AATA AOS EVALATION
Transfer and On-Time Performance Study: Before and After AOS Implementation

October 1996 – May 1999

Abstract

This study develops, using data before AOS in 1996 and 1997 and after AOS in 1998 and 1999, implementation data on AATA's on-time performance and vehicle-to-vehicle timing of transfers at four major transfer location. Systematic evaluation of on-time performance indicated that AATA improved on-time departures. The opposite was observed regarding on-time arrivals. Bus-to-bus transfer times within AATA system tended to have no significant change from 1997 to 1999. Some improvement was noted when on time performance and transfer times were analyzed jointly.

Overview of AATA's Advanced Operating System

In 1997, the Ann Arbor (Michigan) Transportation Authority began deploying advanced public transportation systems (APTS) technologies in its fixed route and paratransit operations. The project's concept is the integration of a range of such technologies into a comprehensive system, termed the "Advanced Operating System" (AOS) to "smart buses", "smart travelers," and a "smart operation center" to benefit from timely and coordinated information on critical aspects of transit operation and maintenance. The prime contractor for the project was Rockwell, and providers of other integrated subsystems included: Digital Recorders Research of Triangle Park, North Carolina; Trapeze Software of Mississauga, Ontario; Prima Facie of King of Prussia, Pennsylvania; REI of Omaha, Nebraska; Red Pines Instruments of Denbigh, Ontario; and Multisystems, Inc. Cambridge, Massachusetts. Evaluator for the project was a team from the Urban and Regional Planning Program of the College of Architecture and Urban Planning, University of Michigan.

"The Smart Bus"

Central to the system is the deployment of automatic vehicle location (AVL) technology in order to provide continuous real time data on the location of transit vehicles. Each bus determines its location using global positioning satellite (GPS) technology; differential corrections are broadcast to the vehicles so they can calculate their locations within one or two meters. A Mobile Data Terminal (MDT) in each vehicle stores complete route schedules on an insertable memory card. The GPS system provides accurate time to the vehicles. Buses compare scheduled times and locations with actual locations to determine their schedule adherence. If a bus determines that it is running late, the driver is advised, and if necessary, the onboard computer notifies the Operation Center. The AVL also triggers an outside destination announcement and the internal next-stop signs and announcement. It also integrates location data with fare collection, electronic controlled engine data and ultimately, automated passenger counters,

The AATA network makes use of extensive timed transfers at four major transfer points. When a bus is running behind schedule, AOS enables digital bus-to-bus communications to improve the transfer between buses; the driver of the first bus can send a digital request (that includes the bus' location) to hold the second bus to ensure that a passenger will not miss a desired transfer.

Video surveillance is provided on board vehicles for security, as well as to help resolve any claims that may arise.

On the paratransit side, drivers receive their entire schedules and mark their arrival and departure times with date, time and location information as well as all the features above.

"The Smart Operation Center"

The AATA Operation Center collects and acts upon information provided by the transit vehicle and drivers. Each AATA bus has an 800 MHZ radio and onboard computer. The system minimizes voice transmissions by providing data messages that summarize vehicle status, operating condition, and location. Out-of-tolerance engine conditions such as oil pressure and temperature are reported in real time to the onboard computer, the Operations Center and the Maintenance Department.

Through the use of real time displays of vehicle location and schedule adherence reporting, dispatchers working at the Operation Center can manage the system and assist drivers by inserting overload vehicles in the system or recommending re-routing options. All changes to the route and schedule database are noted and automatically updated.

Onboard the vehicle, the driver has an onboard emergency system. When encountering a life-threatening situation, the driver covertly alerts the dispatcher, who immediately notes the vehicle's location on the system's center map and dials the appropriate agency. The system also allows the dispatcher to open up a central public address system inside the vehicle to monitor the situation. The system also supports responsive reporting of routine, non-life-threatening emergencies, such as passenger inconvenience.

For paratransit vehicles, reservations, scheduling, flexible integration with fixed-route, and after-trip information utilize Trapeze software. All of these elements are based on real-time information generated with the Rockwell TransitMasterTM software.

"The Smart Traveler"

The "smart travler" a person informed about his or her transportation options, as well as about current conditions relative to transit use. Inside the bus, next stop announcements, date, time and route are given to passengers utilizing the onboard public address system and a two line LED display. The driver also has the ability to trigger timed and periodic announcements for special events that can be made to support the system. Outside the bus, the current route information is announced to waiting passengers, and the destination signs are changed based upon the location. Kiosks provide real-time bus location information at selected locations; ultimately this information will be provided to travelers at their home or workplace via telephone, cable television or internet.

Transferring and Schedule Adherence in the AATA System

A major beneficial outcome sought from the "Advanced Operating System" (AOS) deployed by the Ann Arbor Transportation Authority (AATA) is the improvement of the bus-to-bus passenger transfer. The Ann Arbor system has been developed around timed transfers at a number of transfer points within the service area, including the Blake Transit Center in downtown Ann Arbor, the Ypsilanti Transit Center, Arborland Mall, University Hospital, and others. Effective transfers are critical to travelers' mobility throughout the system and drivers and dispatchers have been attempting to ensure smooth transferring as much as possible.

