Evaluating Centralized versus Decentralized Zoning Strategies for Metropolitan ADA Paratransit Services

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Abstract: Americans with Disabilities Act (ADA) paratransit systems are dial-a-ride services that provide public transportation to disabled customers. In large metropolitan areas, these services might use zoning strategies to simplify their management. The objective of this paper is to provide a more in-depth evaluation and comparison between centralized and decentralized zoning strategies. This is achieved by developing a simulation model to evaluate the effects of zoning strategies on the productivity and quality of service for the particular ADA paratransit service, using actual demand data from the city of Houston. Four decentralized zoning strategies are compared with a centralized no-zoning strategy. Higher degrees of decentralization degrade the operational efficiency in terms of larger fleet size because the causative empty trip kilometers are greater. The intrazonal trip percentages of demand and productivity are positively correlated.
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Introduction

Since the passage of the Americans with Disabilities Act (ADA) in 1990, public transit operators have been required to provide disabled passengers with a level of service that is comparable with that which is offered to regular passengers. This is to be achieved either through a fixed-route bus system with proper handicap accessibility or through ADA paratransit services, which are shared-ride flexible services with no fixed routes or schedules that pick up and drop off customers at desired locations and within specified time windows. As of 2007 there were more than 5,300 providers of paratransit services for the elderly and persons with disabilities. Most of these paratransit services were created after the passage of the ADA. In the United States, paratransit trips increased by 38 million from 1995 to 2006, a 3.3% average annual increase in ridership. During the same period, operating expenses increased on average by more than 10% annually. Additionally, the cost per patron for paratransit services is much higher than for regular transit. In 2007, paratransit ridership comprised only 2% of total public transit ridership, but 13% of total operating costs in the United States [American Public Transportation Association (APTA) 2009]. Hence, an improvement in productivity without sacrificing service quality is a very desirable and much-needed goal for these services.

The objective of this paper is to provide a more in-depth analysis that compares and contrasts centralized and decentralized (zoning) strategies for paratransit services. In the former, the entire service area is treated as a single zone; in the latter, multiple zones are defined and managed independently to downgrade the operational complexity of these services, particularly for large metropolitan areas. Zoning paratransit systems has several advantages. First, for service providers, smaller zones are easier to manage and control. In addition, drivers prefer to be assigned to smaller, more familiar zones rather than to larger zones. Smaller zones can also help reduce the effort that is needed to generate feasible schedules and routes, and can help drivers to deliver customers a better quality of service and a higher on-time rate. Adopting the decentralized zoning strategy, however, will likely increase the number of total assigned vehicles and empty trip kilometers (defined as the kilometers driven by a vehicle with no customers onboard, excluding the first/last trip segments to/from the depot) relative to the centralized strategy. This is because additional geographical constraints are added to the system and the scheduling solution cannot improve. Whereas the advantages of zoning are more intuitive, a quantification of the worsening effect of zoning on the scheduling solution is not easy to determine. It would therefore be desirable to help planners and operators make more informed tradeoff-based decisions amongst alternative organizational solutions, such as the centralized and decentralized approaches.

ADA paratransit is a type of demand-responsive transit service, also known as the dial-a-ride system. Its scheduling and routing is termed the dial-a-ride problem (DARP) in the operations research field. The objective of the DARP is commonly to minimize the total number of vehicles and/or total travel kilometers. Given that the DARP is a nondeterministic polynomial-time (NP)-hard problem, it is virtually impossible to find its optimal solution in a reasonable time for large-scale scenarios, and approximation algorithms must be adopted to construct the schedules. There is a significant body of literature with respect to models and algorithms that relate to the DARP. Cordeau and Laporte (2007) published the most recent and comprehensive surveys on the DARP.

In comparison, performance evaluations of practical strategies, such as the effects of zoning strategies on the DARP, have received meagre attention. Several papers have surveyed the performance of dial-a-ride systems. Wilson and Hendrickson (1980) summarized previous models that predicted the performance of flexible-routed

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transportation systems. McKnight and Pagano (1984) explored the service quality of the DARP by investigating 42 service providers in the United States. Paquette et al. (2009) concluded that further study was needed for better understanding the trade-offs among costs, operational policies, and quality in dial-a-ride systems.

Analytic analysis and simulation are two primary methods which are applicable to evaluating the performance of the practical strategies of system design. Daganzo (1978) first developed an approximate analytic model of a demand-responsive transportation system. This study provides a simple model for estimating the average total time (waiting and riding times) in the system. Fu (2003) provided an analytic model to predict fleet size and quality-of-service measurements. Diana et al. (2006) proposed analytic equations to calculate fleet size for a square service area. Li and Quadrifoglio (2009) developed an analytic model to determine the optimal service zone for feeder transit services. The analytic model is easier for parametric analyses of such systems; however, this model renders it difficult to build a close form expression, especially when time-window constraints, irregular service areas, and nonuniform distributions of the origins and destinations of requests are considered.

Relative to the analytic model, simulation methods have been applied to evaluations of performance measures, especially when considering the effects of various system designs and stochastic event analyses on dial-a-ride systems. Wilson et al. (1970) developed a computer-aided routing system (CARS), which built relationships between performance parameters and different scheduling algorithms. Xiang et al. (2008) developed a simulation to evaluate the influence of different stochastic factors. To evaluate the operational improvements that are achieved by the application of automatic vehicle location technology, Fu (2002) applied a simulation model to an analysis. Shinoda et al. (2004) developed a simulation method to compare the performance of dial-a-ride systems and fixed-route bus systems. Quadrifoglio et al. (2008) considered the impact of specific operating practices on zoning strategies and time-window setting, a design currently used by demand-responsive transit providers.

