Innovative Operating Strategies for Paratransit Services with Zoning

Wei Lu, Chung-Wei Shen, and Luca Quadrifoglio

Paratransit services constitute a large industry that provides transportation services to disabled and elderly customers across the country. Demand for these services has been growing since the Americans with Disabilities Act (ADA) was signed into law in 1990 and will continue to grow in the foreseeable future. Rather than adopt a centralized operating strategy, some large transit agencies use decentralized zoning for easier management and better overall reliability (i.e., higher percentage of on-time performance). However, this strategy is inefficient, because a service provider's vehicle is not allowed to pick up customers outside its own service zone. This ban hampers ridesharing and increases the empty trip miles driven. To address this issue, the study reported in this paper explored innovative ADA operating strategies that allowed service providers to serve both trips of cross-zonal customers in need of round trip rides. Three innovative policies were proposed. New algorithms were developed to incorporate the proposed strategies into the insertions heuristically. Simulation experiments on the basis of data in Houston, Texas, and Los Angeles, California, were conducted to quantify the performance improvement over current policy. Results showed that, without sacrifices to customer levels of service, the best of the three policies analyzed could significantly reduce the inefficient empty trip miles by up to 25%. As a result, the policy could save up to 6.8% in assigned vehicles and lower the total mileage by 8%; these results implied a significant savings in operating costs with a reasonable level of service quality maintained.

Paratransit services constitute a large industry that provides transportation services to disabled and elderly customers across the nation. Demand for these services has been growing since the Americans with Disabilities Act (ADA) became law in 1990, and no signs indicate a reversal in this trend. More than 30 million paratransit trips a year are requested from the U.S. population. The demand for this type of service has grown 8% annually, and ridership has more than tripled over a 15-year period. Today more than 5,500 services offer paratransit to the elderly and persons with disabilities nationwide. In a city like Houston, Texas, about 5,000 trip requests are made each day and more than double that number are requested in Los Angeles County, California. In parallel, the operating costs have risen even more (12% a year), and increased by six times in the same 15-year time span. Lastly, the ratio between passenger miles and vehicle hours, a major performance indicator commonly used for paratransit services, has shown a steady, undesirable decrease and is half what it was 15 years previously.

Demand-responsive services operate according to varied rules and policies. Maximum service time windows (for pickup and drop-off) may be of different durations (usually between 20 to 40 min) and a maximum ride time in general is guaranteed to riders (usually 1.5 to 2.5 times the hypothetical taxi direct ride time). To ensure easier, smoother, and less costly operations management and more reliable service to customers (i.e., higher percentage of on-time service), a number of transit agencies in the United States, primarily in large cities, have begun to adopt decentralized control strategies as opposed to centralized ones. Rather than consider a whole, large, unique geographical region within which customers are allowed to request their transportation service, the entire service area is divided into "zones." A number of possible zoning strategies have been adopted by transit agencies in the United States. Some systems may refer cross-zonal passengers to taxis or carriers that mostly provide cross-zonal rides. Others may have hybrid operating policies. These operating choices can have a significant impact on overall service performance (*1*). The most common zoning strategies (Figure 1) are as follows:

1. Independently managed zoning. Zones are served and independently operated by different providers. The pickup location of each customer determines the zone and its service provider. Vehicles are, however, allowed to traverse zone boundaries to drop off cross-zonal customers. Los Angeles County, for example, adopted this zoning strategy.
2. Zoning with transfer. Zones are served and operated by different providers. The pickup location of each customer determines the zone and its service provider. Cross-zonal customers need to switch vehicles at specific transfer locations. However, to do so requires coordination and synchronization between providers, to ensure transfer customers an acceptably short wait time. Boston, Massachusetts, San Diego, California, Chicago, Illinois, and the Twin Cities in Minnesota, for example, adopted this operating strategy.

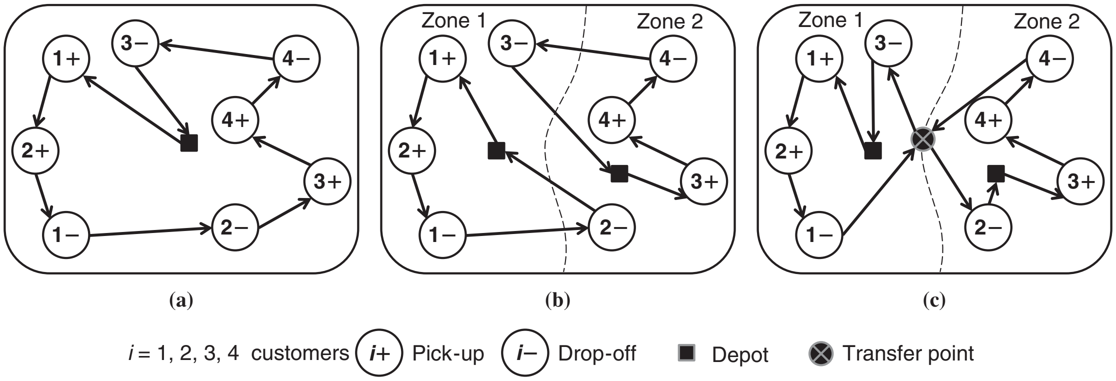
Smaller and independent zones are easier and less costly to manage than others. They ensure better on-time performance to passengers, and in general they lead to higher job satisfaction by call center personnel and drivers, who are more likely to be assigned to a limited and familiar driving range than in another kind of system. However, this apparently simplifying strategy comes at a price in terms of operating costs, level of service, or both. Demand-responsive services such as these rely heavily on efficient ridesharing to reduce their cost. A major part of the operating costs of these services is incurred by empty trip miles (i.e., miles driven by the vehicle with no customer on board).