Some impediments to effective timing of transfers remain, however, and it is hoped that the AOS will aid in partly overcoming these. The key element behind effective timing of transfers in any transit system is schedule adherence. Thus to the extent that AOS improves schedule adherence throughout the AATA network, e.g. through provision of pacing information for drivers, locational information for dispatchers, or long run travel condition information for route planners, the system is likely to improve the general timing of transfers. With AOS, drivers will initiate digital bus-to-bus communications to issue transfer requests, a system that is anticipated to increase transfer reliability and limit delay to specifically requested vehicles.

In order to gauge the impact of AOS on the timing of transfers within the AATA system, this study developed before AOS (March 12 to May 1, 1997) and after AOS (March 18 to May 8, 1998 and 1999) implementation data on the vehicle-to-vehicle timing of transfers at the four transfer locations listed above. Summary statistics from three years are compared by individual route, observation site, and AATA system as a whole if possible.

In addition to timing transfers within the AATA system, schedule adherence data was collected for routes at major timepoints. Based on National Transit Database data collection, schedule adherence data was collected for the pre-AOS implementation (October 1996 to March 1997), and then for after period in 1998 and 1999 based on the same schedule of trips. The sampled trips provide an accurate assessment of the on-time performance of buses as a whole. Summary statistics of individual routes are included, when possible.

Methodology

This study is based on two separate sets of data: observations at the four major transfer points throughout the AATA system, and route by route observations at timepoints along the routes. The transfer point observations enabled an assessment of the impact of AOS on transferring as well as providing schedule adherence data within a limited geographic area. The timepoint data, while not allowing measurement of tranfer coordination, offers more broadly based measures of schedule adherence. Finally since the two datasets were developed entirely separately, they can be used to corroborate one another.

Measurement of transfer wait times between AATA routes requires the collection of sample data on the actual arrival and departure times of all pairs of routes that share a transfer point, The arrival and departure times of all AATA routes during a certain time period are recorded through the on-site observations in 1997 and 1998, while 1999 data are obtained from replying historic AVL data stored in AATA's computer system. Based upon the observed arrival and departure data, vehicle-to-vehicle transfer times are calculated if there is a chance to make a transfer between the two vehicles.

The data collections were conducted over a eight-week long period in all three years, ranging from middle March to early May. Bus arrivals and departures were observed over randomly selected two-hour time periods at each site in the morning (7:30am to 9:30am), mid-day (11:00am to 1:00pm), and afternoon (3:30pm to 5:30pm) on weekdays, and 2:00pm to 4:00pm on Saturdays. In order to reduce the sampling error, a repeated observation was conducted for each time period at all sites. Since there are few passengers at University Hospital bus stop during the weekend, weekday-only survey was conducted there.

In total, 504 pairs of bus arrivals and departures are observed at BTC, 248 at YTC, 208 at Arborland Mall, and 226 at University Hospital. The sampling rates range from 45.1% to 52.6% on weekdays and 18.7% to 21.6% on Saturdays, depending on the observation site.

The collection of schedule adherence data for AATA is based on sampling fixed-route on-time performance at timepoints along the scheduled route. For the 1997 sample, this data was hand recorded by surveyors riding buses selected for evaluation. Both 1998 and 1999's data were collected by replaying historic AVL data stored in AATA's computer system. Sampled routes could be queried to obtain schedule adherence information.

Fixed route bus service was sampled over a 19 week period starting in November to the following March. Both the 1996-1997 and 1998-1999 time periods sampled routes over the whole observation period. However, due to the lack of AVL data for the 1997-1998 period, only a seven week period in February and March of 1998 was used to determine scheduled adherence. Fixed route trips were randomly selected for the week based on National Transit Database requirements for the federal government. The selected routes were then measured at timepoints established in published schedules to determine schedule adherence. Due to the nature of the sampling process system-wide schedule adherence can be estimated, but the performance of individual routes is not as certain. In total, 2,686 time points were measured in 1996-1997, 695 in 1998 and 2,546 in 1998-1999.

AATA On-time Performance

Definitions

On-time performance is measured by the differences between the scheduled and observed arrival and departure times of each route:

On-time arrival = observed arrival time – scheduled arrival time

On-time departure = observed departure time – scheduled departure time

In other words, negative value means earlier than schedule, and positive value means later than schedule.

Schedule adherence performance is measured by the difference between the scheduled and observed times at major time points of each route:

On-time performance = observed time point departure – scheduled time point departure

In other words, a negative value means a bus left a time point earlier than the scheduled time, while a positive value means the bus left later than the scheduled time.

Statistics of AATA On-time Arrivals and Departures

Bus on-time arrivals and departures are divided into six different categories (< -6, -6 - < -3, -3 - < 0, 0 - < 3, 3 - < 6, and > = 6 minutes). The frequency (percentage) distributions of above categories will reflect the actual on-time performance (how much before or after the scheduled time).

AATA routes are timed to be able to arrive at the BTC and YTC two to three minutes before the scheduled time and to depart from these location three minutes after schedule. At all other locations, the time listed on the Ride Guide is the true scheduled arrival or departure time. According to this, we designate 0–3 minutes earlier than scheduled arrival times at all the four transfer points as the preferred on-time arrivals, and 3-6 minutes later than scheduled departure times as preferred on-time departures. Each route observed will have a distribution of observations falling in these categories.