Based on the writers' previous review, existing research that is relevant to paratransit operating designs is still limited, and the decision analysis tradeoffs between centralized and decentralized strategies have not been fully explored. This paper addresses a gap in the literature that is associated with zoning strategies and productivity analysis based on real paratransit demand data, provided by METROLift of Houston, Texas. Because an analytic investigation of the problem is very difficult to develop without drastic approximations, a simulation approach was used for this investigation. The writers compared the currently adopted centralized strategy with hypothetical but plausible decentralized scenarios that the writers set in accordance with demand distribution characteristics and METROLift's suggestions. Through simulation and statistical comparison methods, the performance of zoning strategies was analyzed.

The remainder of this paper is organized into four additional sections, as follows: the ADA paratransit services in Houston, the simulation model and zoning strategies, a performance analysis of the simulation outputs, and conclusions.

Data Analysis

Houston is the fourth most populous city in the nation (less than only New York, Los Angeles, and Chicago), and it is the largest city in the southern United States. The dial-a-ride services that are provided in the Houston area, collectively termed METROLift, are offered by the Metropolitan Transit Authority of Harris County.

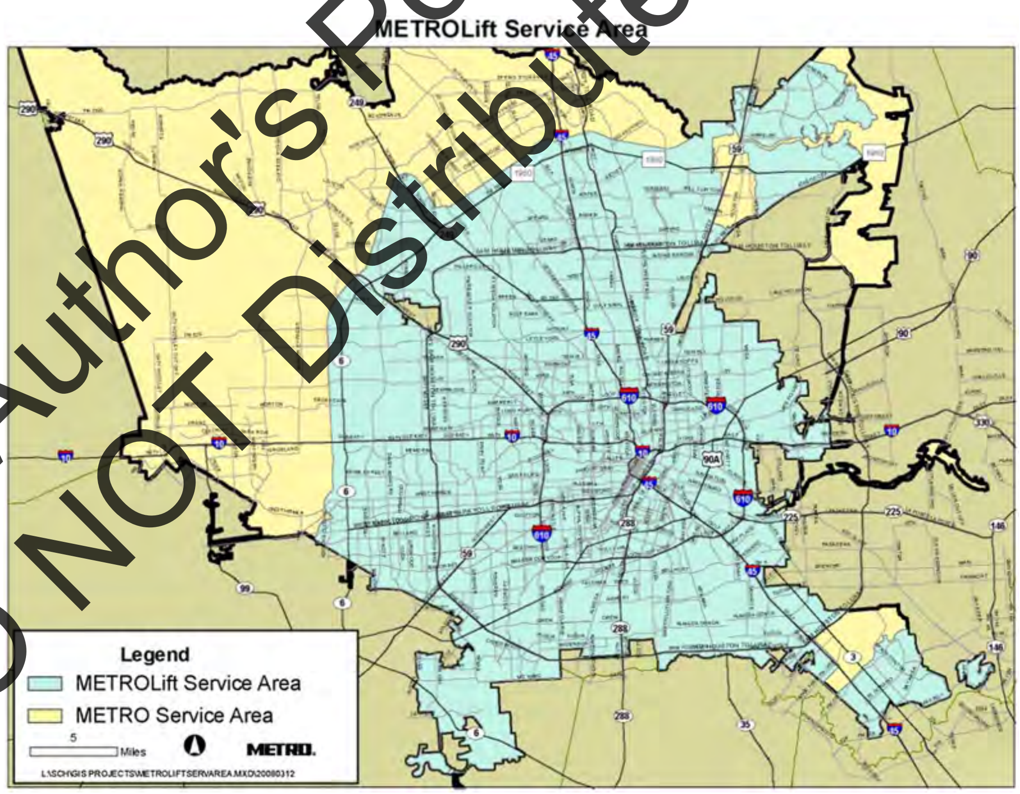

Fig. 1. Service area of METROLift (Shen, C.-W., and Quadrifoglio, L. Evaluation of Zoning Design with Transfers for Paratransit Services. In Transportation Research Record: Journal of the Transportation Research Board, No. 2277, Fig. 7, p. 87. Copyright, National Academy of Sciences, Washington, DC, 2012. Reproduced with permission of the Transportation Research Board)

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People with disabilities have the right to access this service. Fig. 1 shows a map of the service area (Shen and Quadrifoglio 2012). The approximate distances from east to west and from north to south are both 48 km. The fare for a single ticket is US$1.15 per ride. The operating hours are 5 a.m. to 11 p.m. from Monday–Friday, 7 a.m. to 12 a.m. on Saturdays, and 7 a.m. to 11 p.m. on Sundays and holidays. All trips must be scheduled 1 day in advance. Once customers make their own reservations, the schedule operator will give estimated scheduled pickup times. These times are within 20 min, for a resulting 40-min time window (other U.S. cities typically use a 20- or 30-min window). More than 5,000 trips are made through this service during weekdays. 1.44 million annual trips were provided by METROLift in 2007 (APTA 2009). The system has two depots; one is for the van provider and another is for the sedan provider. The vans can accommodate up to four wheelchairs or 10 ambulatory persons separately. The taxicabs can accommodate up to one wheelchair or four ambulatory persons. During weekdays, the average total number of scheduled vehicles is 274 vehicles/day, which includes 138 vans and 136 taxicabs. No specific zoning strategy is currently employed by METROLift.

