an intermediate stage to a fully driven DRT service because it combines the flexibility and reliability of DRT services with the fixed routes and timetables of conventional public transport services. Passengers are guaranteed earliest pick-up and latest drop-off times. Passengers fix one of these in real-time either through a mobile phone or at the passenger-stop's electronic panel. Transport was supplied by a fixed fleet of vehicles based on the same depot. For each vehicle, the scheduling module of the system determines the next stop to approach by skipping several stops from its timetable. The aim of this approach is to maximize the number of requests that can be served while planning a set of minimum-cost vehicle routes capable of accommodating as many requests as possible. This is performed under a set of constraints that guarantees commuter satisfaction and reduces passenger inconvenience.

Second, this system differs from existing DRT systems in terms of the technologies used to realize it. The system is implemented using cutting-edge technologies such as Android applications, real-time vehicle tracking, and cloud computing technology. Operators and city authorities can deploy systems utilizing the existing infrastructure without the need for additional complex infrastructure, such as local servers.

Furthermore, the comparison techniques used were successful in showing that the proposed system performed almost as well as a conventional public transport system when passenger demand was at its highest, while outperforming it when passenger demand was low to moderate. The deployment of such a system would help reduce passengers' access time and window time sizes, maximize the number of trip cycles per day, and provide a more satisfactory personalized service, while simultaneously saving operational costs.

6.1 Remaining challenges

Further research is required to develop methods to completely transform a conventional public transport system into a full DRT system. This section addresses the challenges associated with this approach. As previously discussed, in the proposed hybrid smart DRT system, savings to the operator came at a slight expense to passengers in terms of access time at certain hours during the day. With shorter vehicle trip cycles, the initial timetables may shift throughout the day, which may make some vehicles unavailable at certain times and create confusion for some passengers. This issue can be addressed by introducing an algorithm that allows vehicles to deviate from their initial timetables by picking up passengers from different stops, as shown in Fig. 20.

Although this approach might increase the number of requests that can be served, it might also result in a longer window time for some commuters. Building on this, a suitable algorithm that somehow balances the trade-off between passenger and commuter access times and window time sizes can be introduced.

Another challenge that should be addressed is the fare rate calculations and payment methods. For the system to be fully categorized as a DRT service, the fare must be charged on a per-passenger and not a per-vehicle basis. It can also be argued that, because DRT is an intermediate service, that is, a higher-quality service than a conventional public transport service, but not an exclusive service like a taxi, a fare could be charged between the two values, with an added premium over and above a conventional public transport service. However, it has been noted that premium fares are difficult to implement because

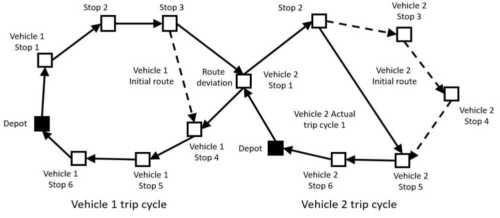

Fig. 20. Vehicle route deviation example.

passengers do not perceive the flexibility of the system, as they consider the service to be a normal public transport service. Moreover, the variety of payment methods available to commuters, such as cash, RFID tags, and ATM cards, make it difficult to set a flexible fare structure.

References

[1] K. Uchimura, H. Takahashi, and T. Saitoh, "Demand responsive services in hierarchical transportation system," *IEEE Trans. Vech. Technol.*, vol. 51, no. 4, pp. 760-766, Jul. 2002. (https://doi.org/10.1109/TVT.2002.1015354)

[2] K. Tsubouchi, H. Yamato, and K. Hiekata, "Innovative on-demand bus system in japan," *IET Intell. Transport Syst.*, vol. 4, no. 4, pp. 270279, Dec. 2010. (https://doi.org/10.1049/iet-its.2009.0113)