In contrast buses are to arrive at time points according to the printed schedule (The Ride Guide), with a few exceptions. Each route sampled will have observations taken at time points that will fall into the categories above. With these categories the on-time performance for the three sample periods can be compared. The ‘best’ condition would be all buses on time, so the 0 to < 3 minute category would be the target area for increases. However, other factors effect on-time performance such as traffic conditions, including, weather and construction, so both the 0 to < 3 minute and 3 to < 6 minute categories are the targeted areas for on time performance. Percentage point increases in these two categories would be ideal.

In this way we can compare the percentage point changes of the preferred on-time performance from 1997 to 1999, both by observation site and AATA system as a whole. Percentage point increases refer to a growing share of observations within the desired time window and decreases refer to a shrinking share of observations within this window.

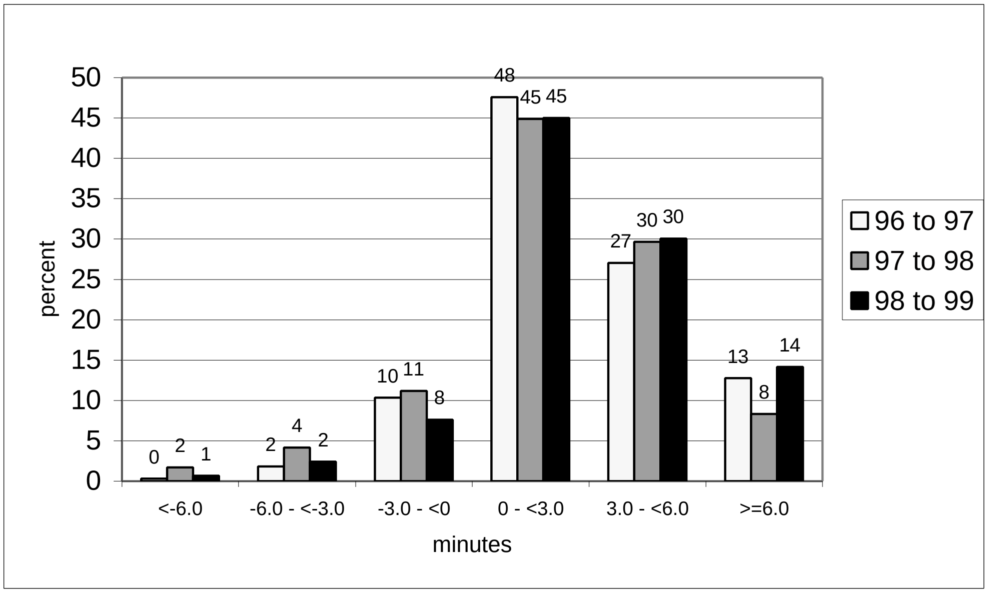

Figure A: Distribution of Overall Schedule Adherence, 1996-1999
(Based on time point data)

When considering the schedule adherence of AATA buses as a whole, there was no statistically significant difference in the mean on time performance between 1996 and 1998 (figure A). However, when time categories are looked at, there are some small but statistically significant ($p < .05$) changes from 1996 to 1998. There was a small decrease (two percentage point) in the amount of buses that arrive between 3 to < 0 minutes early, as well as a three percentage point increase for buses 3 to < 6 minutes late.

In an analysis based on transfer point data, arrivals throughout the AATA system as a whole, were found to be slightly more punctual in 1997 than in 1998 and 1999 (figure 1). The opposite result is observed in terms of on-time departures (figure 2).

With regard to the observation site, AATA tends to have better on-time arrivals only at the University Hospital. However, on-time departures are improved at BTC, YTC, and also the University Hospital. Worse on-time performance are observed at Arborland Mall from 1997 to 1999 (figure 3 to figure 10).

More statistics about AATA on-time performance by individual route and AATA on-time performance on weekdays are presented in Appendix A (Table A1 – A10, and Figure B1 – B10).

Regression Analysis with On-time Performance Data (1997 and 1999)

The preceding analysis reported on changes in on-time performance alone with no regard to potential intervening factors, such as time of day of or place of the on-time observation. This section seeks to isolate the impact of the post-AOS implementation period on on-time performance by controlling for these other variables within a multiple regression framework. In particular, the analysis defines three dependent variables:

1. ARRIVAL1: This variable is defined as minutes of delay of a bus arrival relative to its scheduled arrival time. Early arrival times here are counted as zero minutes of delay.

2. ARRIVAL2: Similar to ARRIVAL1, this variable represents minutes of delay relative to the scheduled arrival time. But in this variable, late arrivals are eliminated entirely. The purpose of this variable is to gauge whether AOS pacing information assists in preventing buses from getting ahead of schedule.