In the following subsections, the writers analyze the real demand data offered by METROLift, including the distribution of pickup/drop-off locations and the distribution of requested pickup times. These distributions will be used to generate the input data for the simulation model.

Pickup and Drop-Off Locations

The writers used weekday travel data as the reference for location distribution. Figs. 2 and 3 show the distributions of pickup and drop-off locations. Each square in Figs. 2 and 3 represents a 1.6 × 1.6 km area (1 × 1 mi area). More than 90% of the requests are roundtrips. The pickup and drop-off locations are spread throughout the entire service area, but both contain an identical high-demand-density area. Through an inspection of the trip requests that travel to and from this high-density area, there are medical institutions within this area. The requested pickup locations for these medical institutions are scattered across the entire area. This distribution can be considered as a single-core demand pattern.

Pickup Time Distribution

Fig. 4 shows the distribution of requested pickup times and cumulative percentages. The cumulative percentage curve shows that more than 90% of the requested pickup times are between 6 a.m. and 7 p.m. The morning peak hours are from 7 a.m. to 9 a.m.; the afternoon peak hour is from 3 p.m. to 4 p.m. The dial-a-ride service's peak hours are more concentrated than those of other transportation systems, and the peak hours are slightly earlier, especially the afternoon peak hour. This might be attributable to the opening hours of most medical institutions. For trips whose destinations are within the high-density area, the requested pickup times are concentrated during morning peak hours. For trips whose origins are within the high-density area, the pickup times are concentrated during the afternoon peak hour. This special time and location travel pattern must be separately reproduced in the simulation input data to emulate this specific demand pattern. The writers describe the procedure in detail in the customer generation section.

Simulation Model

In this section, the writers present the simulation model and the zoning scenarios. First, the network assumptions are described. This is followed by an overview of the customer-generation method, setting of simulation parameters, scheduling algorithm, and development of the zoning scenario.

Network Assumptions

The simulation area covers the pickup/drop-off locations shown in the data analysis section. The Manhattan (rectilinear) distance is used to calculate the travel distance between each pair of points. For example, A (x_1, y_1) and B (x_2, y_2) represent the pickup and drop-off points, respectively. The travel distance between

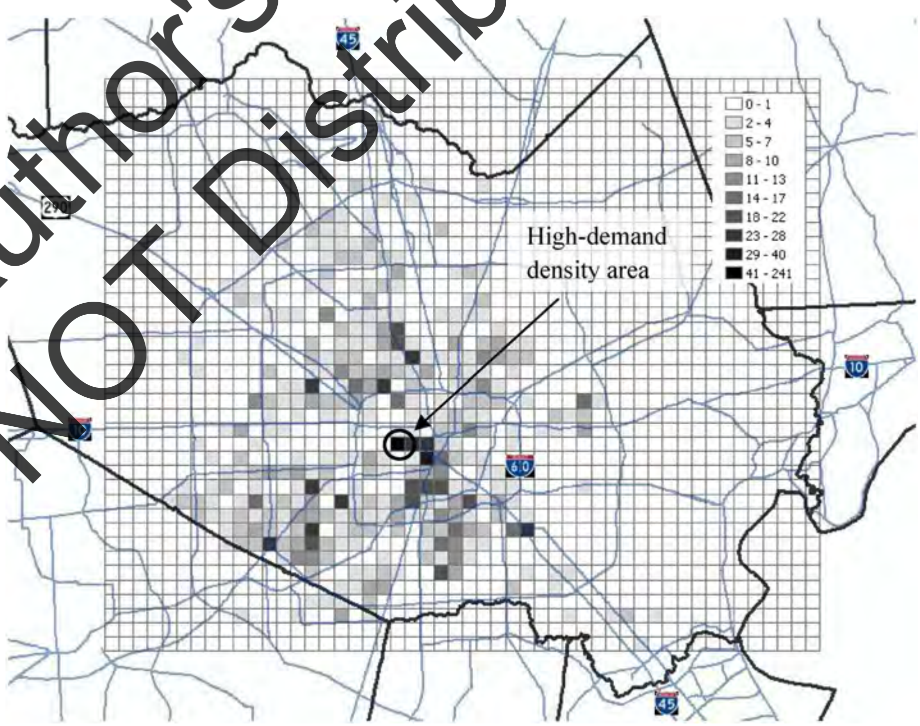

Fig. 2. Distribution of pickup locations

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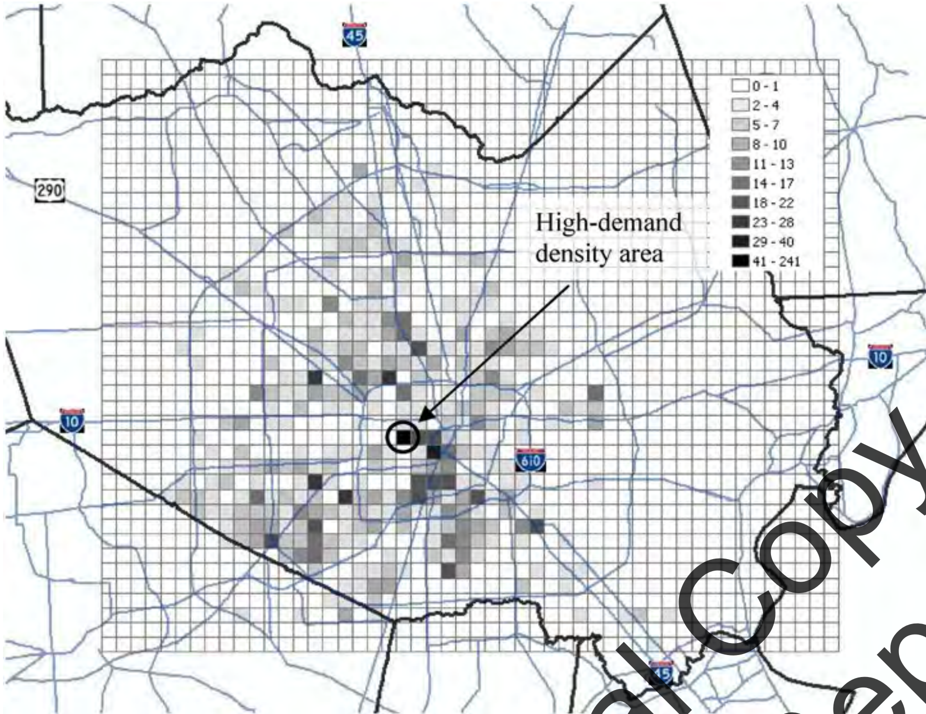

