IDEA

Innovations Deserving Exploratory Analysis Programs

Transit IDEA Program

Improving Bus Transit On-Time Performance through the Use of AVL Data

Final Report for
Transit IDEA Project 63(a)

Prepared by:
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August 2014

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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IDEA Program Final Report

TRANSIT-63(A)

Prepared for the IDEA Program
Transportation Research Board
The National Academies

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ACKNOWLEDGEMENTS

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Mr. Chris White
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Mr. Owen O'Neill
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Allentown, PA

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EXECUTIVE SUMMARY

The purpose of this project was to develop a set of desktop tools to analyze archived fixed-route transit automatic vehicle location (AVL) data for the purpose of measuring on-time performance and developing schedule times (running times) between timepoints. The tools were developed using data from the Capital District Transportation Authority (CDTA) in Albany, NY. The project was also intended to determine if the system developed could be exported to other transit agencies with a different AVL system that that used by CDTA.

Through consultation with staff of the CDTA, we developed a set of requirements for the system including the reports to be produced, formats and user interfaces. We developed a prototype system which included a number of reports on on-time performance and running times both from originating terminals as well as intermediate timepoints on a route. Further, we prepared a set of tools which assessed the layover time at the end of scheduled transit trips. The prototype was developed using CDTA data and revisions were made based on comments from the CDTA staff and those of the Project Review Panel. In addition, we applied the software to data from the Ann Arbor Transportation Authority and the Lehigh and Northampton Transportation Authority in Allentown, PA.

We determined that using archived transit AVL data could be used to provide reasonable results in running times. While it is theoretically possible to reduce the peak fleet requirement by reducing running times, we did not experience this. This is likely due to the fact that the system was applied to smaller transit agencies which have few buses to begin with on the routes they operate. The tools we did develop could improve the on-time performance of transit systems or determine the upper bound on on-time percentage given underlying variability in the transit travel times due to factors outside of the control of transit operators such as vehicle traffic.

The procedure for the determination of appropriate running times consisted of two analyses: terminal to terminal times and times between intermediate timepoints. Suggested terminal to terminal times were established by finding the time necessary to assure that the subsequent trip on a vehicle assignment could depart on-time with a certain probability such as 95%. Suggested intermediate timepoint times were established by determining the specific time which would maximize the number of bus trips which would depart from timepoints between one minute early and five minutes late.

We were able to apply a few statistical tools to transit AVL data to make the determination of appropriate running times but also make the system accessible to transit schedulers through the development of a simple user interface.

The application of these tools to the transit systems in Ann Arbor and Allentown demonstrated that the system could be exported to develop appropriate running times on data from different AVL products. This would require some reformatting of data from these AVL systems.

Our expectation is to work with firms which develop AVL products to determine the feasibility of commercialization of the desktop tools developed in this project.

CONCEPT AND INNOVATION

Transit operators for generations have been vexed by the problems associated with on-time performance and the role of proper running times in improving service quality to customers. The American Transit Association, the predecessor to APTA (the American Passenger Transportation Association), commissioned a staff study of running time determination in 1947 which concluded.:

> *"It is extremely important that the schedule maker have at his disposal adequate and correctly obtained data upon which to base an estimate of the running time for the line for which he is about to prepare a schedule. Running time is important because it determines in large measure the degree of convenience which the public will receive from a schedule from the standpoints of speed and elapsed time in their travels. It is also important because it has much to do with the efficiency of a schedule and its resulting cost of operation from the company point of view"(1)*

Transit managers properly suggest that a large proportion of deviations from on-time performance are beyond their control. Traffic congestion and boarding delays, for example, are clearly outside of their area of influence. Transit managers, do, however, have the capability of determining the allowed (scheduled) times between timepoints and the scheduled layover at the end of a trip. Further, through supervision, they can control the punctuality of terminal departure times which is a strong determinant of on-time performance along the route.

The introduction of automatic vehicle location (AVL) systems has provided a wealth of data to effectively assess the causes of poor on-time performance. Further, there has been some research in the literature on the effect of on-time performance on transit customer waiting time, an important determinant of the mode of travel in urban areas, particularly for those with non-transit travel options. Early **or** late buses each elongate the customer wait time. While the case is more obvious for late buses, early bus departures cause customer to miss their bus and wait for the following bus on a route.[1] Improvements in on-time performance and the reliability between days can improve the rider experience.

Prior to the introduction of AVL systems, running times were established through field observation data which were expensive to collect and lacked the sample size and random selection necessary to make valid statistical inferences. In several cases, establishing running times was done reactively – only on complaints from bus drivers who had difficulty adhering to the published schedule or customers who complained about repeated poor service regularity.

Even though AVL systems have been widely introduced at the larger transit agencies, there has been little use made of the data to support transit scheduling. These systems are typically introduced to improve the quality (accuracy) of customer information, particularly to customers waiting at bus stops, and to provide transit managers a visual representation of the status of buses in order to introduce field control measures such as holding specific buses to reduce bunching, adding unscheduled trips and short-turning (reversing the direction of a bus prior to completion of the entire trip).

There are two primary reasons why transit AVL systems have so far not produced useful running time tools for transit management:

- Transit analysts and managers have adopted their business processes to a data-poor environment. To establish running times, for example, transit staffs normally deploy either field or on-board observers to take a small set of samples to compute mean running times.

- The number of observations generated by AVL systems is extremely large and beyond the capability of desktop tools with which transit staff are familiar. Accordingly, staff rely on the support of installation contractors who often have limited subject matter knowledge in transit operations.

We have developed in this IDEA project, a set of diagnostic and optimization tools which has the following features:

[1] Regular (frequent) customers compensate for occasional early bus departures by arriving much earlier than the published schedule.

- Data interface to the AVL systems produced by three firms in the marketplace. These three firms command about 90% of the domestic transit AVL market.

- Simple user interface which focuses on problem solving. While appropriately robust statistical procedures are used in the optimization of running times, the user is able to effectively use the software with no statistical knowledge.