3. DEPARTURE: This variable equals the observed departure time minus the scheduled departure time for all observations.

Seven independent variables are:

1. DUMYEAR: 0 for 1997 and 1 for 1999 observations.
2. DUMNOON: 0 for weekdays' AM (7:30-9:30), PM (3:30-5:30), and Saturdays' PM (2:00-4:00) observations; 1 for weekdays' noon (11:00-13:00) observations.
3. DUMPM: 0 for weekdays' AM (7:30-9:30), noon (11:00-13:00) and Saturdays' PM (2:00-4:00) observations; 1 for weekdays' PM (3:30-5:30) observations.
4. DUMSAT: 0 for weekdays' AM (7:30-9:30), noon (11:00-13:00 and PM (3:30-5:30) observations; 1 for Saturdays' PM (2:00-4:00) observations.
5. DUMALM: 0 for BTC, YTC and UMH; 1 for Arborland Mall.
6. DUMUMH: 0 for BTC, YTC and ALM; 1 for UM Hospital.
7. DUMYTC: 0 for BTC, ALM and UMH; 1 for YTC.

Table 1 Regression Results with 1997 and 1999 on-time performance data
(coefficients, t statistics, and R square)

	Model 1	Model 2	Model 3
	Dependent Variable: arrival 1	Dependent Variable: arrival 2	Dependent Variable: departure
(Constant)	**0.238**	**-2.612**	**3.214**
	(-3.09)	(-27.72)	(20.51)
DUMYEAR	**-0.552***	**-0.237**	**-0.749**
	(-0.85)	(-2.84)	(-5.08)
DUMNOON			
DUMPM	**0.454**		**0.384**
	(-5.74)		(2.34)
DUMSAT		**-0.654**	**0.441**
		(-5.04)	(-3.71)
DUMALM	**0.768**	**0.861**	**-0.782**
	(-8.28)	(6.91)	(-2.04)
DUMUMH	**0.686**	**1.333**	**-2.338**
	(-7.52)	(9.68)	(-10.23)
DUMYTC	**0.248**		
	(-2.78)		
R Square	**0.06**	**.114**	**.097**
---t statistics in parentheses; Blank value		or* means not significant	

Model 1 suggests that controlling for location of observation and time of day, 1999 observations were better in on-time performance than their 1997 counterparts, but that the difference was NOT statistically significant. Model 2 indicates significant improvement associated with pacing information; that is, buses did arrive closer to their target time in 1999 than in 1997 and was statistically significant. Finally, departure time was closer to schedule in 1999 versus 1997, as indicated by the negative and significant coefficient of DUMYEAR. However, the regression results indicate little explanatory power over on-time performance as shown by the R-square statistics that are all lower than 0.10.

Based on the results presented in previous tables, it would appear that AOS had more affect on AATA's on-time departures than arrivals. The reasons for significant improvements in departure schedule adherence without corresponding improvements in arrivals are not obvious from the data, but can be speculated upon. In interviews with drivers many drivers expressed the feeling that they are continually aware of their adherence or lack of adherence to schedule, even without advanced technology. The factors leading to late arrivals may well be beyond drivers' or dispatchers' control, including traffic conditions, boarding and securing of wheelchair users, or inclement weather. In contrast, departures from major transfer points tend to be more under the control of the driver. The display of a uniform time systemwide may have a synchronizing impact, in contrast to drivers' reliance on individual wristwatches that vary one from another. It may be, however, that other phenomena are interacting with this simple synchronization. First, the time display is visible to the passengers, most of whom are aware of the schedule. Thus discomfort at the obviousness of clearly late departures may prompt some drivers to improve schedule adherence to the extent that this is under their control. Secondly, drivers are aware of the potential for electronic observation of bus location by time. The potential of constant surveillance may be a source of inspiration to drivers to improve adherence of their departure time to schedules, even if this means shorter breaks. Finally, some improvement in the schedule adherence of departure times may be attributable to the replacement of voice communications with digital bus-to-bus data transfer. Before the implementation of AOS, a driver of a late bus wishing to request that a bus be held for a transferring passenger would call that information to the dispatcher, who in turn, was to pass it along to the driver of the second bus. The problem was that in a timed transfer system, these requests would tend to come in bunches; the dispatcher, unable to cope with the volume of requests would call for a hold on all buses leaving a given transit center, even though perhaps only one or two would receive a transferring passenger. Under AOS, the handling of these requests in direct bus-to-bus digital communications precludes unnecessary waits by buses that are not receiving transferring passengers.

Bus-to-bus Transfer Times: 1997, 1998, and 1999

Apart from on time performance per se, a goal of AOS is to improve the effectiveness of bus-to-bus transfers. This section gauges change in transferring performance. The topics include the frequency of average transfer time, overall frequency of transferring time by location, he relationship between transferring performance and on-time performance, and the percentage of successful transfers by location and by route. It should be noted that the data in this section pertain to the timing of vehicles without regard to the numbers of passengers transferring between them. In this way it is best viewed as a measure of the quality of potential transfers, rather than actual.

Measurement of Transfer Times

Bus-to-bus transfer times are quantified by calculating the difference of their arrival times. For example, the transfer time from bus A to bus B equals to bus B's arrival time minus bus A's arrival time. There are five possible outcomes in this calculation (Fig. 12).

Case (1): If bus A arrives later than bus B arrives but earlier than bus B departs, then the transfer time from A to B is zero.

Case (2): If bus A arrives earlier than bus B arrives, the transfer time from A to B equals to the difference of their arrival times.