Fig. 3. Distribution of drop-off locations

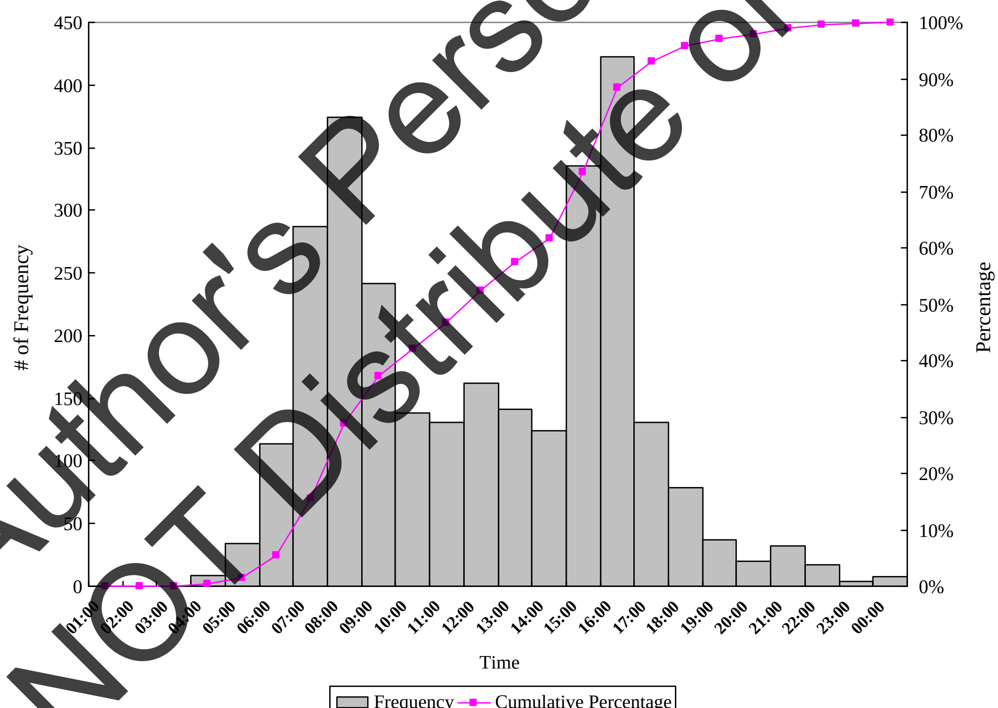

Fig. 4. Distribution of requested pickup times and cumulative percentages

A and B can be calculated as $|x_1 - x_2| + |y_1 - y_2|$. This calculation implies that the network is arranged in a grid pattern. This estimated travel distance is reasonably close to the actual travel distance; see Quadrifoglio et al. (2008). The writers consider the system to be a deterministic case, such the travel time between two points is only a function of travel distance and vehicular speed.

Customer Generation

In the simulation, generation of a trip requires the following information: pickup and drop-off locations, requested pickup time, number of passengers, and whether a wheelchair-accessible vehicle is needed. More than 90% of customers request home-based roundtrips, i.e., the first trip segment is bound for the

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destination (outbound trip) and the second trip segment is back to the origin (inbound trip). The pickup and drop-off locations for the outbound trip are determined first, and the inbound trip is generated by the assumption that the origin of the inbound trip is the destination of the outbound trip and the destination of the inbound trip is the origin of the outbound trip. For each outbound trip, its pickup and drop-off locations are sampled independently from the actual pickup and drop-off distributions, using Figs. 2 and 3, respectively. Furthermore, because the pickup and drop-off locations are independently generated, the pickup and drop-off points might be within the same square mile area, which might be unreasonable in reality. Therefore, if the generated drop-off location is the same as its pickup location, a new drop-off location will be produced.

There are three groups of requests when the corresponding pickup times are sampled. First, if the origin of a request is within the high-density area shown in Fig. 2, the pickup time of the trip is sampled from the time distribution built by requests whose origins are within the high-density area. Second, if the destination of a request is within the high-density area shown in Fig. 3, the pickup time of the trip is sampled from the time distribution built by requests whose destinations are within the high-density area. Third, if the origin and destination of a request are not within the high-density area, the cumulative pickup time distribution in Fig. 4 is used to generate the requested pickup time. The pickup time of the inbound trip must be later than the pickup time of its outbound trip and the direct travel time.