- The use of a number of default parameters such as identification of periods throughout the day where the running times are identical. This reduces the set up time (and cost) typically associated with transit software.

INVESTIGATION

We have developed a prototype data analysis system for automatic vehicle location data from a bus transit system and have applied the tool to three bus systems. The objectives of this system are to diagnose the on-time performance of a bus transit system and develop a set of scheduled (running times) which maximizes the probability that buses will run on time.

The specific analyses performed by this system include three data assessments: (1) on time performance at the route, trip and stop level (2) assesses the layover (end of bus trip) adequacy and the development of appropriate schedule running times. The assessment of on-time performance (first assessment) helps in identifying "hot spots" – times and locations of poor performance which may require additional attention such as traffic operation changes, relocation of bus stops or other operational changes. The other two assessments (layover and running time) are suitable tools to remedy identified problem areas. In this work, we did not make any determination or assessment of the suitability of certain locations as timepoints. We assumed that the quantity and spacing of timepoints was determined by local criteria.

DATABASE STRUCTURE

The software was developed using Microsoft Access with VBA (Visual Basic for Applications). This enabled importing data from existing scheduling systems. There are three types of tables (files) required to operate the system. These are (1) transit system AVL data (2) transit system schedule data and (3) customizable application-specific tables.

AVL Data

Transit operators with automatic vehicle location (AVL) systems usually collect significant data on their operation. A typical AVL system records for each bus passing a scheduled timepoint:

Date
Bus number
Block number – the vehicle assignment number
Trip ID – a unique identifying number for each scheduled trip
Route
Direction
Pattern – a variation of the path operated on a route
Timepoint ID
Scheduled arrival time
Actual arrival time
Scheduled departure time
Actual departure time

As a point of reference, a transit system with about 200 vehicles will generate about 3,000,000 records annually.

Schedule Files

For each schedule season, frequently referred to as a pick, a table is required which contains for each trip a unique trip number, route, service (weekday, Saturday or Sunday) and direction, starting time and location and ending time and location. Commercial scheduling software generally has some table of trips which are exported to the AVL system.

Customized Files

The system uses a number of tables specific to the application. These are generated by the user. Some contain default values which obviate the need for customized tables. These include:

tblCalendar	Table which shows the service (weekday, Saturday or Sunday) associated with each date.
tblLayoverDescription	Table which describes the amount of layover with an attribute of either Inadequate, Low, Adequate or Generous
tblOnTimeDefinition	Associates a value with each amount of deviation from on-time.
tblRoutes	Table describing the route numbers and names in the transit system
tblScheduleSummary	This is a table with one record for each scheduled trip. It shows the route, service and direction for each trip as well as the start time and location of the trip and the end time and location of the trip
tblTimeConversion	For each minute in the day, table shows time in minutes after midnight, seconds after midnight and period in the day (Early AM, AM Peak Midday, PM Peak and Night)
tblTimepoints	For each route and direction combination illustrates the sequence of timepoints, their ID number and abbreviation and the type of timepoint (Terminal departure, terminal arrival or midpoint)
tblTimeWindowBoundaries	For each route, service and direction combination, this table contains a number of time windows throughout the day for which the running time would be the same. There is a maximum of 10 time periods for each route, service and direction combination

SUMMARY OF REPORTS

The table below shows the reports which the prototype system can develop:

Table 1 – System Developed Reports

On-time Reports

On-time by route, service

On-time by timepoint

On-time by timepoint by time period

Terminal on-yime departure report

Layover Reports

Actual vs. scheduled layover time

Layover adequacy

Running Time

Existing terminal to terminal times - tables

Existing terminal to terminal times - graphic
Optimum terminal to terminal times
Optimum intermediate times - summary
Optimum intermediate times - detail

ON-TIME PERFORMANCE

We developed a number of on-time performance (OTP) reports which displayed on-time quality at the route, timepoint and time of day level. The system enables users to either define on-time performance themselves of use a default value of one-minute early to 5 minutes late, a common industry standard. We also prepared a report which showed the OTP of terminal departures. Since terminal departure times contribute significantly to overall on-time performance, a metric of the proportion of terminal departures which were made within one minute of the scheduled departure time was developed. Figure 1 shows a sample detailed on-time performance report.

LAYOVER ADEQUACY

We developed two reports on bus layovers to be used as diagnostic tools. Layover time, the time between bus arrival at a terminal and the departure on the subsequent trip, has a significant influence on on-time performance. The two reports included a comparison between actual and scheduled layover time (Figure 2) and the other showing the adequacy of actual layover time (Figure 3.) The software allows the user to define the time intervals for inadequate, adequate and generous layover times. In the transit system whose data are used in this prototype, inadequate was defined as layovers under 5 minutes, adequate was in the 5 to 15 minute range and generous was defined as layovers exceeding 15 minutes.

Route Detail By Timepoint by Period

Period from: 1/27/2013 ***to*** 5/4/2013

Service Weekday

Route: 4 Washtenaw Avenue via Hospital ***Direction:*** Eastbound

	Total	Very early	Early	On time	Late	Very late
Stop Name: Blake Transit Center						
AM Peak	615	0%	6%	93%	1%	0%
Midday	960	5%	5%	89%	1%	0%
PM Peak	700	0%	7%	92%	1%	0%
Night	623	0%	0%	97%	3%	0%
Timepoint total:	2,898	2%	5%	92%	1%	0%
Stop Name: Medical Center						
AM Peak	555	0%	0%	98%	1%	1%
Midday	876	0%	0%	98%	2%	0%
PM Peak	820	0%	0%	95%	5%	0%
Night	626	0%	0%	94%	6%	0%
Timepoint total:	2,877	0%	0%	96%	3%	0%
Stop Name: Washtenaw-Manchester						
AM Peak	585	0%	0%	96%	3%	1%
Midday	879	0%	0%	96%	4%	0%
PM Peak	753	0%	0%	76%	22%	2%
Night	694	0%	0%	70%	28%	2%
Timepoint total:	2,911	0%	0%	85%	14%	1%
Stop Name: Washtenaw-Pittsfield						
AM Peak	553	0%	2%	97%	1%	0%
Midday	811	0%	0%	98%	1%	0%
PM Peak	808	0%	0%	77%	19%	3%
Night	692	0%	0%	84%	14%	1%
Timepoint total:	2,864	0%	1%	89%	9%	1%