When an independently managed zoning operating strategy is adopted, cross-zonal customers need to be dropped off outside their pickup zone. The service provider's vehicle brings the customers to

---

W. Lu, Room 601-D, and L. Quadrifoglio, Room 301-I, CE/TTI Building, Zachry Department of Civil Engineering, Texas A&M University, 3136 TAMU, College Station, TX 77843-3136. C.-W. Shen, Department of Transportation Science, National Taiwan Ocean University, Technology Building, Room 730, Keelung, 20224, Taiwan. Corresponding author: L. Quadrifoglio, quadrifo@tamu.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2469, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 120–128.
DOI: 10.3141/2469-13



(a) (b) (c)

FIGURE 1 Most common paratransit operating strategies.

their destination but is not allowed to pick them up outside of its own service zone. This zoning strategy clearly prohibits some ridesharing and increases the number of empty trip miles driven, which eventually increases the costs of these services considerably. Cross-zonal customer transit requests can be as high as 30% of the daily demand (Los Angeles County). Further, customers whose pickup and drop-off locations are in different zones must rely on two providers for their round trip, with potentially different booking rules and potentially reduced level of service.

The original centralized strategy (still used in cities like Houston, for example) may have several drawbacks, primarily linked to potentially extended geographical size, yet it is the one that most minimizes operating costs and maximizes level of service. The study reported in this paper proposed the use of zoning solutions to overcome the drawbacks of the currently adopted strategy to maintain operating efficiency and a level of service close to that of the centralized strategy.

LITERATURE REVIEW

In this section, a review is presented of the paratransit scheduling problem, more formally known as the dial-a-ride problem (DARP), which is a special kind of vehicle routing problem. The DARP is one that involves the determination of routes and schedules for vehicles to transport travelers from a pickup point to a drop-off point. The problem has been studied extensively over the past few decades, and researchers have focused mainly on the development of an optimization algorithm because of its combinatorial characteristic. Cordeau and Laporte (*2*) and Berbeglia et al. (*3*) provided the comprehensive classification of modeling and the solution method of DARP. Exact approaches, classic heuristics, and metaheuristics are the three major solving technique domains. Researchers also have considered the dynamic DARP, because unexpected events might disrupt the original schedule. Coslovich et al. tackled the dynamic DARP with unexpected customers, and a two-phase insertion algorithm was developed (*4*).

The performance of dial-a-ride services has received increasing attention. McKnight and Pagano found that the quality of special transportation services for elderly and disabled persons tended to increase as the ridership of the provider increased (*5*). Wilson and Hendrickson reviewed the earlier models that predicted the performance of flexible routed transportation systems (*6*). Paquette et al. suggested that further study was needed to better understand the trade-offs among costs and the quality of different operational policies in dial-a-ride systems (*7*).

Coordination of paratransit services increases not only efficiency and productivity but mobility. An evaluation by Burkhardt indicated that about $700 million per year could be generated to transportation providers in the United States after implementation of successful coordination (*8*). Consolidation of interzonal transportation would be likely to reduce trip costs through a higher rate of ridesharing and a lower rate of empty return miles (*9*). Häll et al. introduced the integrated DARP and proposed that some part of a journey might be carried out by a fixed-route service (*10*). Aldaihani and Dessouky proposed a system that integrated fixed routes within a pickup and delivery problem (*11*). An integer programming formulation of the cooperative pickup and delivery problem with time windows was analyzed by Lin, who concluded that the cooperative strategy might achieve savings in total cost and vehicles used (*12*). It was shown that zoning with transfers for paratransit services provided noticeable improvement in efficiency, while a minimum service standard was maintained (*13*).

The analytical and simulation methods are two applicable tools to evaluate the performance of practical management strategies. The approximate analytical model of a demand-responsive transportation system was first proposed by Daganzo (*14*). It did not consider the explicit time window for each customer. Fu provided an analytic model to predict the fleet size and quality of service measurements (*15*). Li and Quadrifoglio developed an analytic model to determine the optimal service zone for feeder transit service (*16*). However, they assumed that trip origins and destinations were distributed uniformly over the service area. The analytic model is a powerful tool for parametric analysis of the system. However, it is extremely difficult to build a closed-form expression of the problem.

Simulation methods have been applied to the evaluation of performance measurements on dial-a-ride systems (*10*). Simulation also has been used to compare the performance of dial-a-ride systems and fixed-route bus systems (*17*). With the use of paratransit data in Houston, Shen and Quadrifoglio performed a simulation that showed the adoption of a decentralized strategy increased the total vehicles used and the empty backhaul miles driven, compared with a centralized strategy (*18*).

Paratransit services operate not only in the United States but all over the world. The literature indicates that in different places in the world these services all face similar challenges, such as regulation, integration, and the central problem addressed here, namely operating cost (*19, 20*). The literature also shows that researchers have looked at the cost problem from a variety of perspectives, but thus far none has investigated the innovative scheduling policies proposed in this paper.