Case (3): If bus A arrives later than bus B departures, passengers will not be able to make a transfer at the scheduled transfer point and have to wait for another round of bus service. The transfer time from A to B then equals to the time difference between bus A's arrival time and the next round bus B's arrival time.

Case (4): Because of though routing, bus B is continuing a trip on bus A, the transfer time from A to B is always zero.

Case (5): If bus A arrives later than bus B departs, but bus B is the last observed service during the two hour survey, no transfer time is calculated and the transfer time from A to B was recorded as missing.

Frequency of Average Transfer Times

Transfer times from one specific route to all other routes or from all other routes to one specific route could be obtained though cross-tabulation in SPSS. In this part of analysis, we select transfer to time (from all routes to a specific route) as the focus of our study.

Since AATA has different service frequency on weekday and on weekend, we present separated analysis with weekday and Saturday transfer times. In addition, the transfer times between the routes that share less than or equal to 6 minutes transferring period are specially selected in order to see how good AATA system could coordinate transfers within a certain time period. In this case, only those routes that have relatively higher passenger volumes are selected for the study, namely route #1 to #7 at BTC, route #3, #4, #5, #6, #10 and #11 at YTC, #4, #7 and #22 at Arborland Mall, #2 and #4 at University Hospital.

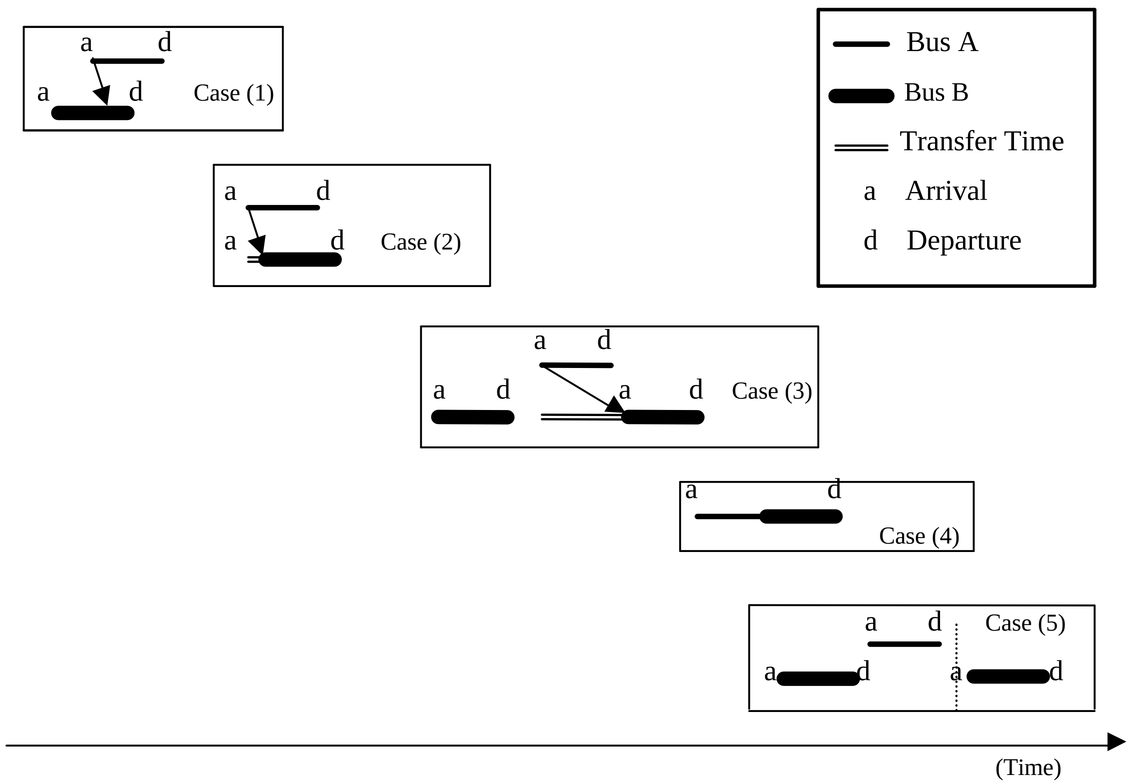

Figure 11 Outcomes of Transfer Time Calculations

Transfer times from all AATA routes to a specific route are divided into six categories:

- 0 - <3 minutes
- 3 - <6 minutes
- 6 - <12 minutes
- 12 - <20 minutes
- >= 20 minutes

In terms of the average transfer times, there are no significant changes from 1997 to 1999 on weekdays (Figure 13 and 15). However, the average transfer times on Saturdays tend to increase in 1999 than their counterpart in 1997 (Figure 17).

Overall Frequency of Transferring Times by Location

Transfer times are divided into three different types: transfers between all routes on weekdays; transfers between selected routes that share 6 minutes of transfer point; and transfers between all routes on Saturdays. According to the overall frequency distribution of these three types of transferring times, it appears that there are less chance to make a transfer within 3 minutes across AATA system in 1999 than in 1997, and the changes are statistically significant (Figure 18 to Figure 21 and Table 2). At the same time, however, more transfers could be made between 3 and 6 minutes. It is also found that there are more transfers that will take longer than 12 minutes in 1999 than 1997.