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FIGURE 1 - On Time Performance Report

Difference Between Actual and Scheduled Layover

Service: Weekday **Between:** 01/29/2013 **and** 05/26/2013

Route: 18 Delaware Avenue

Time Period	Total	Actual Layover Less than Scheduled Layover					Actual Layover Greater than Scheduled Layover				
		-21 to -25	-16 to -20	-11 to -15	-6 to -10	-1 to -5	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25
Arriving Direction:	**East**										
AM Peak	873				58	345	431	32			
Midday	956				85	437	417	6			
PM Peak	693			4	181	330	169	5			
Night	405			1	5	77	283	32			
Arriving Direction:	**West**										
AM Peak	871			1	65	238	541	18			
Midday	949			1	124	362	443	15			
PM Peak	846		1	20	448	210	158	3			
Night	481				16	89	335	30			
Route total	*6074*		*1*	*27*	*982*	*2088*	*2777*	*141*			

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FIGURE 2 – Difference Between Actual and Scheduled Layover Time

Analysis Of Layover Adequacy

Service: Weekday **Between:** 01/29/2013 **and** 05/26/2013

Route: **18** **Delaware Avenue**

Arriving Direction: **East**

Time Period	*Terminal*	*Total*	*Inadequate*	*Low*	*Adequate*	*Generous*	*Outlier*
AM Peak	GREYHOUND TERMINAL	867		9	385	468	5
Midday	GREYHOUND TERMINAL	928	5	20	489	404	10
PM Peak	GREYHOUND TERMINAL	688	17	62	416	187	6
Night	GREYHOUND TERMINAL	403	1		89	312	1
Direction Total		*2927*	*23*	*91*	*1383*	*1386*	*44*

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FIGURE 3 - Analysis of Layover Adequacy

RUNNING TIME DETERMINATION

Terminal to Terminal Times

Most of the work in the project was devoted to determination of appropriate running times for transit routes. There were two fundamental analyses in this part of the project (1) determination of terminal to terminal (half-cycle) times and (2) determination of appropriate running times for intermediate non-terminal timepoints.

The first report produced was a description of the distribution of actual running times for each trip. This was shown in tabular and graphical form (Figures 4 and 5). For each scheduled trip, the mean value and standard deviation of the actual terminal to terminal time was developed. The purpose of this exercise was to enable schedulers to partition the operating day into a number of time intervals during which the scheduled times would be the same. While each individual scheduled trip has its own mean and standard deviation, it is not practical to have a different set of running time for each trip. Accordingly, common scheduling practice is to partition the day into several times periods, such as early morning, morning peak, midday, PM peak and night. Further, some agencies have transition periods between peak and off–peak hours to “feather” the changes in running times. In this system, we enable up to 10 periods daily. Further, different running time plans may be introduced for weekdays, Saturday and Sundays.

We attempted to find some statistically optimal way of partitioning but were unable to do so. Accordingly, we enabled the user to partition the day into homogeneous running time periods.

We developed a procedure to assess half-cycle times, the time interval between the scheduled departure time from one terminal to the scheduled departure time on the subsequent trip in the vehicle schedule. This is the actual running time plus layover time. The layover time is necessary for two reasons, driver break time and a buffer time to allow for schedule recovery. Transit operators use a common rule of between 10% and 15% time for driver break. On routes with even moderate terminal-to-terminal time variation, the ability to depart on-time for the subsequent trip is compromised without some additional time beyond the minimum for driver break. In this work, we computed the mean and standard deviation of actual terminal to terminal times. We then determined the minimum running time necessary to assure on-time departure on the subsequent trip with 95%, 98% and 99% probability. The 95% level was the mean plus 1.64 times the standard deviation; the 99% level was determined as the mean plus 2.05 times the standard deviation and the 99% level was determined as the mean plus 2.32 times the standard deviation. We developed a report which shows the trade-off between running time and reliability. That is, we reported on the minimum running time necessary to achieve a specific reliability. We also showed the minimum time duration necessary to assure that there was, on average, sufficient time for driver break. Prudent practice would be to select the running time which was the larger of the time required for driver break and the timer required for adequate schedule recovery time. A sample report describing terminal to terminal times is shown in Figure 6.

