# CENTRALIZED VS. DECENTRALIZED ZONING STRATEGIES FOR METROPOLITAN PARATRANSIT SYSTEMS

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## ABSTRACT

ADA paratransit systems are dial-a-ride services providing public transportation to disabled customers. In large metropolitan areas, these services might adopt 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 for the city of Houston, Texas, by developing a simulation model to evaluate the effect of zoning strategies on the productivity and service quality for the ADA paratransit service. Three decentralized zoning strategies are compared to a centralized no-zoning strategy. Results show that the decentralized "Four-zone" strategy, as opposed to the centralized no-zoning strategy, needs a fleet larger by 17 percent, its empty trip miles are larger by 11 percent, values for the passenger trips per vehicle revenue hour are lower and its average waiting time is 3.7 percent lower.

*Keywords: paratransit, zoning strategies, simulation*

## INTRODUCTION

Since the passage of the Americans Disabilities Act (ADA) in 1990, the public transit operators have been required to provide disabled passengers with a level of service comparable to the one offered to regular passengers either with the accessible use of the fixed route bus system or with paratransit services, which are shared ride flexible services with no fixed routes and schedules and pick-up and drop-off customers at their desired place within specified time windows. There are over 5,300 providers of paratransit services for the elderly and persons with disabilities as of 2007; most of them began after the ADA. The paratransit's trips have increased by 14 million from 2007 to 2008 in the United States: a 6.6% increase in ridership. However, the cost per patron for paratransit services is much higher than for regular transit. In 2007, the paratransit ridership made up only 2% of the whole public transit ridership but 13% of the total operating cost in the United States (APTA 2009). Hence, an improvement of the productivity without sacrificing service quality is a very desirable and much needed goal for these services.

The paratransit scheduling problem is formally known as the dial-a-ride problem (DARP) which consists of constructing a set of routes and schedules in shared-ride mode that satisfies travel requests for pick-up and drop-off locations at specified time windows. The objective of DARP is commonly to minimize the total number of vehicles and/or total travel miles. The objective of this paper is to provide a more in-depth analysis between centralized and decentralized (zoning) strategies for dial-a-ride services. In the former, the entire service area is treated as single zone; in the latter multiple zones are defined and managed independently to downgrade the operation complexity of these services especially for large metropolitan area. In fact, for service providers, smaller zones are easier to manage and control. In addition, drivers prefer to be assigned to a smaller familiar zone instead of a larger one. The smaller zones can also help to reduce the effort to generate feasible schedules and routes, since the DARP has been proven to be a NP-hard problem, which means that it is virtually impossible to find its optimal solution in reasonable time for large scale scenarios and approximation algorithms need to be adopted for constructing the schedules. Adopting the decentralized strategy, however, will likely increase the number of total assigned vehicles and empty trip miles (defined as the miles driven by a vehicle with no customers onboard, excluding the first/last trip segments to/from the depot) compared to the centralized strategy, since additional geographical constraints are added to the system and the scheduling solution cannot improve. However, while the advantages of zoning are more intuitive, a quantification of the worsening effect of zoning on the scheduling solution is not easy to determine and would be desirable to help planners and operators make more informed trade-offs decisions between alternative organizational solutions, such as centralized and decentralized tactics.

Because an analytic investigation of the problem is very difficult to develop without drastic approximations, a simulation approach was used to investigate it. The analysis was based on real paratransit demand data courteously provided by METROLift of Houston, Texas. We compare the currently adopted centralized strategy with hypothetical but plausible decentralized scenarios that we set accordingly to the demand distribution characteristics and following METROLift suggestions. Through simulation and statistic comparison methods, the performance of zoning strategies was analyzed.

The rest of this paper is organized into four additional sections. Section two reviews the relevant literature on DARP. Section three introduces the simulation model and develops the zoning strategies. Section four describes the performance analysis of simulation output. Section five ends with conclusions.

## LITERATURE REVIEW

In this section, we review the papers dealing with the performance evaluation of DARP. Categorized by the applicable tools to evaluate the performance of practical management strategies, the analytic analysis and simulation models are two major methods. The approximate analytic model of a demand responsive transportation system was first developed by Daganzo (1978). This study focused on the real-time algorithms for dial-a-ride systems. Fu (2003) provided an analytic model to predict the fleet size and quality-of-service measurements. Diana et al. (2006) proposed analytic equations to calculate the fleet size for a square service area. Li and Quadrifoglio (2009) developed an analytic model to determine the optimal service zone for feeder transit service. The analytic model is easier for parametric analysis of the system; however, it is hard to build a close form expression.