Detailed information about transfer times by individual route are presented in Appendix B (Table B1 – Table B6).

Table 2 Overall Frequency of Transferring Times by Location

			1997		1998		1999		1997 - 1999
Location	transferring cases	minutes	frequency	%	frequency	%	frequency	%	% change
		< 3	292	47.3	361	43.3	288	42.8	-4.5
		3 - <6	96	15.6	128	15.4	100	14.9	-0.7
	between all routes on weekdays	6 - <9	87	14.1	116	13.9	97	14.4	0.3
		9 - <12	46	7.5	83	10.0	57	8.5	1.0
		>= 12	96	15.6	145	17.4	131	19.5	3.9
		overall	617	100	833	100	673	100	
Arborland Mall		< 3	194	64.2	361	53.9	288	65.8	1.5
	between selected routes on weekdays	3 - <6	46	15.2	127	19.0	100	22.8	7.6
		6 - <9	31	10.3	93	13.9	50	11.4	1.2
		9 - <12	13	4.3	61	9.1	0	0.0	-4.3
		>= 12	18	6.0	28	4.2	0	0.0	-6.0
		overall	302	100	670	100	438	100	
		< 3	42	39.6	50	36.8	29	31.9	-7.8
		3 - <6	19	17.9	14	10.3	12	13.2	-4.7
	between all routes on saturdays	6 - <9	5	4.7	11	8.1	9	9.9	5.2
		9 - <12	4	3.8	8	5.9	3	3.3	-0.5
		>= 12	36	34.0	53	39.0	38	41.8	7.8
		overall	106	100	136	100	91	100	
		< 3	3701	57.6	3748	59.3	2844	52.5	-5.1
		3 - <6	591	9.2	588	9.3	529	9.8	0.6
	between all routes on weekdays	6 - <9	425	6.6	194	3.1	188	3.5	-3.1
		9 - <12	346	5.4	226	3.6	157	2.9	-2.5
		>= 12	1362	21.2	1566	24.8	1701	31.4	10.2
		overall	6425	100	6322	100	5419	100	
BTC		< 3	1751	83.6	1799	80.3	1821	78.9	-4.7
	between selected routes on weekdays	3 - <6	227	10.8	312	13.9	361	15.6	4.8
		6 - <9	80	3.8	101	4.5	104	4.5	0.7
		9 - <12	12	0.6	28	1.3	16	0.7	0.1
		>= 12	24	1.1	0	0.0	5	0.2	-0.9
		overall	2094	100	2240	100	2307	100	
		< 3	464	53.0	396	45.9	423	49.2	-3.8
		3 - <6	90	10.3	91	10.5	59	6.9	-3.4
	between all routes on saturdays	6 - <9	17	1.9	29	3.4	23	2.7	0.7
		9 - <12	14	1.6	9	1.0	21	2.4	0.8
		>= 12	291	33.2	338	39.2	334	38.8	5.6
		overall	876	100	863	100	860	100	
		< 3	264	22.4	274	22.0	319	23.5	1.1
		3 - <6	166	14.1	187	15.0	176	13.0	-1.1
	between all routes on weekdays	6 - <9	138	11.7	166	13.4	219	16.1	4.4
		9 - <12	101	8.6	115	9.3	127	9.3	0.8
		>= 12	509	43.2	501	40.3	518	38.1	-5.1
UM Hospital		overall	1178	100	1243	100	1359	100	
		< 3	121	48.2	150	35.6	178	38.9	-9.3
	between selected routes on weekdays	3 - <6	41	16.3	95	22.6	107	23.4	7.1
		6 - <9	12	4.8	81	19.2	123	26.9	22.1
		9 - <12	10	4.0	58	13.8	47	10.3	6.3
		>= 12	67	26.7	37	8.8	2	0.4	-26.3
		overall	251	100	421	100	457	100	
		< 3	415	29.5	331	28.6	429	31.8	2.3
		3 - <6	113	8.0	90	7.8	105	7.8	-0.2
	between all routes on weekdays	6 - <9	92	6.5	78	6.7	62	4.6	-1.9
		9 - <12	102	7.2	98	8.5	87	6.4	-0.8
		>= 12	687	48.8	561	48.4	667	49.4	0.6
		overall	1409	100	1158	100	1350	100	
YTC		< 3	297	83.2	269	66.4	445	74.8	-8.4
	between selected routes on weekdays	3 - <6	35	9.8	58	14.3	98	16.5	6.7
		6 - <9	11	3.1	43	10.6	38	6.4	3.3
		9 - <12	2	0.6	23	5.7	14	2.4	1.8
		>= 12	12	3.4	12	3.0	0	0.0	-3.4
		overall	357	100	405	100	595	100	
		< 3	51	42.1	66	35.9	59	38.3	-3.8
		3 - <6	8	6.6	7	3.8	7	4.5	-2.1
	between all routes on saturdays	6 - <9	2	1.7	1	0.5	5	3.2	1.6
		9 - <12	4	3.3	2	1.1	5	3.2	-0.1
		>= 12	56	46.3	108	58.7	78	50.6	4.4
		overall	121	100	184	100	154	100	
		< 3	4672	48.5	4714	49.3	4103	41.1	-7.3*
		3 - <6	966	10.0	993	10.4	1307	13.1	3.0*
	between all routes on weekdays	6 - <9	742	7.7	554	5.8	645	6.5	-1.2
		9 - <12	595	6.2	522	5.5	464	4.7	-1.5
Overall of		>= 12	2654	27.6	2773	29.0	3457	34.7	7.0*
All Locations		overall	9629	100.0	9556	100.0	9976	100.0	
		< 3	2363	78.7	2579	69.0	4254	65.4	-13.2*
	between selected routes on weekdays	3 - <6	349	11.6	592	15.8	1340	20.6	8.9*
		6 - <9	134	4.5	318	8.5	616	9.5	5.0*
		9 - <12	37	1.2	170	4.6	219	3.4	2.1
		>= 12	121	4.0	77	2.1	76	1.2	-2.8
		overall	3004	100.0	3736	100.0	6505	100.0	
		< 3	557	50.5	512	43.3	458	40.7	-9.7*
		3 - <6	117	10.6	112	9.5	120	10.7	0.05
	between all routes on saturdays	6 - <9	24	2.2	41	3.5	45	4.0	1.8
		9 - <12	22	2.0	19	1.6	33	2.9	0.9
		>= 12	383	34.7	499	42.2	469	41.7	6.9*
		overall	1103	100.0	1183	100.0	1125	100.0	