Actual Run Time Statistics By Trip

Service *Weekday* **Start Date:** *1/27/2013* **End Date:** *5/4/2013*

Route *4 Washtenaw Avenue via Hospital*

Direction *Eastbound*

TripStartTime			Scheduled Time	Mean	StDev	Count	Lower	Upper	Mode	Mode Count
6:53 AM	BTC	YTC	42	36.5	2.7	70	33.8	39.2	36	17
7:08 AM	BTC	YTC	42	37.7	2.7	69	34.9	40.4	36	19
7:23 AM	BTC	YTC	42	35.9	1.7	69	34.2	37.6	35	32
7:38 AM	BTC	YTC	42	36.7	2.7	68	34.0	39.4	37	25
7:53 AM	BTC	YTC	42	36.1	2.7	69	33.4	38.8	36	30
8:08 AM	BTC	YTC	42	36.2	1.4	68	34.8	37.6	36	36
8:23 AM	BTC	YTC	42	36.0	1.9	69	34.1	37.9	35	21
8:38 AM	BTC	YTC	42	35.2	1.8	69	33.4	37.0	35	23
9:03 AM	BTC	YTC	42	35.9	1.7	70	34.2	37.6	36	26
9:33 AM	BTC	YTC	42	36.4	1.5	70	35.0	37.9	37	24
10:03 AM	BTC	YTC	42	37.1	2.2	70	34.9	39.3	37	15
10:33 AM	BTC	YTC	42	37.4	2.6	69	34.8	40.0	36	22
11:03 AM	BTC	YTC	42	39.0	3.2	70	35.8	42.2	38	13
11:33 AM	BTC	YTC	42	38.7	3.4	70	35.3	42.1	37	12
12:03 PM	BTC	YTC	44	40.1	3.6	70	36.5	43.8	38	13
12:33 PM	BTC	YTC	44	40.7	2.8	70	37.9	43.5	40	18
1:03 PM	BTC	YTC	44	40.1	3.3	69	36.7	43.4	39	17
1:33 PM	BTC	YTC	44	40.4	3.3	69	37.1	43.7	37	13
2:03 PM	BTC	YTC	44	41.8	3.5	68	38.3	45.3	39	16
2:33 PM	BTC	YTC	44	42.1	3.2	69	38.9	45.3	40	14
2:53 PM	BTC	YTC	44	39.2	2.5	64	36.7	41.6	38	19
3:08 PM	BTC	YTC	44	39.0	3.6	63	35.5	42.6	38	15
3:23 PM	BTC	YTC	44	41.2	3.0	69	38.3	44.2	40	12
3:38 PM	BTC	YTC	44	40.7	4.3	20	36.4	45.0	NM	4
3:53 PM	BTC	YTC	44	45.3	4.6	69	40.7	49.8	42	9
4:08 PM	BTC	YTC	44	42.7	3.1	68	39.5	45.8	40	10
4:23 PM	BTC	YTC	44	41.9	3.1	68	38.8	45.0	43	11
4:38 PM	BTC	YTC	44	44.6	4.1	68	40.5	48.7	44	10
4:53 PM	BTC	YTC	44	48.0	3.0	50	45.0	51.0	48	10
5:08 PM	BTC	YTC	44	47.9	4.8	14	43.1	52.7	NM	2
5:23 PM	BTC	YTC	44	44.5	4.8	55	39.7	49.3	NM	8
5:38 PM	BTC	YTC	44	42.9	3.1	65	39.8	46.1	43	12
5:53 PM	BTC	YTC	44	40.8	2.7	43	38.1	43.5	39	14
6:18 PM	BTC	YTC	42	40.6	2.6	67	38.0	43.3	41	12
6:48 PM	BTC	YTC	42	40.6	2.4	69	38.2	43.0	39	14
7:18 PM	BTC	YTC	42	41.1	2.5	69	38.5	43.6	40	14
7:48 PM	BTC	YTC	42	39.3	2.7	69	36.6	42.0	39	13
8:18 PM	BTC	YTC	42	37.0	1.8	69	35.2	38.7	37	22
8:48 PM	BTC	YTC	42	37.4	1.6	69	35.8	39.1	37	21

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FIGURE 4 – Existing Terminal to Terminal Times