Compared to the analytic model, simulation methods have been applied to stochastic event analysis and the evaluation of performance measurements on dial-a-ride systems. Wilson et al. (1970) developed a computer aided routing system (CARS) which built the relationships between performance parameters and different scheduling algorithms. Xiang et al. (2008) adopted a simulation to evaluate the influence of different stochastic factors. In order to evaluate the operational improvement from the application of automatic vehicle location technology, Fu (2002) applied a simulation model to analyze. 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 of zoning strategy and time window setting which is currently used by demand responsive transit providers.

In comparison, the performance evaluation of practical operation strategies such as zoning strategy on DARP has received meagre attention. McKnight and Pagano (1984) explored the service quality of DARP by investigating 42 service providers in the United States. Wilson and Hendrickson (1980) summarized the earlier models that predicted the performance of flexible routed transportation system. Paquette et al. (2009) concluded that the further study is needed for better understanding the trade-offs among costs, operational policies and quality in dial-a-ride systems.

The existing research dealing with paratransit operating policies is still limited, and the trade-offs decision analysis between centralized and decentralized strategies have not been determined. Our paper is to address a literature gap associated with zoning strategies and the quality-of-service analysis within a representative US city: Houston, TX.

# DATA ANALYSIS

Houston is the 4$^{th}$ most populated city in the nation (trailing only New York, Los Angeles and Chicago), and is the largest in the southern United States. The dial-a-ride services provided in Houston area, called METROLift, is offered by Metropolitan Transit Authority of Harris County. People with disabilities have the right to access this service. Figure 1 shows the map of service area. The rough distances from east to west and from north to south are both 30 miles. The fare for single ticket is $1.15 per ride. The operating hours are 5 a.m. to 11 p.m. from Monday to Friday, 7 a.m. to 12 a.m. on Saturday, and 7 a.m. to 11 p.m. on Sunday and holidays. All trips need to be scheduled one day in advance for making a reservation. Once customers make the reservation, the schedule operator will give the estimated scheduled pick-up times. These times can change plus or minus 20 minutes for a resulting 40 min time window (other US cities adopt 20 or 30 min). Over 5,000 trips utilize this service during weekdays; 1.44 million annual trips are 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 4 wheelchairs or 10 ambulatory persons separately; the taxi cabs can accommodate up to 1 wheelchair or 4 ambulatory persons. During weekdays, the average total scheduled vehicles are 256 per day including 123 vans and 133 taxi cabs. No specific zoning strategy is employed by METROLift now.