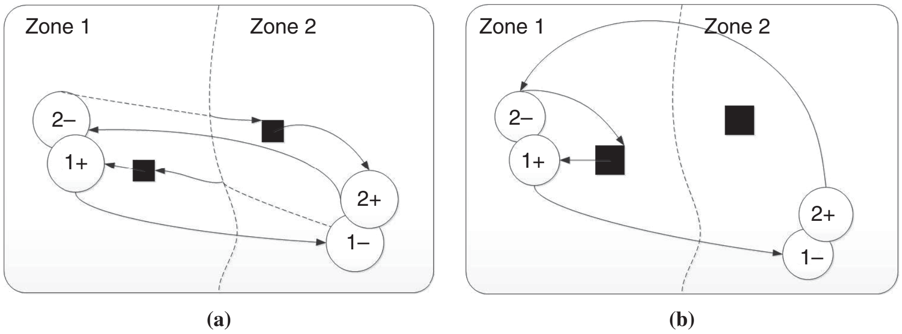


FIGURE 2 Key difference between operating strategies.

PROPOSED OPERATING STRATEGY

The innovative operating strategies for paratransit services proposed here have some similarity with the independently managed zoning operating strategy already described, with a fundamental difference: providers that serve a given zone can pick up out-of-zone passengers in need of a return trip to that zone. This means that cross-zonal passengers can use the services of the provider that operates in the zone of their pickup location, and be dropped off out of their original zone (which already is currently done). However, these customers may take their return trip with the same provider and not be forced to use the provider that operates in their destination zone. The concept is illustrated in Figure 2.

A cross-zonal customer needs to be transported from his or her origin 1+ to the destination 1– (in another zone) and later needs a return trip from Zone 2+ (same location of 1–) to 2– (same location of 1+). In Figure 2*a,* the independently managed zoning operating strategy would have the first vehicle (which belongs to the left-side Zone 1) pick the customer up at 1+ and drop him or her off at 1– (likely along with other ridesharing customers, although not shown here). The dashed portion of the arrow from 1– to the depot in Zone 1 has a high likelihood to correspond to an empty trip drive, because this vehicle is not allowed to pick up other customers in the right-side Zone 2. Similarly, the return trip of the same customer occurs in a vehicle that belongs to Zone 2, which makes a similar trip. The dashed portion of the arrow that goes from 2– to the depot in Zone 2 represents the segment of the trip that is highly likely to be empty.

The newly proposed strategy (Figure 2*b*) would allow the first vehicle to pick up other customers that were returning to their original left-side Zone 1 in the portion of the trip from 1– to the depot in Zone 1. Similarly, the customer could be served by a left-side zone vehicle for the return trip. The portion of the trip from the depot in Zone 1 to Zone 2 or other zones need not be empty, because other cross-zonal customers from Zone 1 could be dropped off in Zone 2. Most customers (not only cross-zonal ones) are in need of daily round trips, as opposed to one-way trips. Therefore, modification of a rule that affects nearly all cross-zonal customers could have a great impact on the performance measures.

ALGORITHM DESCRIPTION

In this section, the algorithms are introduced to distribute the customers into different zones according to the corresponding policies proposed. The simulation model also could serve customers in a dynamic scenario, in which booking requests were made not only before the service date but also during the service date. The insertion algorithm used to route and schedule the customers also is described. A basic, two-zone model is described first to illustrate the logic of the proposed policies. The model is then extended to four zones, and it is shown how they can be applied to actual cases in Houston and Los Angeles.

Basic Two-Zone Model

Three new policies were proposed to distribute interzonal customers into different operation zones. They are described here, along with the old policy, still widely used by operating agencies. The logic behind the redistribution of customer trips was to construct more efficient routes through a reduction in "deadhead" mileage as much as possible.

1. Old policy. Each trip was assigned to the zone according to its pickup location (e.g., for an interzonal customer, the first trip was operated by Zone A, and the return trip was operated by Zone B) as shown in Figure 3.

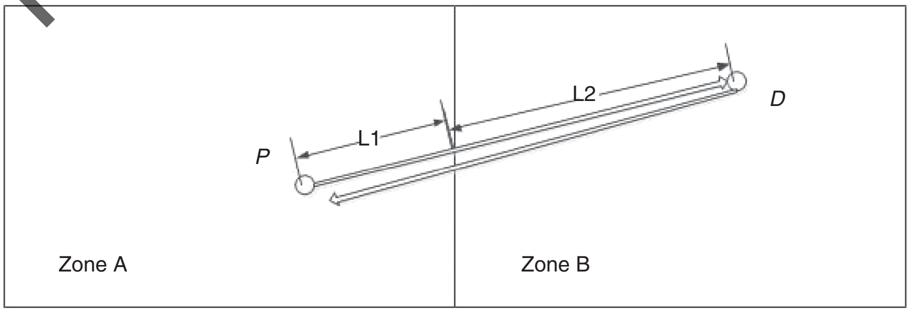


FIGURE 3 Two-zone customer distribution (P = pickup location; D = drop-off location).

2. New policy. Both trips were operated by the zone generated by the customer. In the case shown in Figure 3, the operator was Zone A for both trips under the new policy.
3. Alternative 1. The two alternative policies distribute the customers according to their proximity to the border of the two zones, and assign a customer's return trip to one of the two zones to which he or she more naturally belongs. As is shown in Figure 3, if the distance between the pickup location and the border (L1) is less than the distance between the drop-off location and the border (L2), the return trip is assigned to Zone B, which intuitively is the more efficient carrier of the customer than Zone A. The operator of the first trip remains Zone A, because the pickup location was generated there.
4. Alternative 2. This policy is the most flexible one of all. It is similar to Alternative Policy 1, with a slight difference: the initial trip and the return trip are assigned to the zone to which the customer naturally belongs (i.e., the zone that has a larger portion of either of the trips in it), as described in Alternative Policy 1. In Figure 3, both trips are assigned to Zone B.