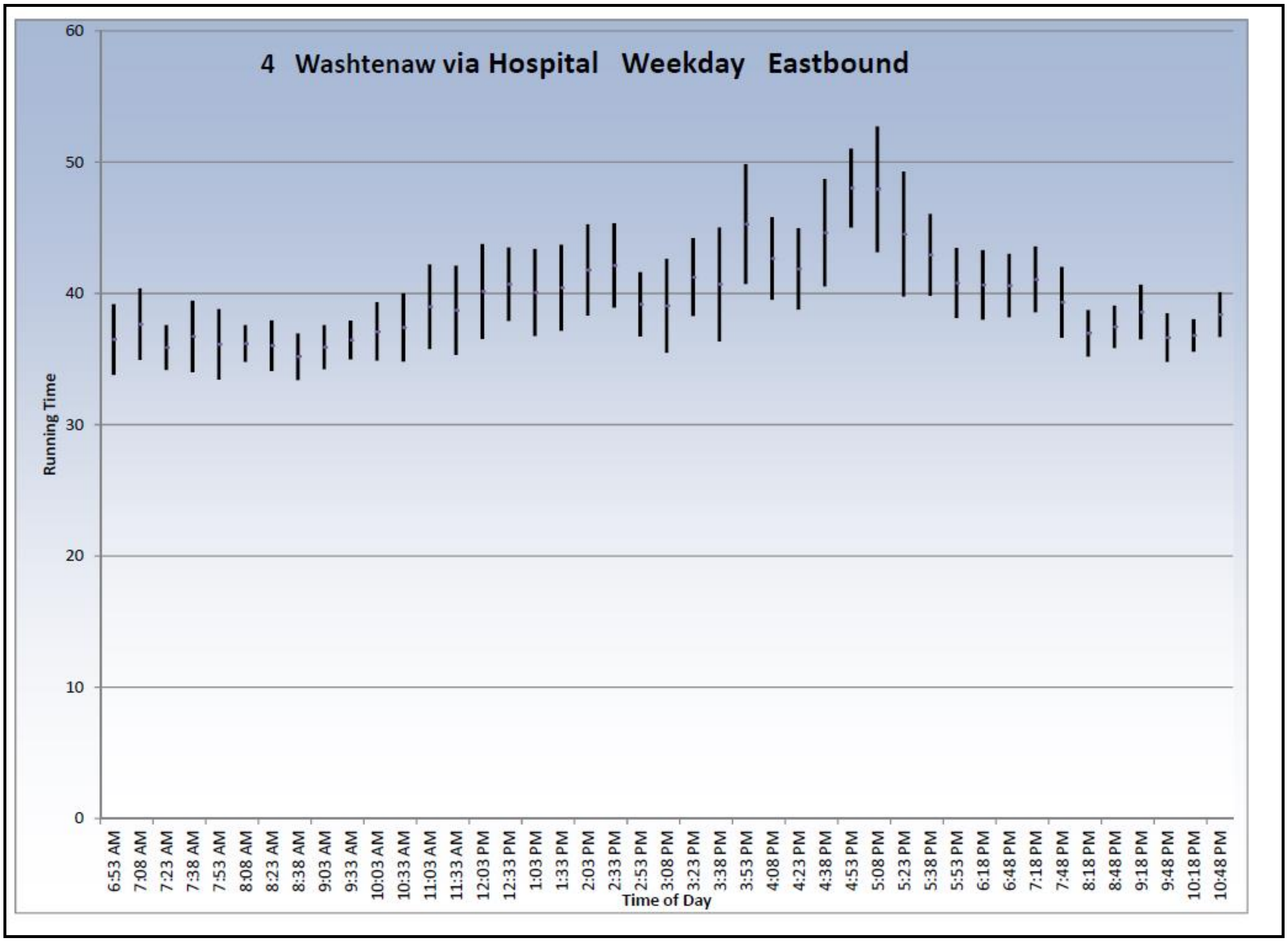

FIGURE 5 - Distribution of Terminal to Terminal Times

Half Cycle Run Time Report

Route 4 Washtenaw Avenue via Hospital

Service Weekday **Direction** Eastbound

Start Date: 1/27/2013 **End Date:** 5/4/2013

TimeWindow		Start Location	End Location	Mean RunTime	Run Time ForLayover	95* Percent	98 Percent	99 Percent
12:01:00 AM	11:00:00 AM	BTC	YTC	36	40	40	41	42
11:01:00 AM	4:00:00 PM	BTC	YTC	40	44	46	47	48
4:01:00 PM	6:00:00 PM	BTC	YTC	44	48	51	53	54
6:01:00 PM	11:59:00 PM	BTC	YTC	39	43	45	47	48

** - At this run time 95% of subsequent trips will be able to depart on time.*

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FIGURE 6 - Half Cycle Run Time Report

Intermediate Timepoint Running Times

Once terminal to terminal times are established, the next task is to establish timepoints for the intermediate scheduled points between terminals. These locations are considered control points for the route and common practice is to hold early buses at these points until the scheduled departure time. On-board customers are very averse to waiting at stops so the schedule practice is to develop running times which are far more likely to result in late arrivals than early arrivals. A common industry practice is to consider as "on time" a departing bus which is between one minute early and five minutes late. (Early arrivals at terminal stops are generally not considered early for the purpose of measuring on-time performance.)

Our procedure for establishing intermediate running times was to determine the distribution of actual running times from the beginning route terminal to the specific time point and establish a running time at which the proportion of on-time bus departures using the -1 to +5 minute metric, was maximized. This is illustrated in the two charts below. The first chart shows the number of observations for each level of running time for a specific pair of timepoints for a particular time of day. If the running time is set at 29 minutes (Figure 7) then all departures between 28 minutes and 34 minutes will be considered on-time. In this case, that level is 72% minutes. If the running time is established at 28 minutes (one minute shorter) then the proportion of trips that depart on-time from the stop increases to76% In this analysis, we are trying to find the "sweet spot" where any change in running time results in poorer on-time performance. For this analysis, we assumed a log-normal distribution of running times since this distribution better fits the operating environment where there are more events which cause buses to run late than there are events which cause buses to run early resulting in a skewed distribution.

To determine the best running time for a specific timepoint, the minimum and maximum of the observations of running time between a terminal and that timepoint for a specific route, service, direction and time period combination were determined. For each integer value of time t in the range, the cumulative probability distribution of running times between (t-1) and (t+5) was estimated. This allowed for considering buses as "on time" if they are between 1 minute early and 5 minutes late. The value of t between the minimum and maximum observed value for which the cumulative probability distribution was maximized was computed and recommended as the best running time between the trip terminal and the timepoint.

The system produces intermediate run time optimization reports showing the suggested running time for each timepoint as measured from the trip starting terminal. This procedure was used instead of times between intermediate timepoints since there is likely to be correlation between travel times on route segments which would distort the results. Using times from terminals reduces this source of error. A report on intermediate timepoints is shown in Figure 9.