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

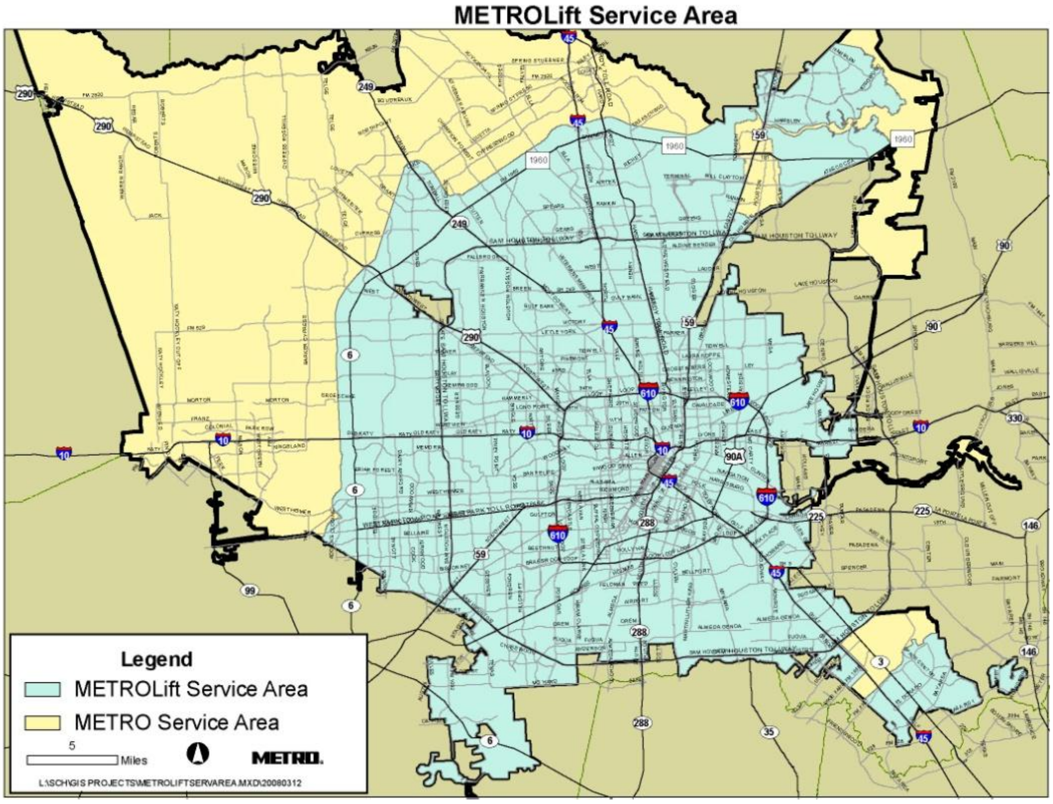


Figure 1 – Service area of METROLift

## Pick-up and Drop-off Locations

Figures 2 and 3 show the distributions of pick-up and drop-off location. We use a weekday travel data as the reference of location distribution. Each square in the figures represents a one by one mile area. The pick-up and drop-off locations spread the whole service area, but both have an ultra high density square mile at the same area. Through the inspection of trip requests that travel to and from this high density area, we found that there are hospitals within this area. The requested pick-up times to this hospital are concentrated during morning peak hours, and the pick-up times from hospitals are concentrated during afternoon peak hours. This special time and location travel pattern need to separately reproducing the simulation input data in order to emulate the real demand pattern. We describe the detail procedure in customer generation section.