[3] M. P. Linares, J. Barceló, C. Carmona, and L. Montero, "Analysis and operational challenges of dynamic ride sharing demand responsive transportation models," *Transportation Res. Procedia*, vol. 21, pp. 110-129, Jun. 2017. (https://doi.org/10.1016/j.trpro.2017.03.082)

[4] R. Gomes, J. P. de Sousa, and T. Dias, "A graspbased approach for demand responsive transportation," *Int. J. Transportation*, vol. 2, no. 1, pp. 21-32, 2014. (http://dx.doi.org/10.14257/ijt.2014.2.1.02)

[5] D. Paul B. Hajinasab, J. Holmgren, A. Jevinger, and J. A. Persson, "The fourth wave of digitalization and public transport: Opportunities and challenges," *Sustainability*, vol. 8, no. 12, pp. 1-16, Nov. 2016. (https://doi.org/10.3390/su8121248)

[6] Z. Belinova, P. Bures, and P. Jesty, "Intelligent transport system architecture different approaches and future trends," *Data and Mobility*, vol. 81, pp. 115-125, 2010. (https://doi.org/10.1007/978-3-642-15503-1_11)

[7] A. Aouto, J.-M. Lee, and D.-S. Kim, "Demand responsive transportation system for low-demand parts of metropolitan area," in *Proc. KICS Conf.*, pp. 1379-1380, 2021, Available online at (https://www.dbpia.co.kr/pdf/pdfView.do?nodeId=NODE10587532).

[8] C. H. Häll, H. Andersson, J. T. Lundgren, and P. Värbrand, "The integrated Dial-a-Ride problem," *Public Transport*, vol. 1, no. 1, pp. 39-54, May 2009. (https://doi.org/10.1007/s12469-008-0006-1)

[9] I. Kaddoura, G. Leich, and K. Nagel, "The impact of pricing and service area design on the modal shift towards demand responsive transit," *Procedia Comput. Sci.*, vol. 170, pp 807-812, 2020. (https://doi.org/10.1016/j.procs.2020.03.152).

[10] K. Uchimura, H. Takahashi, and T. Saitoh, "Demand responsive services in hierarchical public transportation system," *IEEE Trans. Veh. Technol.*, vol. 51, no. 4, pp. 760-766, Jul. 2002. (https://doi.org/10.1109/TVT.2002.1015354).

[11] George E. Gray, and Lester A. Hoel, "Public transportation," *Transport. Res. Part A: Policy and Practice*, vol. 27, no. 5, pp. 413-415, Sep. 1993. (https://doi.org/10.1016/0965-8564(93)90040-R)

[12] Y. Niitani, "*Urban Transportation Planning*," Gihodo Shuppan Co., vol. 3, 2017. (https://gihodobooks.sslserve.jp/book/1848-2.html).

[13] J. D. Nelson, S. Wright, B. Masson, G. Ambrosino, and A. Naniopoulos, "Recent developments in flexible transport services," *Research in Transport. Econ.*, vol. 29, no. 1, pp. 243-248, 2010. (https://doi.org/10.1016/j.retrec.2010.07.030).

[14] J. Mageean, and J. D. Nelson, "The evaluation of demand responsive transport services in Europe," *J. Transport Geography*, vol. 11, no. 4, pp. 255-270, Dec. 2003. (https://doi.org/10.1016/S0966-6923(03)00026-7).

[15] L. Davison, M. Enoch, T. Ryley, M. Quddus, and C. Wang, "A survey of demand responsive transport in Great Britain," *Transport Policy*, vol. 31, pp. 47-54, Jan.

2014. (https://doi.org/10.1016/j.tranpol.2013.11.004).

[16] J. Brake, J. D. Nelson, and S. Wright, "Demand responsive transport: towards the emergence of a new market segment," *J. Transport Geography*, vol. 12, no. 4, pp. 323-337, Dec. 2004. (https://doi.org/10.1016/j.jtrangeo.2004.08.011).