* means statistically significant

The Relationship Between On-time Performance and Transfer Times

In order to jointly analyze transfer time and on-time performance analysis, a coordinate graph is created for each location and for each route (including the 23 routes that have higher proportion of passenger volumes: 7 routes at BTC, 6 at YTC, 6 at Arborland Mall, and 4 at University Hospital).

In the graphs (figure 22 to Figure 26) on following pages, a pair of buses is graphed by the transfer times between buses (as y) and the on-time arrival of the bus that is transferring from (as x). For example, if bus A arrives three minutes earlier than schedule, and transfer time from bus A to bus B is four minutes, then the point on the graph is (x = 3, y = 4). However, each point may not necessarily represent one pair of buses; instead, it may present several pair of buses that have same x AND y values.

In order to facilitate comparisons, we defined four concentric zones in order to track changes in the distribution between zones. Points in zone #1 have better on-time arrivals and transfer time than points in zone #2, #3 or #4, as points closer to the origin are preferred.

Among the four observation locations, transfers are all improved from 1997 to 1999 (although 1998 might have higher or lower % value than 1997 and 1999). Considering AATA system as a whole, the preferred zone distribution (zone #1) also increased by 2.8% from 1997 to 1999 and was statistically significant (Table 3).

Table 3 The relationship between on-time performance and transfer times

		# of observations			percent distribution			97-99
Location	zone	1997#	1998#	1999#	1997	1998	1999	% change
BTC	#1	1129	1277	1197	49	59	53	3.5*
	#2	681	728	741	30	34	33	2.5*
	#3	215	123	253	10	6	11	1.1
	#4	263	38	89	11	1	4	-7.1*
	total	**2288**	**2166**	**2280**	100	100	100	0
YTC	#1	208	77	170	37	27	38	0.5
	#2	157	83	165	28	29	36	8.4*
	#3	59	46	87	11	16	19	8.2*
	#4	136	79	31	24	28	7	-17.2*
	total	**560**	**285**	**453**	100	100	100	0
ALM	#1	203	147	205	39	32	47	7.8*
	#2	157	149	157	31	32	36	4.8*
	#3	97	122	66	19	26	15	-3.9
	#4	58	44	10	11	10	2	-8.7*
	total	**515**	**462**	**438**	100	100	100	0
UMH	#1	52	88	129	24	34	32	7.6*
	#2	58	87	98	27	33	24	-2.9
	#3	62	65	136	28	25	33	5.3
	#4	46	22	45	21	8	11	-9.9*
	total	**218**	**262**	**408**	100	100	100	0
All locations	#1	1537	1589	1701	45	50	48	2.8*
	#2	1092	1047	1161	32	33	32	0.6
	#3	448	356	542	13	11	15	2.1*
	#4	361	183	175	11	6	5	-5.6*
	total	**3438**	**3175**	**3579**	100	100	100	0

* Means statistically significant at 95% confidence interval

Percentage of Successful Transfers by Location and by Route (weekdays)

During the 6 hours observation period on weekdays, there are different potential number of transfers that could be made from a specific route to all other routes at each location. We select the following 23 routes which have relatively higher transferring passengers according to previous study (Levine and Palathinkara, 1996) as the focus of the study. Transfers only include those that are scheduled within 6 minutes of each other. In general, transfers are improved at BTC, YTC, and University Hospital from 1997 to 1999. With regard to individual routes, there are also more routes that have higher percentage of successful transfers in 1999 than in 1997 (positive change).