Four-Zone Model

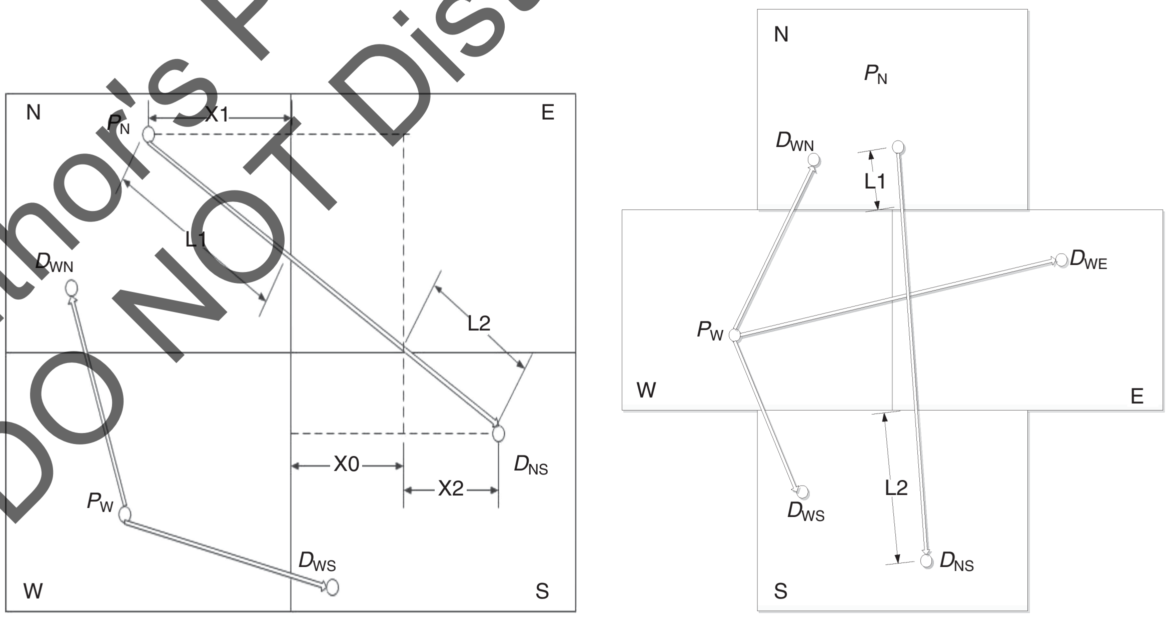
The two-zone customer distribution model was extended to the four-zone model. The whole service area was divided into four zones, namely the northern region (N), the eastern region (E), the western region (W) and the southern region (S), as is shown in Figure 4. For zones that have common borders (e.g., N and W, W and E, W and S), the customer distribution follows the same logic as in the two-zone model for the four policies. Distribution for the zones not close to each other (i.e., N and S), is tricky, as the following description of the four policies shows.

The old policy and the new policy in a four-zone model follow a similar manner as in the two-zone model. For Alternative Policy 1, customers are still assigned according to their proximity to the border of the two zones (pickup zone and drop-off zone). In the four-zone case, the geometry indicates that L1 > L2 if and only if X1 > X2 [i.e., (X1 + X0 > X2 + X0)] (Figure 4). This geometric relationship provides a simplified way to compare L1 and L2. Alternative Policy 2 extends naturally from the two-zone model. It remains the most flexible policy of the four.

Pseudocode

The algorithm for trip distribution and insertion is summarized as follows. This algorithm incorporates dynamic insertion.

```
Step 0. (a) Generate customers according to the prespecified distribution and (b) distribute the trips of each customer to different zones according to different policies;
Step 1. For each of the zones, set $i = 0$ ($i$ represents the number of vehicles used), while for unassigned trips not equal to 0: (a) for each depot, generate one empty route from it, (b) choose first trip in the unassigned trip list, (c) check all possible insertions for feasibility, (d) if more than one feasible insertion is found, select the one that minimizes the additional travel distance for the existing route, and (e) update the schedule of the inserted route and delete the trip that is just inserted from the unassigned trip list;
Step 2. If a feasible insertion cannot be found, set $i = i + 1$ and then go to Step 1a;
Step 3. Record the basic schedule after all the static requests have been inserted;
Step 4. Within the service time period: (a) generate dynamic customers with predefined probability and (b) distribute the trips of each dynamic customer to different zones according to different policies;
Step 5. For each of the zones ($j$ represents the number of existing routes) while dynamic trips are not serviced: (a) choose the first trip in the unassigned trip list, (b) check all the possible insertions in each of the existing (or newly generated) routes for feasibility, (c) insert the trip into the first available route, and (d) update the schedule of the inserted route and delete the trip that is just inserted from the unassigned trip list; and
```



(a) (b)

FIGURE 4 Four-zone customer distribution: (*a*) Houston and (*b*) Los Angeles.

Step 6. If none of the existing routes can accommodate the dynamic trip, then generate one empty route, let *j* represent the number of existing routes, then set $j = j + 1$ and go to Step 5*a*.

SIMULATION EXPERIMENTS

The Manhattan (rectilinear) distance was used to calculate the travel distance between different locations. For example, $A(x_1, y_1)$ and $B(x_2, y_2)$ were two points that either were the pickup or the drop-off location, respectively. The travel distance between A and B was calculated as $|x_1 - x_2| + |y_1 - y_2|$. The Manhattan distance commonly is used in urban road networks, which follow a grid pattern. Although it was an approximation, this estimated travel distance was verified to be reasonably close to the actual travel distance in the literature (*1*). In any case, an update of the results is under way, with the use of more accurate, actual network distances. No traffic jams were assumed in the system. As a result, the travel time between two points was only a matter of travel distance and vehicle speed.