Parameters

The simulation model uses the following system parameters, which are currently used by METROLift:

- Vehicle speed: 32 km/h (20 mi/h);
- Ambulatory passenger: boarding time = 1 min; disembarking time = 1 min;
- Wheelchair passenger: boarding time = 6 min; disembarking time = 4 min;
- Time window: 40 min and the requested pick-up time;
- Maximum ride-time factor: customers have different parameters, in accordance with their direct travel distances (actual ride time divided by direct ride time; see Fig. 5);
- Size of available fleets: unlimited for vans; and
- Van capacity: up to four wheelchairs or 10 ambulatory persons.

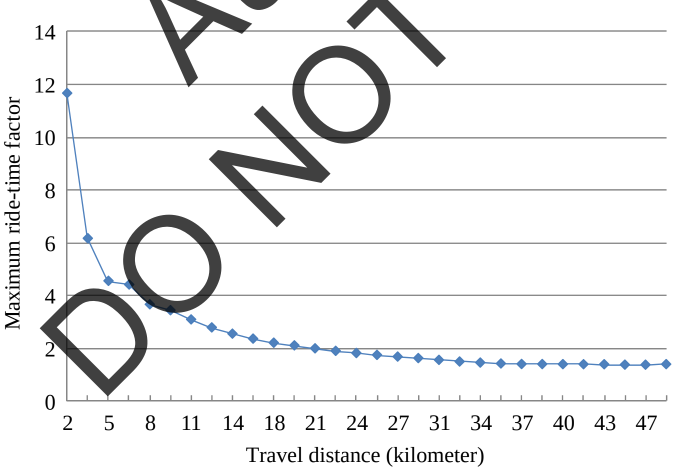

Fig. 5. Maximum ride time factors with respect to travel distance

Scheduling Algorithm

A sequential insertion algorithm was used to schedule the dial-a-ride services. The concept of the insertion algorithm is explained in the following paragraph.

The trips are ranked in accordance with ascending requested pickup times. At the beginning of each insertion run, an empty route is generated from and ends at the depot. The writers inserted one trip (two points) at a time into each zone. The insertions create deviations in these circular routes. Each unassigned trip searches for feasible insertions with minimal extra travel distance. During the procedure of searching for feasible insertions, four constraints are taken into consideration. First, for each customer the drop-off time should always be later than the corresponding pickup time. Second, the unassigned trips can be assigned only to the time slots within their pickup and drop-off time windows. Third, after inserting the new trip, the writers check whether this insertion will violate the successive assigned customers' time windows. Fourth, the vehicle capacity must be satisfied in the process of inserting the unassigned trips. When each unassigned trip is inserted into a feasible position, the trip is marked as assigned; otherwise, the trip is marked as unassigned. If there are any unassigned trips after one run, this indicates that the existing routes cannot accommodate any unassigned trips; the existing routes are then moved to the set of generated routes. Afterwards, new empty routes are generated and the remaining unassigned trips are checked by the same insertion procedure until all of the trips are assigned to a route. In this algorithm, the writers allow both nonempty and empty-load vehicles to wait at pickup locations before the ready service time. This assumption can increase the possibility of feasible insertions when operating the algorithm. The scheduling algorithms were coded in C++ and were run on an Intel Core Duo 2 GHz processor. The pseudocode of the algorithm is as follows:

Algorithm 1. Insertion algorithm

```
begin
While (there still are unassigned trips)
  For each depot, generate one empty route from and end to it
  For each unassigned trip do
    Check all feasible insertions where the consequence constraints, time-window constraints, and capacity constraints
    are not violated
    If (there is at least one feasible insertion) then
      Select the insertion that minimizes the additional travel
      distance for the existing route
      Insert the unassigned trip
      Update the schedule of the inserted route and delete trips
      from unassigned lists if need
    End if
  End for
End while
end
```

Zoning Scenarios

Dividing the entire service area into smaller zones can be achieved through various rules. The rules include adopting natural boundaries, such as existing major highway corridors, administrative zones, the perimeter of the predefined service area, and depot locations within the service area. For a zonal-based design, if a customer's pickup and drop-off location belong to different zones, this can be defined as an interzonal trip; otherwise, the trip is intrazonal. The method of accommodating interzonal trips into the routing schedule determines the operational types. In this paper, the service providers only pick up customers whose origins are

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within its service zone, i.e., the interzonal trips are served by providers in accordance with the origins. Therefore, for an interzonal round trip, the return trip must be made by another provider, which means that the customer is required to make two different reservations.

The key to determining service zones is to accommodate a high volume of intrazonal trips, and balance the percentage of interzonal trips within each zone. Considering the setting of zoning scenarios within the context of Houston, as the writers noted previously, there is an extremely high-frequency square area that contains major medical institutions where many trips begin and terminate. It is roughly situated in the gravity center of the demand distribution and also the geographic center of the entire service area. Furthermore, after investigating the distributions of the customers to and from this high-frequency area, both distributions are scattered evenly throughout the entire service area. This square area should not be arranged into any single zone but is suitable to serve as the break center point to avoid unbalanced percentages of interzonal trips for each zone. The writers explain the effect of interzonal trips on the performance of paratransit systems in the section that pertains to the analysis and comparison of zoning strategies. Zooming in on the center point, the boundary lines diffuse from this square area. According to the previous approach, three zoning scenarios are introduced: north/south, east/west, and northeast/northwest/southeast/southwest (four zones). For each zoning scenario, the customers that are within the breakpoint square area must be arranged into different zones. The number of customers to and from the breakpoint square area will then be categorized within the zones in accordance with the proportion of demand requests of each zone. Table 1 summarizes the intrazonal and interzonal percentages for each zone in accordance with a corresponding zoning scenario. For zoning cases, each zone assumes one depot in the center of its zone.