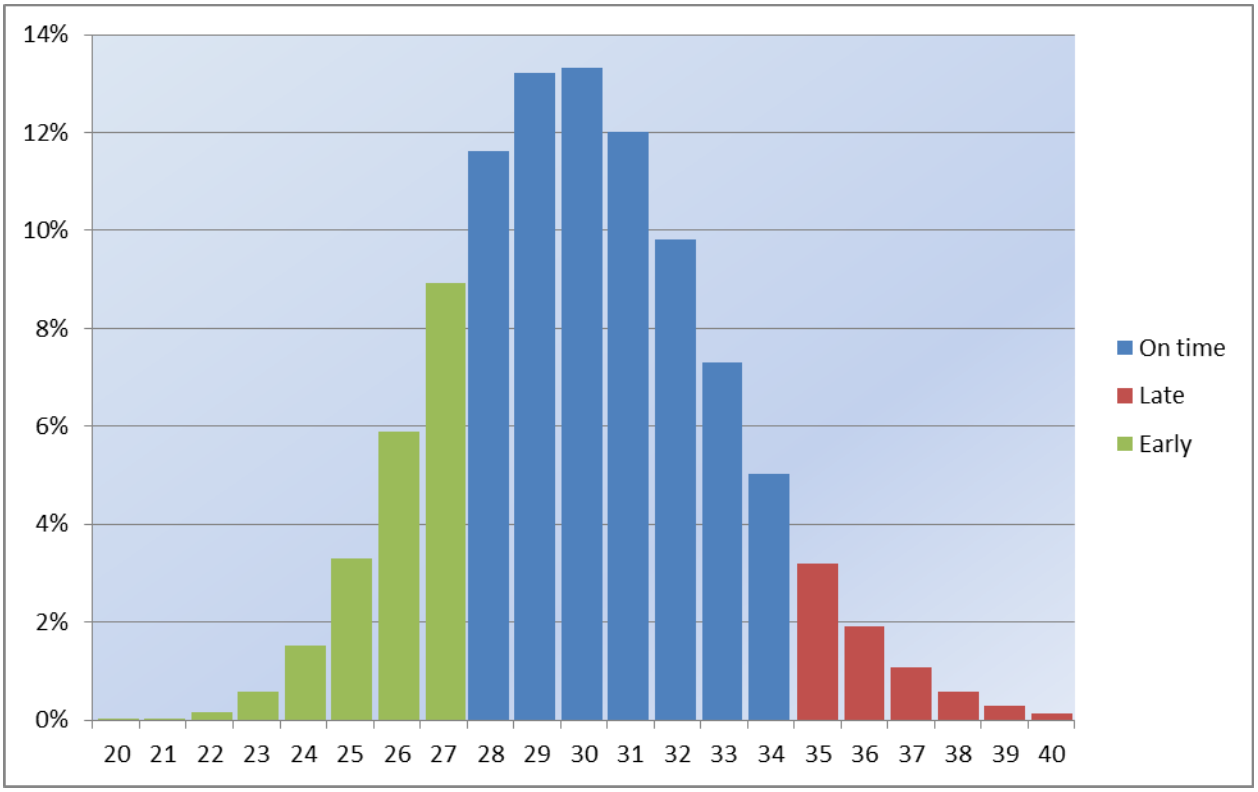

FIGURE 7 - Running Time Histogram - 29 Minute Running Time

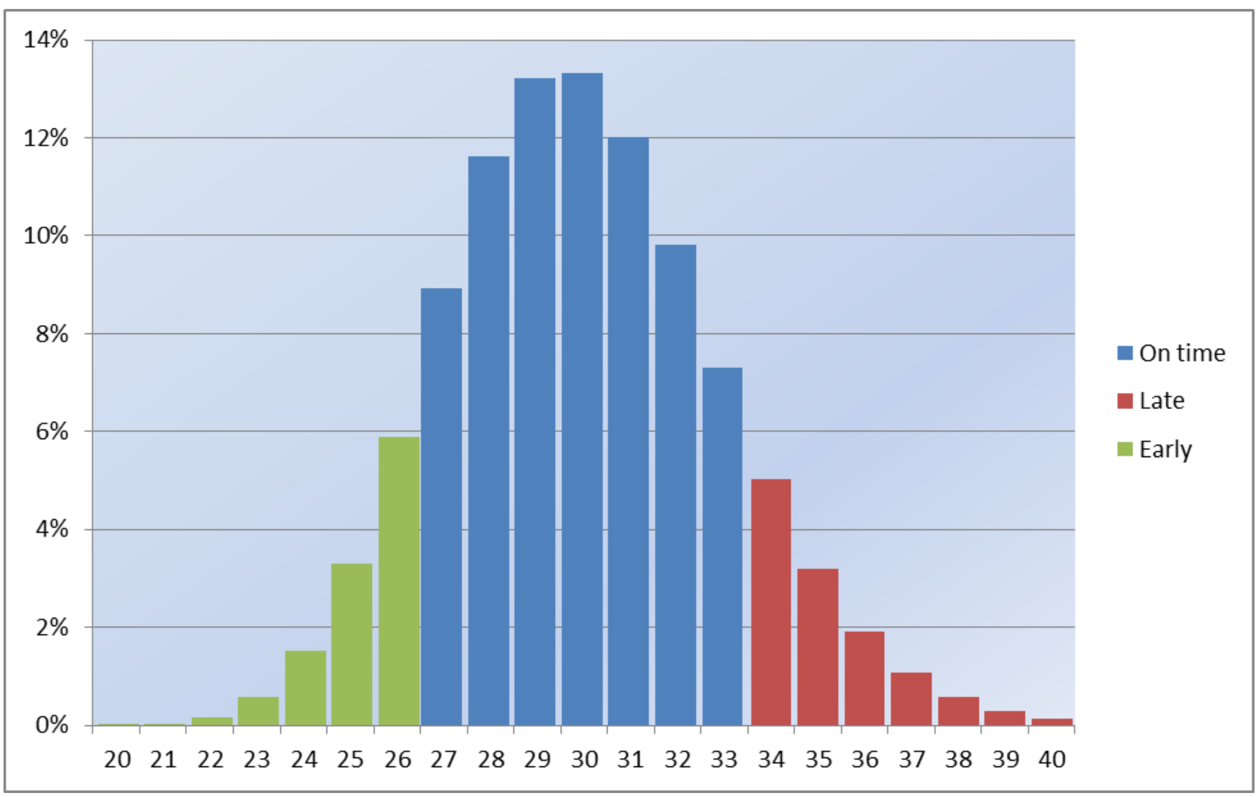

FIGURE 8 - Running Time Histogram - 28 Minute Running Time

Intermediate Timepoint Run Time Optimization

Route: *4 Washtenaw Avenue via Hospital* **Service:** *Weekday*

Direction: *Eastbound* **Begin Date:** 1/27/2013 **End Date:** 5/4/2013

Timepoint Pair and Sequence			TimePeriod			Opimal Run Time	Percent On Time
BTC	MedCtr	2	Morning	12:01 AM	11:00 AM	12	97.5%
BTC	MedCtr	2	Afternoon	11:01 AM	4:00 PM	12	90.8%
BTC	MedCtr	2	PM Peak	4:01 PM	6:00 PM	13	94.2%
BTC	MedCtr	2	Night	6:01 PM	11:59 PM	12	99.3%
BTC	wasman	3	Morning	12:01 AM	11:00 AM	20	93.6%
BTC	wasman	3	Afternoon	11:01 AM	4:00 PM	21	83.2%
BTC	wasman	3	PM Peak	4:01 PM	6:00 PM	24	78.5%
BTC	wasman	3	Night	6:01 PM	11:59 PM	21	90.7%
BTC	waspit	4	Morning	12:01 AM	11:00 AM	26	97.4%
BTC	waspit	4	Afternoon	11:01 AM	4:00 PM	28	83.3%
BTC	waspit	4	PM Peak	4:01 PM	6:00 PM	31	68.9%
BTC	waspit	4	Night	6:01 PM	11:59 PM	27	89.3%
BTC	wasglf	5	Morning	12:01 AM	11:00 AM	31	96.0%
BTC	wasglf	5	Afternoon	11:01 AM	4:00 PM	34	75.4%
BTC	wasglf	5	PM Peak	4:01 PM	6:00 PM	37	64.3%
BTC	wasglf	5	Night	6:01 PM	11:59 PM	33	83.9%
BTC	wassum	6	Morning	12:01 AM	11:00 AM	37	93.9%
BTC	wassum	6	Afternoon	11:01 AM	4:00 PM	40	71.6%
BTC	wassum	6	PM Peak	4:01 PM	6:00 PM	44	62.4%
BTC	wassum	6	Night	6:01 PM	11:59 PM	39	80.3%
BTC	YTC	7	Morning	12:01 AM	11:00 AM	38	89.8%
BTC	YTC	7	Afternoon	11:01 AM	4:00 PM	42	71.5%
BTC	YTC	7	PM Peak	4:01 PM	6:00 PM	45	60.3%
BTC	YTC	7	Night	6:01 PM	11:59 PM	41	71.9%