Customer Generation

To evaluate the effects of the customer distribution policies, round trips (i.e., the initial trip and the return trip) were generated for each customer. For each trip the following information was gathered: pickup and drop-off locations, requested pickup time, number of passengers, and whether or not a wheelchair-accessible vehicle was needed. The pickup and drop-off locations, and the pickup time, presumably were random but chosen from a distribution of locations and trip start times. The simulation model could handle dynamic requests randomly generated during a simulation. In the simulation model, customers in general were divided into two categories:

1. Static demand. Passengers who booked seats before the service started, typically 1 day before the service date and
2. Dynamic demand. Passengers who booked seats on the day after the service started.

Transit agencies usually require a certain amount of advance notice, ahead of the requested pickup time. In this study, this parameter was set to 30 min. For the whole time horizon of the paratransit service, dynamic demand occurred with a predefined probability. The algorithm ran the static insertion first to get a basic schedule and then to deal with dynamic requests, which would require the fleets to be rescheduled.

Parameters

The following system parameters were used in the simulation:

- Vehicle travel speed: 25 mph;
- Service time of each customer: 1 min;
- Time windows: 20 min, minus and plus the requested time;
- Maximum ride time factor: 2.5 (i.e., ratio of actual ride time divided by direct ride time, mandated by law);
- Unlimited number of vehicles available;
- Van capacity: four wheelchairs or 10 ambulatory persons;
- Cab capacity: one wheelchair or four ambulatory persons;
- Dynamic demand generation probability: 0.05. (i.e., 5% of total requests are dynamic);
- Service time period: 24 h (i.e., paratransit service responds to customer demand 24 h a day); and
- Minimum advance request time: 30 min; customers must book trip at least 30 min before pickup time.

Demand Data Analysis

The actual demand data from Houston and Los Angeles were used to generate the test samples. The data were provided by METROLift in Houston and by Access Services, Inc., in Los Angeles County. On average weekdays, METROLift and Access Services, Inc., provided about 5,000 trips. METROLift used a no-zone strategy. Four hypothetical zones were generated according to the rules developed by Shen and Quadrifoglio (*18*). For Access Services, Inc., six zones covered the service area. Only the northern, southern, eastern, and west-central zones were considered in the study, because demand in the Santa Clarita and Antelope Valley Zones was less than 5% of the total daily average demand. There were 41,241 trips within a 5-day period. Table 1 shows the daily average number of trips for each zone.

To illustrate the distribution of Los Angeles County, the pickup and drop-off distributions for the northern zone are shown in Figure 5. These distributions were used to generate the input data for the simulation model. Each square in the figures represents a 1 by 1 mile area. The number counted in each square area (N) represents the number of trips that end in each area. Other zones had their own distinct distributions of pickup and drop-off locations.

In Los Angeles County, the service area was divided by six zones. Each zone had its designated service provider. Providers could pick up only customers whose trip origins were located within their service area. The drop-off locations had no geographical restrictions. Figure 5*a* shows that the pickup locations were all within the northern zone. Figure 5*b* shows that the drop-off locations were mainly in the northern zone, although some drop-off locations were outside that zone. The pickup time in the northern zone is shown in Figure 6.

Results Analysis

The performance of the policies was investigated from the perspectives of cost and productivity and service quality. In terms of cost and productivity, the number of vehicles and the total mileage were the most straightforward indicators to use to compare the efficiency

TABLE 1 Daily Average Trips, Six Zones in Los Angeles County

Zone	Number of Trips
Northern	1,813
Southern	2,780
Eastern	2,253
West–central	1,402
Santa Clarita	144
Antelope Valley	273