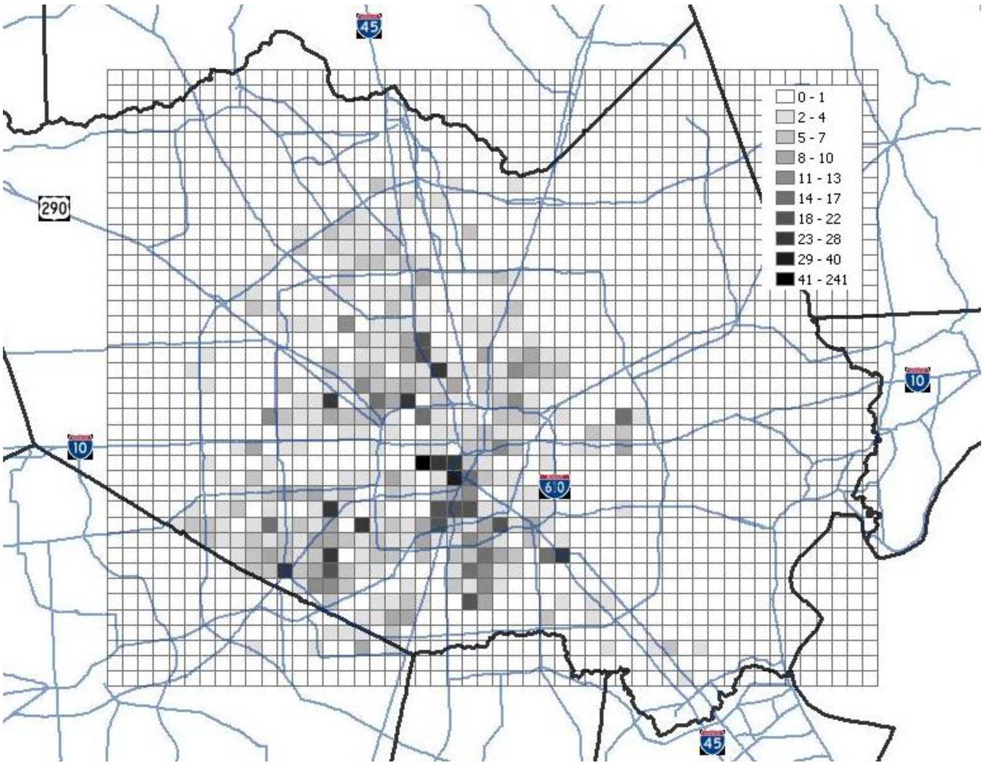


Figure 2 – Distribution of pick-up locations

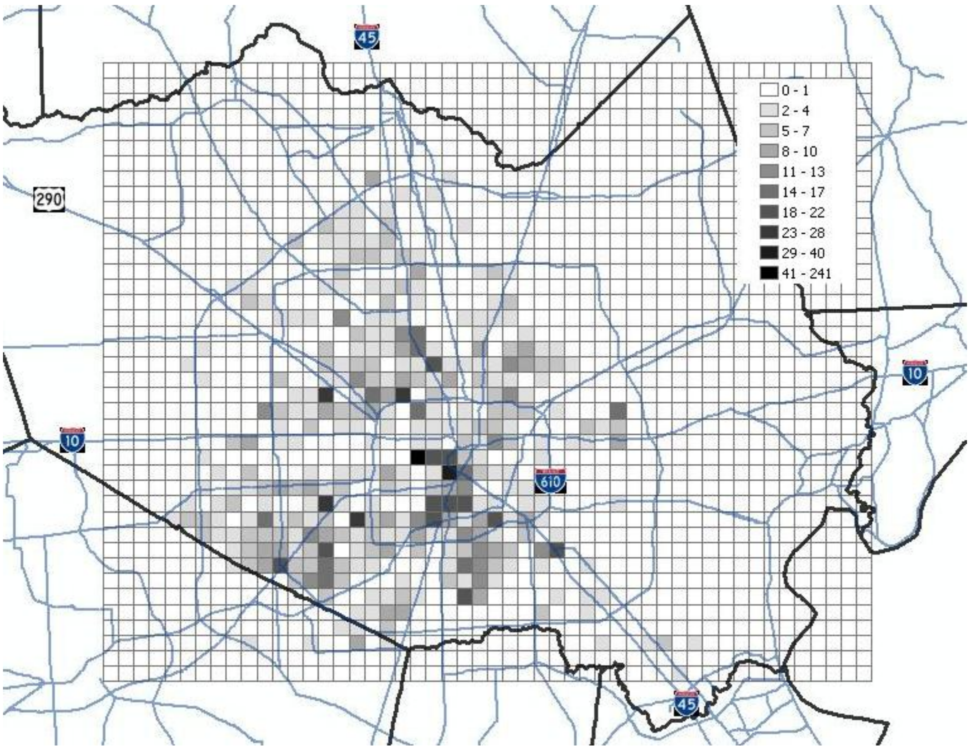


Figure 3 – Distribution of drop-off locations

### Pick-up Time Distribution

The requested pick-up time distribution is shown in Figure 4. The cumulative percentage curve represents that over ninety percent of requested pick-up times lie between 6 am to 7 pm; the morning peak hour is form 7 am to 8 am; the afternoon peak hour is from 3 pm to 4 pm. The dial-a-ride services' peak hour is more concentrated than other transportation systems and the peak hour is a little earlier especially at afternoon peak hour. This might be corresponding to the opening hours of most hospital services.

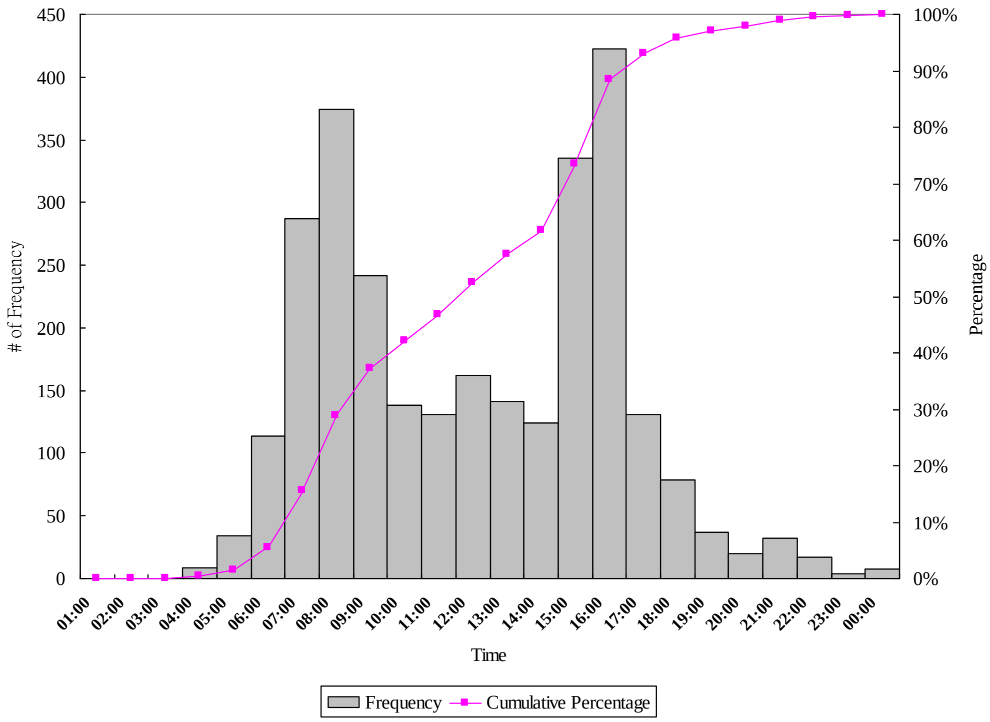


Figure 4 – Distribution of requested pick-up time and cumulative percentage

## SIMULATION MODEL

In this section, we present the simulation model and the zoning scenarios. First the network assumptions are described, and it follows by customer generation method, simulation parameters setting, scheduling algorithms, and zoning scenarios development.