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FIGURE 9 - Intermediate Timepoint Optimization Report

SYSTEM OPERATION

The prototype system is menu driven for ease of use. The figure below shows the relationships between the forms used for the system.

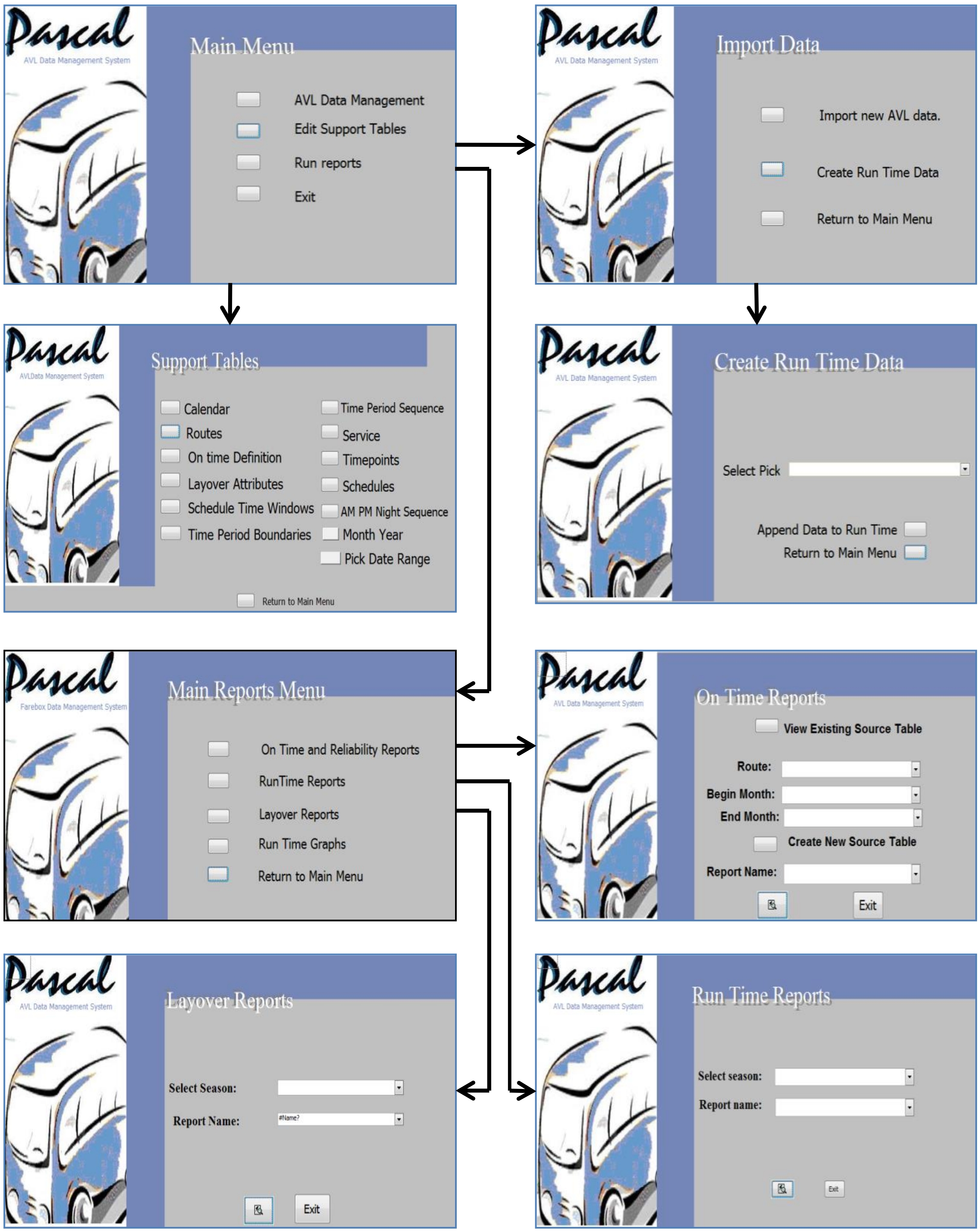

Figure 10 – Relationship Between Forms in the Prototype

OTHER WORK

We attempted to use the data to provide insights into reliability, the consistency of arrival time at stops of successive trips between days. While we were able to develop a report which showed the dispersion of arrival times at stops for a specific trip across successive days, it was difficult to relate management actions to improve this performance metric. This is probably a fruitful area for further investigation.

We also discussed a report on headway control on short headway routes. Common operation practice is to maintain time intervals between successive buses rather than adhere to schedules on short headway route. The transit system to which we applied these data, the Capital District Transportation Authority in Albany, NY did not have a significant amount of service which met this close headway criterion.

APPPLICATION TO CDTA

A prototype system was developed and applied to data from the Capital District Transportation Authority in Albany, NY. CDTA operates a peak fleet of just under 200 scheduled vehicles in revenue services. CDTA uses an automatic vehicle location (AVL) system supplied by INIT, Innovations in Transit, the US subsidiary of a German firm. The system had a facility to export data tables from the AVL system. In addition, CDTA also uses the HASTUS scheduling product developed by Giro, Inc. a Canadian firm. Data from this system was exported to provide schedule data.

The prototype was shared with the CDTA staff. They and members of the advisory panel made several recommendations to enhance its utility.