In addition to the previous three zoning scenarios, the writers attempted to increase the percentage of intrazonal trips by introducing an overlapping, centred core district to create an overlapping strategy. In this case, every zone would include the core area, which might be the trip concentration center (analogous with Boston's paratransit structure). In the scenario with a common core zone, whichever carrier brought the rider to the core zone would carry him/her back to his/her origination point. In this case, approximately 66% of the trips are intrazonal.

Table 1. Pickup and Drop-Off Percentages between Zones

Pickup	Drop-off (%) Northwest	Northeast	Southwest	Southeast
Northwest	59	16	18	7
Northeast	34	39	13	14
Southwest	14	6	64	15
Southeast	9	9	30	52
Pickup	**Drop-off (%) North**	**South**	**East**	**West**
North	74	26	—	—
South	19	81	—	—
East	—	—	57	43
West	—	—	23	77

Performance Analysis

In this section, the writers describe the simulation results based on the demand data and zoning strategy noted previously. First, the performance measurements are defined to evaluate the performance of each zoning strategy. The writers then utilize statistical techniques to analyze and compare the alternative zoning strategies.

Performance Measurements

The writers investigated the performance of zoning strategies from the perspectives of efficiency and service quality (Table 2). From the perspective of efficiency, the number of routes and total kilometers are the most direct indicators to compare the alternative strategies. The writers categorized the total travel distance of each generated route into three parts, as follows: vehicle travel kilometers from and to the depot, travel kilometers with no passengers on board from the first pickup to the last drop-off, and travel kilometers with passengers on board from the first pickup to the last drop-off location.

First, the vehicle travel kilometers from and to the depot are termed deadhead kilometers. In practice, these kilometers are not taken into account when calculating revenue kilometers. Second, the travel kilometers with no passengers on board between the first pickup location and the last drop-off location are termed empty trip kilometers. For the operator, fewer empty trip kilometers is ideal because productivity decreases with an increase in empty trip kilometers. Third, the travel kilometers with passengers on board can be calculated by subtracting deadhead kilometers and empty trip kilometers from the total travel kilometers.

Other useful measurements were also investigated, such as passenger kilometers (total kilometers driven by passengers), passenger kilometers per total kilometer, and passenger trips per vehicle revenue hour, which is the most commonly used index in practice to compare transit service productivity.

In addition to performance measurements from the perspective of productivity, the writers analyzed the zoning strategies from the perspective of quality of service. From this perspective, the deviation time and ride time are the major concerns beyond the fare level. The deviation time is the time difference between the requested pickup time and actual pickup time. The parameter setting section notes that the actual ride time of customers cannot

Table 2. Measurements of Zoning Strategies

Scenario	Number of routes	Total kilometers	Deadhead kilometers	Empty kilometers	Passenger kilometers	Passenger kilometers/total kilometers	Passenger trips/revenue hour	Average deviation time (min)	Average passenger ride time (min)	Revenue hours	Intrazonal percentage
No zoning	289	81,228	13,082	11,018	97,553	1.20	1.55	23.1	38.6	3,226	100
North/south	323	84,284	10,321	15,611	97,405	1.16	1.45	22.6	38.4	3,443	77
East/west	326	88,074	11,404	17,709	97,373	1.11	1.39	22.5	38.4	3,588	67
Four zones	355	91,959	10,997	21,662	97,334	1.06	1.33	21.6	38.4	3,757	52
Four zones overlap	334	86,925	9,439	18,641	97,763	1.12	1.37	21.7	38.6	3,653	66

exceed the maximum ride time, which is attributable to a maximum ride-time factor that corresponds with their direct travel distances.

Analysis and Comparison of Zoning Strategies

The performance of alternative zoning scenarios was compared through 10 replications by simulation. To increase the simulation's statistical efficiency and validation, this paper applies the variance reduction technique (i.e., the writers synchronized a random number across different configurations on any particular replication). This procedure can help to obtain greater precision with fewer simulation replications. All of the pairwise confidence intervals were built for certain important performance measurements with respect to all strategies. Table 2 shows the average results of 10 replications for each zoning strategy; the unit of time is in minutes. The writers use the numbers 1–5 to represent five scenarios (i), as follows: no zoning ($i = 1$), north/south ($i = 2$), east/west ($i = 3$), four zones ($i = 4$), and four zones with core overlap ($i = 5$).

Although the writers' simulation contains some assumptions to simplify the actual scenario, the number of routes that were generated from the simulation is 289, which is very close to the actual number provided by METROLift (the average number of actual routes is approximately 280) for the no-zoning cases (currently adopted in reality). This serves as a validation of the writers' model and its needed assumptions.

To examine whether the measurements are significantly different among the different zoning strategies, the writers constructed all of the pairwise confidence intervals for five measurements, as follows: number of routes, deadhead kilometers, empty (trip) kilometers, passenger trips per vehicle revenue hour, and average deviation time. Because there are 10 paired comparisons among five strategies, the writers set each individual interval at a level 99.50% $(1 - 0.05/10)$ to achieve a 95% overall confidence, in accordance with the Bonferroni correction. In Tables 3–7, the number represents the confidence intervals of differences $\mu_{i_2} - \mu_{i_1}$ for each measurement, for all i_1 and i_2 between 1 and 5, with $i_1 < i_2$. The numbers with superscripts in Tables 3–7 indicate those intervals that are missing zero (i.e., those pairs of strategies that have significantly different numbers of routes).