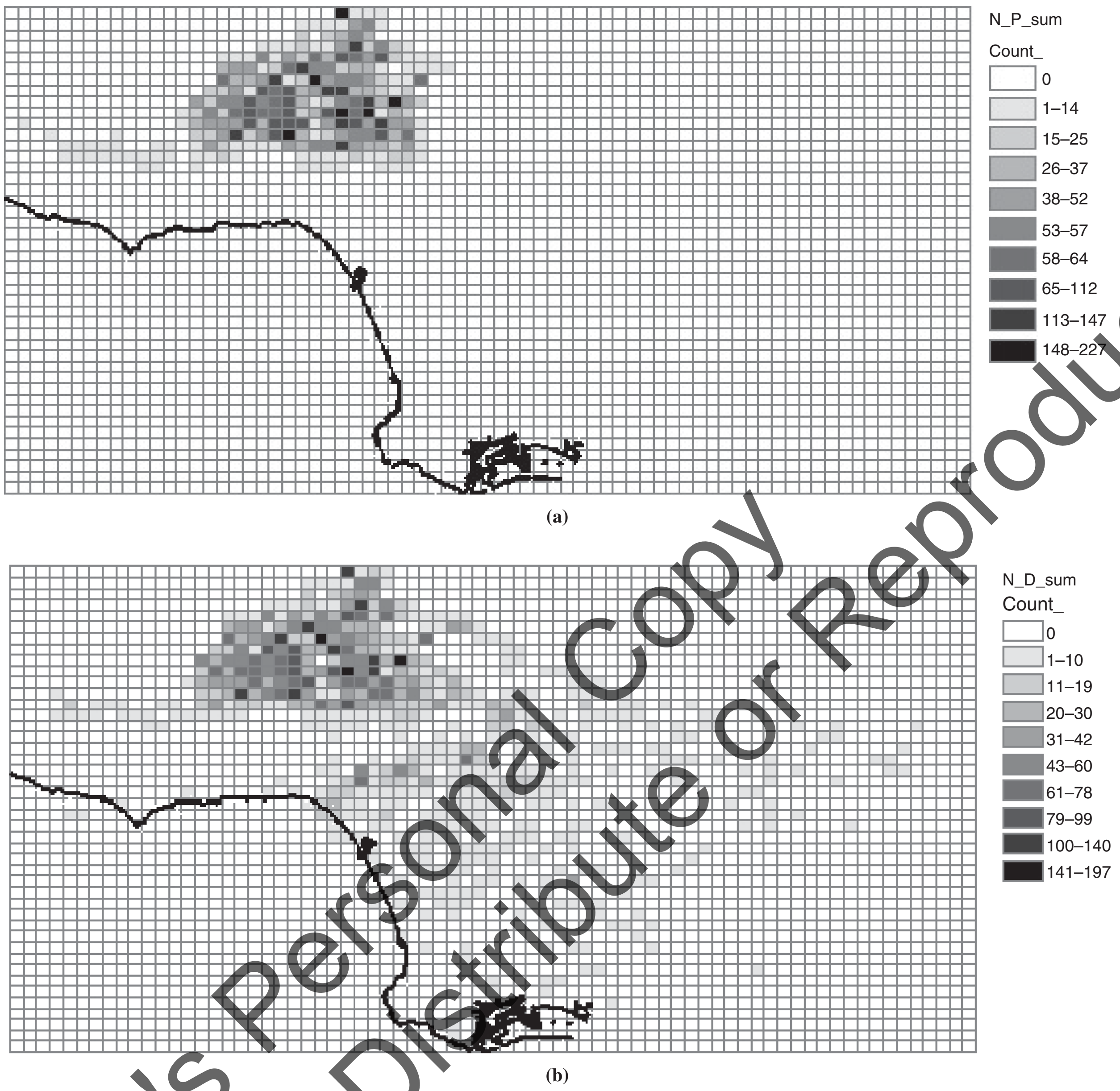


FIGURE 5 Distribution of (*a*) pickup and (*b*) drop-off location from northern zone.

of different policies. The total travel mileage of each vehicle was further divided into two parts, namely the travel miles with no passengers on board (empty trip miles), and travel miles with passengers on board (nonempty trip miles). Because it was possible that vehicles would arrive at the pickup locations earlier than requested, the vehicle wait time at a pickup location was defined as "idle time."

With respect to service quality, customer wait time and ride time are two of the major concerns. Wait time was defined as the time difference between requested pickup time and actual pickup time. A mandatory constraint by law was that the actual ride time could not exceed $K = 2.5$ times of direct ride time.

The performance of alternative customer assignment policies was compared on the basis of data from Houston and Los Angeles. Ten simulation replications were run for each case. The results are summarized in Table 2.

Of the four policies, Alternative 2 had the best performance in terms of the number of vehicles used, total mileage, and empty trip miles. In Houston, Alternative 2 led to the use of 6.8% fewer vehicles and 8% less mileage than under the current policy (i.e., old policy). In Los Angeles, Alternative 2 led to the use of 3.6% fewer vehicles and 5.2% less mileage than under the old policy. These results implied a significant cost reduction once the proposed policy was implemented. A careful look at the results revealed that the reduction of total mileage stemmed from a reduction in empty trip miles (deadhead miles). A significant 25% drop in empty trip miles occurred when Alternative 2 was applied in the case of Houston. The drop was a little lower at 18% in Los Angeles, possibly because of the lower interzonal trip rate there. The significant improvement in the total mileage did not lead to a sacrifice in service quality, which was evident in the customer wait time.