Table 4 Percentage changes of successful transfers in 1997, 1998, and 1999

	From	Scheduled Transfers	Transfers	%	Transfers	%	Transfers	%	1997 - 1999
Location	Route #	to Other Routes	Made in 1997		Made in 1998		Made in 1999		% Change
	1	304	283	93%	291	96%	296	97%	4%
	2	304/384*	298	98%	289	95%	351	91%	-7%
	3	304	293	96%	273	90%	300	99%	3%
BTC subtotal	4	316	306	97%	309	98%	310	98%	1%
	5	320	289	90%	315	98%	308	96%	6%
	6	304	263	87%	298	98%	288	95%	8%
	7	304	255	84%	297	98%	268	88%	4%
BTC subtotal		**2156/2236***	**1987**	**92%**	**2072**	**96%**	**2121**	**95%**	**3%**
	3	86	73	85%	53	62%	78	91%	6%
	4	102	87	85%	62	61%	98	96%	11%
YTC	5	86	64	74%	54	63%	82	95%	21%
	6	56	40	71%	32	57%	44	79%	8%
	10	44	37	84%	37	84%	38	86%	2%
	11	16	11	69%	12	75%	12	75%	6%
YTC subtotal		**390**	**312**	**80%**	**250**	**64%**	**352**	**90%**	**10%**
	4 (OB)	48	38	79%	37	77%	40	83%	4%
	4 (IB)	96	91	95%	80	83%	46	48%	-47%
	7 (OB)	96	77	80%	84	88%	82	85%	5%
ALM	7 (IB)	96	77	80%	82	85%	62	65%	-15%
	22 (NB)	120	87	73%	103	86%	92	77%	4%
	22 (SB)	120	92	77%	93	78%	88	73%	-4%
ALM subtotal		**576**	**462**	**80%**	**479**	**83%**	**410**	**71%**	**-9%**
	2 (OB)	48/82*	27	56%	35	73%	70	85%	29%
	2 (IB)	96/140*	51	53%	71	74%	122	87%	34%
UMH	4 (OB)	96	66	69%	76	79%	80	83%	14%
	4 (IB)	120	74	62%	80	67%	76	63%	**1%**
UMH subtotal		**360**	**218**	**61%**	**262**	**73%**	**348**	**97%**	36%

* means 1999's value

Conclusions

.

Effective transfers in a public transit are critical to travelers' mobility. The reliability and efficiency of bus-to-bus transfer wait time is mainly affected by two factors. The first one is the on-time performance of the transit system. The more reliable on-time arrival and departure of the related buses will in turn greatly increase the reliability of making a smooth transfer between the routes that share a transfer point. The second factor is the design of the transit network. Ideally, if there are more routes that share a short transferring period (e.g. six minutes) within the system, there will be more transfer selections and the transfers among these routes will not be very long.

Based on our observations, AATA system does not show significant improvement from before-AOS in 1997 to after-AOS implementation in 1999 with respect to on-time arrivals. The opposite is observed regarding on-time departures. One possible explanation is that it becomes difficult for AATA to make overall improvement since its system is already very reliable even before the installation of AOS.

Bus-to-bus transfer times within AATA system tend to have no significant change from 1997 to 1999. Some improvement was noted when combined analysis was conducted between on-time performance and transfer times. However, the AOS deployment might have not reached its maximum effectiveness during the time of these evaluations. Further investigations are needed in order to assess whether a more mature AOS deployment would have more unambiguous benefits in on-time performance and transfer time.

Table A11 Regression Results with 1997 and 1998 data (coefficients, t statistics, and R square)

	Model 1 Dependent Variable: Arrival1	Model 2 Dependent Variable: Arrival2	Model 3 Dependent Variable: Departure
(Constant)	**.066**	**-2.58**	**3.282**

	(.926)	(-40.746)	(27.702)
DUMYEAR	**.261** (3.583)	**.049*** (.063)	**.500** (4.566)
DUMNOON	--	--	**.415** (2.992)
DUMPM	**.708** (9.075)	--	**.400** (3.140)
DUMSATDAY	--	**-.544** (-4.621)	**.404** (2.395)
DUMALM	**1.143** (11.1)	**.693** (5.606)	**-1.147** (-7.311)
DUMUMH	**.779** (7.747)	**1.402** (9.532)	**-2.286** (-12.506)
DUMYTC	**.294** (2.988)	--	**-.457** (-3.686)
R Square	**.098**	**.088**	**.096**

(t statistics in parentheses; Blank value or * means not significant)

Model 1 suggests that controlling for location and observation and time of day, 1998 observations were actually worse in on-time performance than their 1997 counterparts, and that the difference was statistically significant. Model 2 indicates no significant improvement associated with pacing information; that is, buses did not arrive closer to their target time in 1998 than in 1997. Finally, departure time was somewhat delayed in 1998 versus 1997, as indicated by the positive and significant coefficient of DUMYEAR.

Overall, the results indicate little explanatory power over on-time performance as shown by the R-square statistics that are all lower than 0.10. Based on the results presented in previous tables, it would appear that the greatest single factor leading to variations in level of on-time performance is the bus route itself; some routes are chronically late, while others have little difficulty keeping up with their schedules.

There are some other factors, such as traffic congestion, that would also affect 1997 and 1998 data to establish causality. For example, the road constructions on US-23 and Huron Parkway which coincidentally happened on the third and sixth week of the data collection period (eight weeks in total) in 1998. Bus service at Arborland Mall and at YTC in 1998 was obviously affected by the construction, especially route #22, #3, #7, #5 (because of through routings with #3) and sometimes #4.