### Network Assumptions

The simulation area covers the pick-up/drop-off locations shown in data analysis section. The Manhattan (rectilinear) distance is used to calculate the travel distance between each pair of point. For example, A$(x_1, y_1)$ and B$(x_2, y_2)$ represent either the pick-up or drop-off point respectively. The travel distance between 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 was verified to be reasonably close to the actual travel distance by Quadrifoglio et al

(2008). We also assume no traffic jams on the system, and the travel time between two points is only a matter of travel distance and vehicle speed.

## Customer Generation

For each customer, the generation of a trip request needs the following information: pick-up and drop-off location, requested pick-up time, the number of passenger, and the need of a wheelchair accessible vehicle. The pick-up and drop-off locations are generated independently from the pick-up and drop-off distribution. First, the pick-up and drop-off one-square mile areas are chosen using one random number stream; another random number stream uses to decide the specific coordinate within the one-square mile area. The above procedure can avoid generating pick-up and drop-off locations from only one specific point within the area.

Furthermore, because the pick-up and drop-off locations are independently generated, the pick-up and drop-off point might create within the same square mile area, which is unreasonable in reality. Therefore, if the generated drop-off location is the same as its pick-up location, a new drop-off location will be produced. Refer to the generation of requested pick-up time, the cumulative distribution in Figure 4 is used to generate the requested pick-up time.

## Parameters Setting

The simulation model will use the following system parameters:

- Vehicles' speed: 25 miles/hour
- Service time of each customer: 1 minute
- Time-windows: 20 minutes minus and plus the requested time
- Maximum ride time factor: 2.5 (the ratio of actual ride time divided by direct ride time)
- Number of available vehicles: unlimited for vans and taxi cabs
- Vans capacity: up to 4 wheelchairs or 10 ambulatory persons
- Cabs capacity: up to 1 wheelchair or 4 ambulatory persons

## Scheduling Algorithm

The insertion algorithm is used to schedule the dial-a-ride services. The concept of the insertion algorithm is as follows. At the beginning of insertion algorithm, one empty route will generate from each depot. Each route starts and ends at the same depot. All unassigned trips need to search the feasible insertion slots from these routes that minimizes the extra travel distance. When each unassigned trip insert into a feasible slot, this trip will be marked as "Assigned", or otherwise it will still be marked as "Unassigned". During the procedure of searching feasible slot, four constraints are taking into consideration. First, for each customer the drop-off time should be always later than its pick-up time. Second, the unassigned trips can only be assigned into the time slots within their pick-up and drop-off time windows. Third, after inserting the new trip, we still need to check whether if this insertion will violate the successive assigned customers' time windows. Finally, the capacity of each route is also needed to consider in the process of inserting the unassigned trips. If there is any "unassigned" trip left after one run, it means the existing routes cannot accommodate any unassigned trip; the existing routes will be move to the set of generated routes. Afterward, the new empty routes are generated and the rest unassigned trips will be checked by the same insertion procedure until all trips are assigned to a route. In our algorithm, we allow both non-empty and empty load vehicles to wait at pick-up location before the ready service time. This assumption can increase the possibility of feasible insertion when operating the algorithm. The scheduling algorithms were coded in C++ and ran on an Intel Core Due 2GHz processor. The pseudo code of the algorithm is as follows:

Insertion Algorithm
Step 0. Set i = 0.
Step 1. While there still have unassigned trips do:

- (a) For each depot, generate one empty route from it and.
- (b) Choose first trip in the unassigned list.
- (c) Check all feasible insertions where the consequence constraints, time window constraints, and capacity constraints are not violated.
- (d) If there is more than one feasible insertions, select one insertion that minimizes the additional travel distance for the existing route and
- (e) Update the schedule of inserted route and delete trips from unassigned lists if need.
- (f) If all the unassigned trips has checked and there still has unassigned trips, set i = i+1 then go to Step 1 (a); else stop.