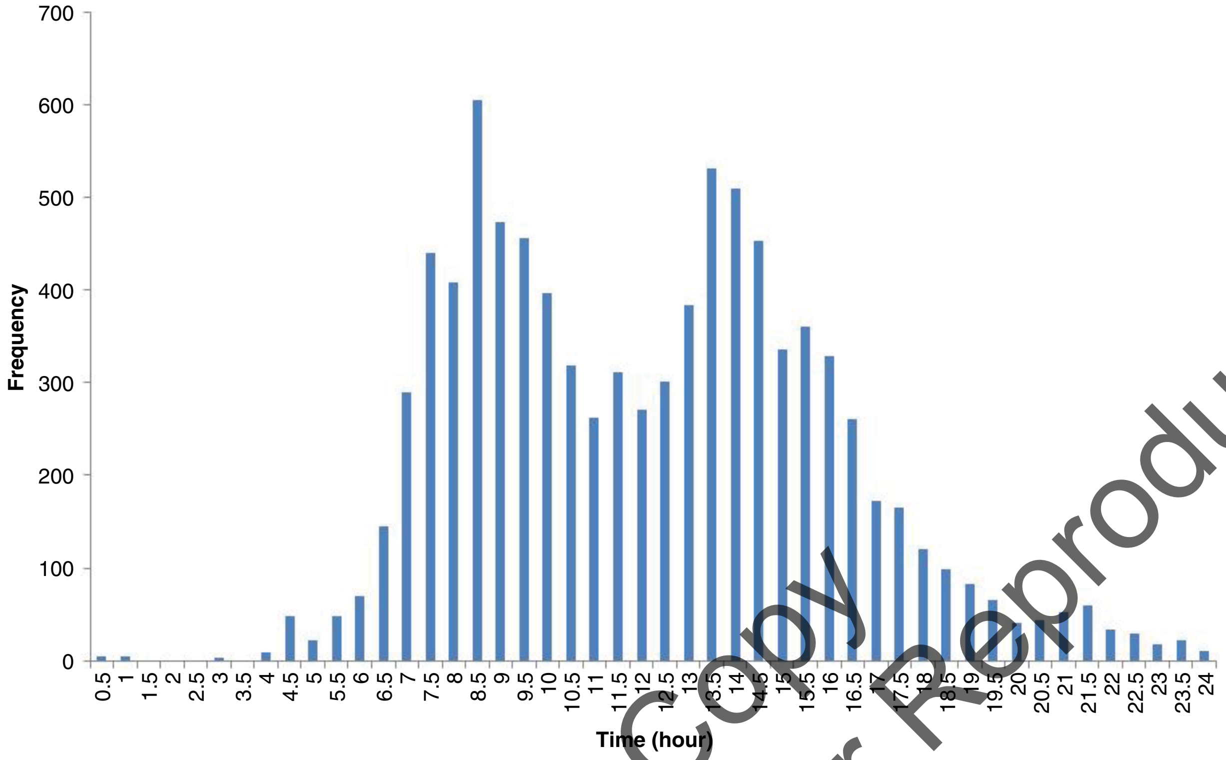


FIGURE 6 Distribution of pickup times for northern zone.

Statistical tests were conducted to further compare the performance of the four policies. Pairwise confidence intervals were constructed for the three variables most related to operation cost (i.e., number of assigned vehicles, empty trip miles, total mileage). The numbers in Table 3 represent the 95% confidence intervals of differences for each performance measurement. Those intervals with asterisks beside the bracket indicate that zero is not in the interval, which means in the corresponding pair of strategies there is a statistically significant difference in the measurement.

In Houston and Los Angeles, the findings on performance measures were similar. Of all of the performance measures, the most flexible policy, Alternative 2, was superior to the other three policies. Again, it was this policy's flexibility that reduced the deadhead miles and promoted ridesharing, which in turn lowered the total mileage and the number of vehicles needed to fulfill requests. The performance of the new policy and Alternative 1 seemed quite close, because neither showed a statistical edge over the other for almost all of the measurements in the two cases except for the total mileage in Los Angeles, where Alt-1 was a better mileage saver than the new policy.

CONCLUSIONS

In this paper, innovative operating strategies for ADA paratransit services are proposed. Specifically, three new policies are proposed to allow providers that serve a given zone to pick up out-of-zone

TABLE 2 Performance of Policies

	Total Vehicles					
Policy	Number of Vehicles	Empty Trip Miles	Nonempty Trip Miles	Total Mileage	Idle Time (min)	Total Customers Wait Time (min)
Houston						
Old	232.5	27,140.3	48,863.1	76,003.4	9,720.9	74,795.2
New	227.1	22,444.7	50,759.6	73,204.3	11,877.2	74,707.6
Alternative 1	225.2	22,629.4	49,823.7	72,453.1	9,836.7	75,135
Alternative 2	216.8	20,419.1	49,491.2	69,910.3	10,514.4	74,582.4
Los Angeles						
Old	429.2	44,160.0	96,509.5	140,669.5	11,325.2	125,309.4
New	417	37,059.4	98,819.4	135,878.8	11,139.8	128,764.9
Alternative 1	417.2	36,975.7	97,427.8	134,403.6	11,175.6	127,105.5
Alternative 2	413.8	36,132.7	97,183.3	133,316.0	10,890.0	127,150.4

TABLE 3 Pairwise Confidence Intervals of Measurements

Paired-*t*	New	Alternative 1	Alternative 2
Houston Data: Number of Assigned Vehicles			
Old	[0.70, 10.10][a]	[2.65, 11.95][a]	[10.85, 20.55][a]
New		[–2.42, 6.22]	[5.76, 14.84][a]
Alternative 1			[3.91, 12.89][a]
Houston Data: Empty Trip Miles			
Old	[4,238.27, 5,152.81][a]	[4,083.04, 4,938.71][a]	[6,312.31, 7,129.95][a]
New		[–626.44, 257.11]	[1,601.85, 2,449.34][a]
Alternative 1			[1,820.10, 2,600.42][a]
Houston Data: Total Mileage			
Old	[1,781.16, 3,817.07][a]	[2,597.12, 4,503.46][a]	[5,202.47, 6,983.75][a]
New		[–212.59, 1,714.94]	[2,391.59, 4,196.40][a]
Alternative 1			[1,720.33, 3,365.30][a]
Los Angeles Data: Number of Assigned Vehicles			
Old	[6.18, 18.22][a]	[6.77, 17.23][a]	[9.50, 21.30][a]
New		[–5.66, 5.26]	[1.89, 6.29][a]
Alternative 1			[1.92, 6.72][a]
Los Angeles Data: Empty Trip Miles			
Old	[6,479.35, 7,721.92][a]	[6,414.70, 7,953.86][a]	[7,348.92, 8,705.67][a]
New		[–538.68, 705.96]	[443.64, 1,409.67][a]
Alternative 1			[163.74, 1,522.29][a]
Los Angeles Data: Total Mileage			
Old	[3,537.85, 6,043.51][a]	[4,968.63, 7,563.22][a]	[6,036.37, 8,670.68][a]
New		[310.70, 2,639.79][a]	[1,374.85, 3,750.84][a]
Alternative 1			[248.56, 2,023.75][a]

[a] Significant difference.