From Tables 3–5, relative to other zoning cases, the no-zoning scenario exhibits a savings in the total number of routes, deadhead kilometers, and empty trip kilometers. On the contrary, the deadhead kilometers and average deviation time increase from the

Table 3. All Pairwise Confidence Intervals of Measurements: Number of Routes

Paired t	i_2: 2	3	4	5
i_1				
1	34.6 ± 8.38[a]	37.2 ± 5.9[a]	66.5 ± 7.05[a]	45 ± 9.14[a]
2	—	2.60 ± 8.40	31.9 ± 5.23[a]	10.4 ± 9.09[a]
3	—	—	29.3 ± 8.73[a]	7.80 ± 7.70[a]
4	—	—	—	-21.5 ± 7.32[a]

[a]Significant difference.

Table 4. All Pairwise Confidence Intervals of Measurements: Deadhead Kilometers

Paired t	i_2: 2	3	4	5
i_1				
1	$-2{,}762.3 \pm 359.45$[a]	$-1{,}679.8 \pm 249.72$[a]	$-2{,}086.2 \pm 295.12$[a]	$-3{,}644.5 \pm 379.82$[a]
2	—	$1{,}082.4 \pm 400.35$[a]	676.1 ± 333.78[a]	-882.2 ± 350.46[a]
3	—	—	-406.4 ± 461.06	$-1{,}964.7 \pm 297.24$[a]
4	—	—	—	$-1{,}558.3 \pm 454.24$[a]

[a]Significant difference.

Table 5. All Pairwise Confidence Intervals of Measurements: Empty Trip Kilometers

Paired t	i_2: 2	3	4	5
i_1				
1	$4{,}594.0 \pm 466.78$	$6{,}692.0 \pm 695.67$	$1{,}0644.2 \pm 412.09$	$7{,}624.7 \pm 489.94$
2	—	$2{,}097.9 \pm 588.23$	$6{,}050.2 \pm 288.20$	$3{,}030.7 \pm 323.92$
3	—	—	$3{,}952.2 \pm 519.52$	932.8 ± 387.60
4	—	—	—	$-3{,}019.4 \pm 269.35$

Note: All of the differences are significant.

Table 6. All Pairwise Confidence Intervals of Measurements: Passenger Trips per Vehicle Revenue Hour

Paired t	i_2: 2	3	4	5
i_1				
1	-0.098 ± 0.017	-0.156 ± 0.029	-0.219 ± 0.019	-0.181 ± 0.022
2	—	-0.058 ± 0.029	-0.121 ± 0.019	-0.083 ± 0.021
3	—	—	-0.063 ± 0.021	-0.025 ± 0.019
4	—	—	—	0.038 ± 0.018

Note: All of the differences are significant.

Table 7. All Pairwise Confidence Intervals of Measurements: Deviation Time

Paired t	i_2			
	2	3	4	5
i_1				
1	-0.537 ± 0.196[a]	-0.582 ± 0.193[a]	-1.487 ± 0.168[a]	-1.455 ± 0.270[a]
2	—	-0.045 ± 0.202	-0.951 ± 0.170[a]	-0.918 ± 0.273[a]
3	—	—	-0.905 ± 0.197[a]	-0.873 ± 0.291[a]
4	—	—	—	0.032 ± 0.257

[a]Significant difference.

zoning strategy to the no-zoning strategy. No-zoning generates the highest number of passenger trips per revenue hour (Table 6). The passenger kilometers and average passenger ride time remain almost the same in all of the scenarios.

Although the total number of routes between the north/south and east/west strategies are not significantly different, the empty trip kilometers in the north/south zoning strategy is 12% less than those in the east/west zoning strategy. The number of passenger trips per revenue hour in the north/south zoning strategy is 4% greater than in the east/west zoning strategy. By introducing overlap into the four-zone case, savings are shown in the number of routes generated (6%) and empty kilometers (14%); thus, the passenger trips per revenue hour increased by 3%.

From the perspective of quality of service, the average deviation time should be as small as possible. All of the pairwise comparisons for average deviation time in each zoning strategy are shown in Table 7. From these, the writers conclude that the four-zone strategy significantly decreases the average deviation time by 6.5% relative to the centralized no-zoning strategy. The comparison between the north/south and east/west strategies does not exhibit a significant difference. The writers infer that this is because the four-zone strategy geographically groups the pickup points into considerably smaller zones relative to the two-zone cases and the no-zoning case. The scheduling algorithm, based on a minimization of extra insertion distance, helps to reduce the deviation from the desired pickup time. Another possible reason is that the increase in generated routes in the four-zone strategy also helps to decrease the average deviation time.

The effect of increasing the intrazonal percentage is evident in the decrease of empty kilometers. Fig. 6(a) presents the percentage of intrazonal trips and empty kilometers for each scenario. When the intrazonal percentage increases from 53% (four-zone strategy) to 67% (east/west zoning strategy), the empty trip kilometers decrease by 18%; the empty trip kilometers decrease significantly, by 12%, when the intrazonal percentage increases from 67 to 77% (north/south zoning strategy). On average, for each percentage increase in the intrazonal percentages, the empty kilometers decrease by approximately 221 km. This trend can be validated by the performance of the four-zone overlap scenario. With an almost equal percentage of intrazonal percentages, the empty kilometers are very similar between the east/west and four-zone overlap scenarios.