## Zoning Scenarios

Dividing the whole 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, size of predefined service area, and depots' location of the service area. For dial-a-ride services, if one customer's pick-up and drop-off location belong to different zones, the return trip needs to be done by another provider which means customer requires making two different reservations. This type of trips can be defined as "interzonal" trips. For service provider, the interzonal trips will generate empty backhaul which means ineffectiveness. Therefore, in our study the setting of zoning scenarios considers the distribution of pick-up and drop-off locations of customers. By checking the pick-up/drop-off distribution in Figure 2 and 3, we found an extremely high frequency square area. This area has a major medical center where many trips go to/from. It is roughly situated in the gravity center of the demand distribution and also the geography center of the whole service area. Furthermore, after investigating the distributions of the customers to and from this high frequency area, it shows that both distributions are scattered in the whole service area. This square area should not be arranged into any solely zone but suitable to serve as the break center point in order to avoid too many interzonal trips. We will explain the effect of interzonal trips on performance of paratransit systems in the section of analysis and comparison of zoning strategies. Cooperating to the center point, the boundary lines diffuse from this square area. According to the above discipline, three zoning scenarios are introduced: North/South, East/West, and NorthEast/NorthWest/SouthEast/SouthWest (Four Zones). For each zoning scenarios, we need to arrange the customers which lie within the breakpoint square area into different zones. The number of customers to and from the breakpoint square area will be categorized to the zones according to the proportion of demand requests of each zone. Table 1 represents the intrazonal and interzonal percentage for each zone by zoning scenarios. For zoning cases, each zone assumes two depots in the center of its zone. One depot is for vans and the other is for cabs.

Table 1 – Pick-up and drop-off percentage between zones

| | Drop-off | | | |
|---|---|---|---|---|
| Pick-up | NorthWest | NorthEast | SouthWest | SouthEast |
| NorthWest | 60% | 17% | 13% | 10% |
| NorthEast | 18% | 58% | 9% | 15% |
| SouthWest | 9% | 4% | 65% | 22% |
| SouthEast | 9% | 10% | 19% | 62% |
| Pick-up | North | South | East | West |
| North | 76% | 24% | — | — |
| South | 15% | 85% | — | — |
| East | — | — | 74% | 26% |
| West | — | — | 28% | 72% |

# PERFORMANCE ANALYSIS

In this section, we describe the simulation results based on the demand data and zoning strategy mentioned previously. The performance measurements are defined to evaluate the performance of each zoning strategy first. Then, we utilize the statistic technique, which is multiple comparisons, to analysis and compare the alternative zoning strategies.

## Performance Measurements

We investigate the performance of zoning strategies from the productivity and service quality perspectives. For productivity perspectives, the number of vehicles is the most direct indicator to compare the efficiency of alternative strategies for DARP. According to the scheduling algorithm, we insert all requests by minimizing the extra travel distance. We categorize the total travel distance of each assigned vehicle into three parts: vehicle travel miles from and to depot, travel miles with no passenger on board from first pick-up to last drop-off, and travel miles with passenger on board from first pick-up to last drop-off location.

First, the vehicle travel miles from and to depot are known as “deadhead miles”. In practice, the METROLift does not take into account this distance in calculating their revenue miles. Second, the travel miles with no passenger on board within the first pick-up location and the last drop-off location are termed as “empty trip mile” in the analysis. For the operator, the smaller empty trip miles are better because the passenger trips per mile decrease with larger empty trip miles. Third, the travel miles with passengers on board can be calculated by subtracting deadhead miles and empty trip miles from total travel miles.

Some other useful measurements are further investigated. Passenger miles are the summation of travel miles multiply by number of customers on board for each travel segment. For some dial-a-ride systems, the vehicles cannot wait with passengers on board; however, our scheduling algorithm allows vehicles to wait at the pick-up place if vehicles arrive before its requested pick-up time whether there has passengers on board or not. We define the vehicles waiting time at pick-up location as “Idle time”. We also provide the “passenger trips per vehicle revenue hour” because it is important to compare the service effectiveness of each zoning strategy.

Except the performance measurements of productivity perspectives, we analyze the performance measurements of service quality perspectives for zoning strategies. From the service quality viewpoint, the customers’ waiting time and ride time are the major concerns except the fare level. The waiting time is the time difference between requested pick-up time and actual pick-up time. The actual ride time of customers cannot exceed K=2.5 times of direct ride time because of maximum ride time factor (this is adopted in Houston; other cities might have different K).

## Analysis and Comparison of Zoning Strategies

The performance of alternative zoning scenarios is compared through 10 replications by simulation. In order to increase the simulation’s statistical efficiency and validation, this paper applies the variance-reduction technique−synchronize the random number across the different configurations on a particular replication. This procedure can help to obtain greater precision with less simulation replications. For each replication, the customers’ pick-up and drop-off locations and requested pick-up times are generated independently in the whole service area. Then the same batch of customers is categorized into zones according to pick-up locations in each zoning scenario. The all pair-wise confidence intervals were built for some important performance measurements over all strategies. Table 2 shows the average results of 10 replications for each zoning strategy and the unit of time is minute. Here, we use the numbers from 1 to 4 to represent four scenarios: No Zoning (i=1), North/South (i=2), East/West (i=3) and Four zones (i=4). We provide both the total number of measurements and measurements per unit to increase the readability based on different purposes. The following comparisons between zoning strategies are based on the total volume because it provides a more direct way to understand the performance of zoning strategies for service operators.