passengers in need of a return trip to that zone. Of these new polices, two of them base the customer assignment decisions on the relative distance between pickup and drop-off locations. In the study presented here, new algorithms were developed that incorporated the proposed strategies into the insertion heuristic, and simulation models were developed to replicate the paratransit operations. To evaluate and analyze the proposed operating strategies, computational experiments were conducted with the use of the simulation model that was built on the basis of Houston and Los Angeles data. Experimental results showed that the proposed strategies led to the use of fewer vehicles (up to 6.8% reduction) and less total mileage (up to 8% reduction) than the current policy. Meanwhile, the idle time and wait time for the proposed policies were about the same level as those times under the current policy. The results implied that application of the operating strategies proposed could reduce the operation costs of paratransit services significantly without a sacrifice in the level of service. Paired-*t* tests confirmed these inferences statistically. Because these proposed policies are easy to implement, they should provide insight to ADA transit agencies that are working hard to save operations cost. The implementation of Alternative 2 might cause a reassignment in cross-zonal customers to different providers under the new policy proposed. The new policies would change the share of customers for each provider, and the earnings would need to be transferred between providers accordingly. This situation poses a major obstacle to the implementation of Alternative 2. Future research might include the conduct of experiments in other cities.

REFERENCES

1. Quadrifoglio, L., M. M. Dessouky, and F. Ordóñez. Simulation Study of Demand Responsive Transit System Design. *Transportation Research Part A: Policy and Practice,* Vol. 42, No. 4, 2008, pp. 718–737.
2. Cordeau, J.-F., and G. Laporte. The Dial-a-Ride Problem: Models and Algorithms. *Annals of Operations Research,* Vol. 153, No. 1, 2007, pp. 29–46.
3. Berbeglia, G., J.-F. Cordeau, I. Gribkovskaia, and G. Laporte. Static Pickup and Delivery Problems: A Classification Scheme and Survey. *TOP,* Vol. 15, No. 1, 2007, pp. 1–31.
4. Coslovich, L., R. Pesenti, and W. Ukovich. A Two-Phase Insertion Technique of Unexpected Customers for a Dynamic Dial-a-Ride Problem. *European Journal of Operational Research,* Vol. 175, No. 3, 2006, pp. 1605–1615.
5. McKnight, C. E., and A. M. Pagano. Effect of Size and Type of Organization on Quality of Special Transportation Services. In *Transportation Research Record 973,* TRB, National Research Council, Washington, D.C., 1984, pp. 39–44.
6. Wilson, N. H. M., and C. Hendrickson. Performance Models of Flexibly Routed Transportation Services. *Transportation Research Part B: Methodological,* Vol. 14, No. 1–2, 1980, pp. 67–78.
7. Paquette, J., J.-F. Cordeau, and G. Laporte. Survey: Quality of Service in Dial-a-Ride Operations. *Computers and Industrial Engineering,* Vol. 56, No. 4, 2009, pp. 1721–1734.
8. Burkhardt, J. E. Economic Benefits of Coordinating Human Service Transportation and Transit Services. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1887,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 55–61.
9. Cook, T. J., J. J. Lawrie, and A. J. Henry. From Rural Single-County to Multicounty Regional Transit Systems: Benefits of Consolidation.

In *Transportation Research Record: Journal of the Transportation Research Board, No. 1841,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 54–61.

10. Häll, C., H. Andersson, J.T. Lundgren, and P. Värbrand. The Integrated Dial-a-Ride Problem. *Public Transport,* Vol. 1, No. 1, 2009, pp. 39–54.
11. Aldaihani, M., and M.M. Dessouky. Hybrid Scheduling Methods for Paratransit Operations. *Computers and Industrial Engineering,* Vol. 45, No. 1, 2003, pp. 75–96.
12. Lin, C.K.Y. Cooperative Strategy for a Vehicle Routing Problem with Pickup and Delivery Time Windows. *Computers and Industrial Engineering,* Vol. 55, No. 4, 2008, pp. 766–782.
13. Shen, C.-W., and L. Quadrifoglio. Evaluation of Zoning Design with Transfers for Paratransit Services. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2277,* Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 82–89.
14. Daganzo, C.F. Approximate Analytic Model of Many-to-Many Demand Responsive Transportation Systems. *Transportation Research,* Vol. 12, No. 5, 1978, pp. 325–333.
15. Fu, L. Analytical Model for Paratransit Capacity and Quality-of-Service Analysis. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1841,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 81–89.
16. Li, X., and L. Quadrifoglio. Optimal Zone Design for Feeder Transit Services. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2111,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 100–108.
17. Shinoda, K., I. Noda, M. Ohta, Y. Kumada, and H. Nakashima. Is Dial-a-Ride Bus Reasonable in Large Scale Towns? Evaluation of Usability of Dial-a-Ride Systems by Simulation. In *Multi-Agent for Mass User Support* (K. Kurumatani, S.-H. Chen, and A. Ohuchi, eds.), Springer, Berlin and Heidelberg, Germany, 2004, pp. 105–119.
18. Shen, C., and L. Quadrifoglio. Evaluating Centralized Versus Decentralized Zoning Strategies for Metropolitan ADA Paratransit Services. *Journal of Transportation Engineering,* Vol. 139, No. 5, 2013, pp. 524–532.
19. Lave, R., and R. Mathias. State of the Art of Paratransit. *Transportation in the New Millennium.* TRB, National Research Council, Washington, D.C., 2000, pp. 1–7.
20. Schalekamp, H., D. Mfinanga, P. Wilkinson, and R. Behrens. International Review of Paratransit Regulation and Integration Experiences: Lessons for Public Transport System Rationalisation and Improvement in African Cities. *Proc., 4th International Conference on Future Urban Transport: Access and Mobility for the Cities of Tomorrow,* Gothenburg, Sweden, 2009.

The Accessible Transportation and Mobility Committee peer-reviewed this paper.