Fig. 6(b) provides the empty kilometers and passenger trips per revenue hour for each zoning scenario. There is an obvious

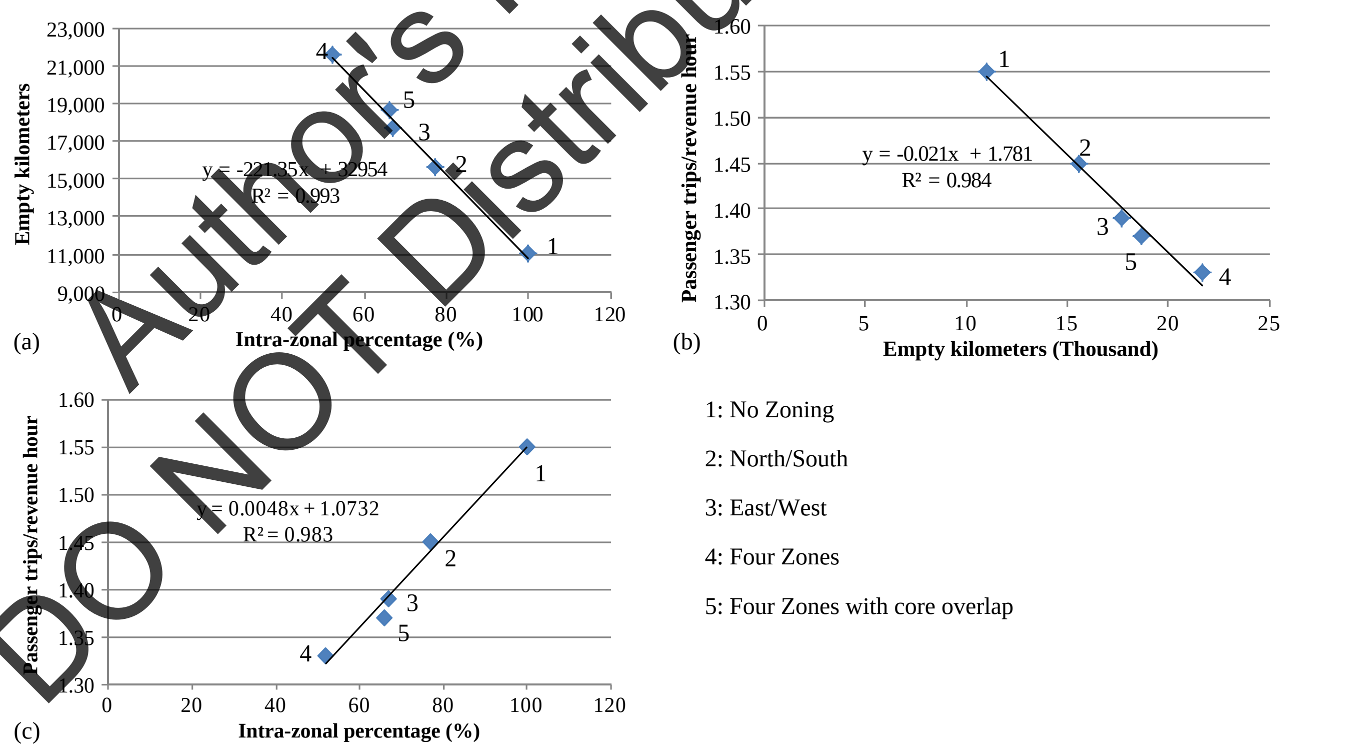

Fig. 6. Trends of productivity among the scenarios: (a) percentage of intrazonal trips and empty kilometers for each scenario; (b) empty kilometers and passenger trips per revenue hour for each zoning scenario; (c) passenger trips per revenue hour as a function of intrazonal percentage

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negative correlation between these two measurements. With each 1,000 increase of empty kilometers, the passenger trips per revenue hour decrease by 0.021. It is desirable to build a relationship between the intrazonal percentage and the passenger trips per revenue kilometer. Fig. 6(c) shows that the passenger trips per revenue hour improve by approximately 0.005 when the intrazonal percentage increases by 1%. This positive correlation can be used by planners or managers when designing zoning policy.

Although the previous results are based on the specific context of Houston, the writers feel that results can be safely considered general, at least for their trends, because many large U.S. metropolitan regions are similarly shaped. Adding the zoning constraints decreases the productivity in general. This is because the addition of any zoning constraints reduces the number of available feasible scheduling solutions, and can only worsen the overall optimal solution by increasing the number of total routes generated and decreasing the passenger trips per vehicle revenue hour relative to the centralized strategy. The actual worsening effect for other cities with different demand configurations would require specific analogous studies.

Conclusions

In this paper, the writers investigated the productivity and quality of service of certain zoning strategies for ADA paratransit systems, through an evaluation of both centralized and decentralized tactics. Four zoning strategies were developed in accordance with the distribution of pickup and drop-off locations in Houston, Texas. A simulation model was introduced and this model can be applied to other systems with modifications to the configuration settings.

Through simulation and statistical comparisons methods, the effects of different zoning strategies on ADA paratransit systems have been analyzed. From the productivity viewpoint, the centralized strategy has the fewest total routes generated and fewest number of empty trip kilometers, which helps to increase the passenger trips per vehicle revenue hour. With respect to quality of service, decentralized zoning strategies decrease the average deviation time for customers. The customers' scheduled ride times remain unchanged in both the centralized and decentralized strategies.

Although the writers utilized the specific context of Houston, the simulation results of the performance measurements' trends with respect to zoning strategies should be similar in other contexts, especially in those with a concentrated area of trip ends. This is because the addition of zoning constraints reduces the number of available feasible solutions and can only worsen the overall optimal solution. However, the degree of this worsening effect will be a function of the actual demand distribution and the design of the service zone.

Further research may be useful for identifying the hidden management costs and benefit structures of different alternatives to fully evaluate the benefit-cost ratio of each of these zoning strategies.

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