Table 2 – Measurements of zoning strategies

| | Total vehicles | Total Customers |
|---|---|---|

| Zoning | i | # of vehicles | Empty trip miles | Non-empty trip miles | Total miles | Passerger miles | Idle time | Wait time | Schedule ride time |
|---|---|---|---|---|---|---|---|---|---|
| No_Zoning | 1 | 223 | 16,957 | 47,921 | 64,878 | 78,297 | 12,806 | 78,873 | 191,971 |
| North/South | 2 | 239 | 17,633 | 48,531 | 66,164 | 78,220 | 16,838 | 77,292 | 192,028 |
| East/West | 3 | 241 | 18,586 | 48,522 | 67,108 | 77,981 | 16,209 | 77,438 | 191,496 |
| Four_zones | 4 | 261 | 18,943 | 49,371 | 68,314 | 78,217 | 21,137 | 75,906 | 192,333 |

| | | | Per vehicle | | | | | Per Customers | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Zoning | i | # of vehicles | Empty trip miles | Non-empty trip miles | Total miles | Passerger miles | Idle time | Wait time | Schedule ride time | Passenger trips/ revenue hour |
| No_Zoning | 1 | 223 | 76.04 | 214.89 | 290.93 | 351.11 | 57.42 | 15.77 | 38.39 | 1.73 |
| North/South | 2 | 239 | 73.78 | 203.06 | 276.84 | 327.28 | 70.45 | 15.46 | 38.41 | 1.66 |
| East/West | 3 | 241 | 77.12 | 201.34 | 278.45 | 323.57 | 67.26 | 15.49 | 38.30 | 1.65 |
| Four_zones | 4 | 261 | 72.58 | 189.16 | 261.74 | 299.68 | 80.99 | 15.18 | 38.47 | 1.58 |

It is worthy to mention that, although our simulation has some assumptions to simplify the real case, the number of assigned vehicles obtained from the simulation is very close to the real number provided by METROLift (less than 5% error) for the no-zoning cases (currently adopted in reality). This serves as a validation of our model and its needed assumptions.

From four zones case to no-zoning case, the savings are shown in total number of assigned vehicles, empty trip miles, and idle time. On the contrary, the passenger trips per vehicle revenue hour and waiting time increase form zoning strategy to no-zoning strategy. The passenger miles and customers' schedule ride time almost remain the same in all scenarios.

In order to examine whether the measurements are significantly different among the four zoning strategies, we constructed the all pair-wise confidence intervals for five measurements: number of assigned vehicles, empty trip miles, idle time, passenger trips per vehicle revenue hour, and waiting time. Because there are six paired comparisons among four strategies, we must make each individual interval at level 99.17 percent (1-0.05/6) to achieve 95 percent overall confidence according to the Bonferroni correction. In table 3, 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 4, with $i_1 < i_2$. The numbers with asterisks in table 3 indicate those intervals missing zero, i.e., those pairs of strategies have significantly different number of assigned vehicles.

For the total number of assigned vehicles in Table 3(a), only the number of assigned vehicles for North/South zoning case is not significantly different from the number of assigned vehicles for East/West zoning case. Other paired comparisons do have significant different number of assigned vehicles.

Although the total number of assigned vehicles between North/South and East/West strategy are not significantly different, the empty trip miles between them do have significant difference. In Table 3(b), all pair-wise comparisons are missing zero except the one between

East/West strategy and four zones strategy. It shows that for empty trip miles, the North/South zoning strategy is significantly smaller than the East/West zoning strategy. When intrazonal percentage increases from 61 percent (Four zones strategy) to 73 percent (East/West zoning strategy), the empty trip miles are statistically equal; however, the empty trip miles significantly decrease when intrazonal percentage increase from 73 percent to 80 percent (North/South zoning strategy). For intrazonal percentage, we therefore suggest that there exist a critical value between 73 to 81 percent which can significantly decrease the empty trip miles.

For passenger trips per vehicle revenue hour, Table 3(c) indicates that only the difference between North/South zoning case and East/West zoning case is not significant. Other paired comparisons do have significant difference. The centralized no-zoning strategy has higher service effectiveness than decentralized zoning strategies. The idle time also shows no difference between North/South zoning case and East/West zoning case while all other comparisons are significant difference (Table 3(d)).