[17] T. J. Ryley, P. A. Stanley, M. P. Enoch, A. M. Zanni, and M. A. Quddus, "Investigating the contribution of demand responsive transport to a sustainable local public transport system," *Res. in Transport. Econ.*, vol. 48, pp. 364-372, Dec. 2014. (https://doi.org/10.1016/j.retrec.2014.09.064).

[18] C. Wang, M. Quddus, M. Enoch, T. Ryley, and L. Davison, "Exploring the propensity to travel by demand responsive transport in the rural area of Lincolnshire in England," *Case Stud. Transport Policy*, vol. 3, no. 2, pp. 129-136, Jun. 2015. (https://doi.org/10.1016/j.cstp.2014.12.006).

[19] T. Liu and A. A. Ceder, "Analysis of a new public-transportservice concept: Customized bus in China," *Transport Policy*, vol. 39, pp. 63-76, Apr. 2015. (https://doi.org/10.1016/j.tranpol.2015.02.004).

[20] H. T. Liu and A. Ceder, "Analysis of a new public-transport-service concept: Customized bus in China," *Transport Policy*, vol. 39, pp. 63-76, 2015. (https://doi.org/10.1016/j.tranpol.2015.02.004).

[21] L. Davison, M. Enoch, T. Ryley, M. Quddus, and C. Wang, "Identifying potential market niches for demand responsive transport," *Res. Transport. Busin. and Manag.*, vol. 3, pp. 50-61, Aug. 2012. (https://doi.org/10.1016/j.rtbm.2012.04.007).

[22] A. Papanikolaoua, S. Basbasa, G. Mintsisa, and C. Taxiltarisa, "A methodological framework for assessing the success of Demand Responsive Transport (DRT) service," *Transport. Res. Procedia*, vol. 24, pp. 393-401, Aug. 2016. (https://doi.org/10.1016/j.trpro.2017.05.095).

[23] J. Mageean and J. D. Nelson, "The evaluation of demand responsive transport services in Europe," *J. Transport Geography*, vol. 11, no. 4, pp. 255-270, 2003. (https://doi.org/10.1016/S0966-6923(03)00026-7).

[24] R. Laws, M. Enoch, and S. Ison, "Demand responsive transport: A review of schemes in england and wales," *J. Public Transport.*, vol. 12, pp. 1-19, Jan. 2009. (https://doi.org/10.5038/2375-0901.12.1.2).

[25] J. Cordeau and G. Laporte, "The Dial-a-Ride Problem (DARP): Variants, modeling issues and algorithms," *Quart. J. Belgian, French and Italian Operations Res. Societies*, vol. 1, no. 2, pp. 89-101, Jun. 2003. (https://doi.org/10.1007/s10288-002-0009-8).

[26] F. F. Liu and S. Shen, "An overview of a heuristic for vehicle routing problem with time windows," *Comput. & Industrial Eng.*, vol. 37, no. 1-2, pp. 331-334, Oct. 1999. (https://doi.org/10.1016/S0360-8352(99)00086-8).

[27] M. L. Fisher, K. O. Jörnsten, and O. B. G. Madsen, "Vehicle routing with time windows: two optimization algorithms," *Handbooks in Operations Res. and Manag. Sci.*, vol. 45, no. 3, pp. 327494, Jun. 1997. (https://doi.org/10.1287/opre.45.3.488)

[28] J. Desrosiers, Y. Dumas, M. M. Solomon, and F. Soumis, "Time constrained routing and scheduling," *Handbooks in Operations Res. and Manag. Sci.*, vol. 8, pp. 35-139, Oct. 1995. (https://doi.org/10.1016/S0927-0507(05)80106-9).

[29] A. T. Ernst, H. Jiang, M. Krishnamoorthy, and D. Sier, "Staff scheduling and rostering: A review of applications, methods and models," *Eur. J. Operational Res.*, vol. 153, no. 1, pp. 3-27, 2004. (https://doi.org/10.1016/S0377-2217(03)00095-X).

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