From the service quality perspective, the waiting time is desired to be as small as possible. The all pair-wise comparisons for waiting time of zoning strategies are shown in Table 3(e). From the 95 percent overall confidence intervals, we conclude that the "Four Zones" strategy significantly decreases the total passengers waiting time compared with all other strategies. Other comparisons are not significantly different instead. We infer that because the "Four Zones" strategy groups the pick-up points into considerably smaller zones compared to other zoning cases, the scheduling algorithm based on minimization of extra insertion distance will help to reduce the deviation from desired pick-up time. Another possible reason is the increase of the assigned vehicles in four zones strategy also helps to decrease the customer's waiting time.

Table 3 – All pair-wise confidence intervals of measurements

(a) Number of Assigned Vehicles

| Paired-t | | $i_2$: 2 | $i_2$: 3 | $i_2$: 4 |
|---|---|---|---|---|
| $i_1$ | 1 | 15.90 ± 7.06* | 18.20 ± 6.52* | 37.90 ± 6.55* |
| | 2 | | 2.30 ± 4.29 | 22.00 ± 3.98* |
| | 3 | | | 19.70 ± 3.92* |

(b) Empty Trip Miles

| Paired-t | | $i_2$: 2 | $i_2$: 3 | $i_2$: 4 |
|---|---|---|---|---|
| $i_1$ | 1 | 675.60 ± 544.04* | 1628.40 ± 522.45* | 1985.40 ± 382.80* |
| | 2 | | 952.80 ± 521.67* | 1309.80 ± 399.07* |
| | 3 | | | 357.00 ± 536.44 |

(c) Passenger Trips per Vehicle Revenue Hour

| Paired-t | | $i_2$ = 2 | $i_2$ = 3 | $i_2$ = 4 |
|---|---|---|---|---|
| $i_1$ | 1 | -0.07 ± 0.04* | -0.08 ± 0.04* | -0.15 ± 0.04* |
| | 2 | | -0.01 ± 0.02 | -0.08 ± 0.02* |
| | 3 | | | -0.07 ± 0.02* |

(d) Idle Time

| Paired-t | | $i_2$ = 2 | $i_2$ = 3 | $i_2$ = 4 |
|---|---|---|---|---|
| $i_1$ | 1 | 4032.60 ±2698.14* | 3403.00 ± 2748.85* | 8331.40 ±2989.69* |
| | 2 | | -629.60 ± 1187.11 | 4298.80 ± 1392.00* |
| | 3 | | | 4928.40 ±1329.00* |

(e) Waiting Time

| Paired-t | | $i_2$ = 2 | $i_2$ = 3 | $i_2$ = 4 |
|---|---|---|---|---|
| $i_1$ | 1 | -1581.80 ± 1883.87 | -1435.40 ± 1552.23 | -2967.70 ± 1611.57* |
| | 2 | | 146.40 ± 1049.32 | -1385.90 ± 1091.02* |
| | 3 | | | -1532.30 ± 701.61* |

* denotes a significant difference

## CONCLUSIONS

In this paper, we investigated the productivity and service quality of zoning strategies on ADA paratransit systems between centralized and decentralized tactics. Three zoning strategies were developed according to the distribution of pick-up and drop-off locations in Houston, Texas. A simulation model was introduced and this model can be used to other systems with the modification of configuration settings.

Through the simulation and statistical comparisons methods, the effect of zoning strategies on ADA paratransit systems has been analyzed. From the productivity view point, the centralized strategy has smallest total assigned vehicles and empty trip miles. The centralized no-zoning strategy lowers the total empty trip miles, and it helps to increase the passenger trips per vehicle revenue hour. Referring to the service quality, the decentralized zoning strategies decrease the waiting time for customers. The customers' schedule ride time is indifferent between the centralized and decentralized strategies.

Although we utilized the specific context of Houston, the simulation results of the performance measurements trend on zoning strategies are expected to be similar in other context. This is because the addition of the zoning constraints reduces the number of available feasible solutions and can only worsen the overall optimal solution by increasing the number of total assigned vehicles and decreasing passenger trips per vehicle revenue hour compared to the centralized strategy. However, the degree of the worsening effect of the zoning strategies will be dependent on the actual demand distribution and the design of service zone.

This paper has demonstrated the quantification of how productivity and service quality vary with alternative centralized and decentralized zoning strategies. Further study might possibly identify the management cost and benefit structure to evaluate the benefit-cost ratio of zoning strategies.

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