The system, as originally designed, performs a complicated scheduling function which is important but used rarely. Most transit systems update schedules between two and four three times annually so it is unlikely that a running time analysis system will be used very often. Accordingly, it was suggested that we make the application simpler to operate. Our first prototype enabled the computation of appropriate running times and on-time performance for any date range for which data were available. We altered this in a second revision to enable the user to select a single month or a month range for on-time results and a single season (alternatively called pick, shape up or runboard) for determination of appropriate running times.

In addition, it was suggested that for the actual terminal to terminal times trips, that we produce the mode (most common value) the running time distribution. These, and several other formatting changes were made.

APPLICATION TO LANTA AND AATA

We communicated with the planning staff of two smaller transit agencies to ascertain the applicability of this prototype to their data. Since one of the original project objectives was to determine if the prototype could be exported to agencies using AVL systems other than that used by CDTA. The two agencies were the Ann Arbor Transportation Authority in Ann Arbor, Michigan and the other was the Lehigh and Northampton Transportation Authority in Allentown, Pennsylvania,. Each of these transit systems uses a different AVL system than the one used by CDTA.

AATA

We obtained data from the Ann Arbor Transportation Authority. The data set was one season of data on Route 4 – Washtenaw Avenue. This is the busiest route in the AATA system and operates between downtown Ann Arbor and downtown Ypsilanti, a distance of about 8 miles. Peak hour headways are about 10 minutes. About 80,000 AVL records were assembled for this. This route has two major patterns – with most trips traveling via the University of Michigan Medical Center and some bypassing this hospital using a shorter path. The route does not have complicated patterns of operation and was an ideal application for the system. It is the practice of AATA to maintain the same running time on its routes throughout the day.

The data required relatively little reformatting. For the most part, default values of on-time performance definition, peak hour definition etc. were used. Rather than import an entire schedule table and convert it, we developed a schedule table specifically for this application. If we were using this data analysis system on all routes, we would have performed a data conversion.

A number of the reports were run using the AATA data. At the outset, the on-time performance of the transit system was remarkably high with fully 90% operating on time. This is due to a number of factors including good running times to begin with, operation in an environment with relatively low congestion and good operations management. Our work suggested that some variation of the running time throughout the day and varying the running times on weekends would slightly improve on-time performance from its existing high level. We found no instance in which the number of vehicles assigned to the route could be reduced by different effective running times.

LANTA

Parallel with our investigation of data supplied by the AATA, we were provided data from the Lehigh and Northampton Transportation Authority in Allentown, Pennsylvania. As in the case of AATA, we obtained one season's dataset on one of the busiest routes in the LANTA system Route 103 - Susquehanna St. Northampton which operates between some suburban shopping malls and, downtown Allentown and Bethlehem. This is a very long route with terminal to terminal times being as high as 1.75 hours. Running times are the same throughout the day and between weekdays and weekend days. The route operated a number of service patterns or paths. These were either variants for night service, deviations to certain employers at certain times of the day or operation over only a part of the entire route on some scheduled trips.

We obtained about 80,000 records, comparable to the dataset from AATA The complicated service pattern introduced some challenges in data conversion. As in the case of AATA, we developed a table of scheduled trips which we would automate if we were assessing the entire LANTA system. The LANTA data set had more outlier data which had to be filtered. However, the on-time performance was over 90%, attributable to the same factors in Ann Arbor – relatively low congestion and good operations management. We identified a few areas where schedules were very "tight". A difficulty in identifying these hot spots is that Route 103 is quite long and any elongation of running time would add to the peak fleet requirement, a key determinant of transit operating cost.

The data conversion of the LANTA data was not as smooth as that of the AATA data. However, we were able to introduce reasonable results.

CONCLUSIONS

This work demonstrated proof-of-concept that AVL data can be used to improve the on-time performance of transit systems through changes in running times. Further, we have shown that this set of analysis tools can be used on data sets from a number of different vendors of AVL systems.

The OTP reports are useful in identifying "hot spots" for further investigation. The system developed here can provide a number of tools to identify the reasons for substandard on-time performance. These include an assessment of on-time performance at terminal departures and assessment of the amount of layover time of scheduled buses.

While the primary objective of optimizing running times is to improve the quality of service to customers, it is possible that shorter running times may reduce operating costs. This would occur if running times were reduced and the number of vehicles required to maintain service frequency were also diminished. We did not observe opportunities to reduce vehicle requirements primarily because the number of vehicles assigned to the routes we observed was small, with the maximum being about 10 vehicles.

We concluded that making reasonable inferences on running time is very data intensive and implementing new schedules involves considerable staff time to develop and requires adaptation by customers. As a result, running times are not updated very frequently.

AVL data can also enable diagnosis of schedule reliability (consistent arrivals at stops on the same scheduled trip across successive days.) We did provide some reporting on this. However, there is limited data on appropriate management actions to control poor reliability. This might be a fruitful area of future research. However, from a customer point of view, this might be secondary to improving the basic level of on-time performance.

Scheduling has some elements of art as well as science. For example, the transition between peak hour running time and off-peak running time sometimes requires a gradual change in order to avoid long gaps in the headway of waiting customers.

We feel that although the tool can be used for optimization, it also has utility as a diagnostic tool to identify the routes, route segments and time periods which have the largest departure from technically optimal running times.

PLAN FOR IMPLEMENTATION

There are at least two pathways for implementing the results of this project. The first would be to work with current AVL system vendors to integrate this software into their project offering as a value-added service. This would enable some differentiation of their project from their competitors. A second channel would be to promote this product directly to transit systems which have AVL systems either when they are implementing new or replacement AVL systems.

The investigator is planning to demonstrate this product at the annual meeting of the New York Public Transit Association in the fall of 2014. Further, the investigator has a number of current and previous clients in the passenger transportation industry which would be targeted for presentations over the next several months.

GLOSSARY

AVL – automatic vehicle location

Block – a set of trips, usually on a single route which comprise an assignment to a single bus.

Cycle time – the duration of time that it takes a bus to leave a route terminal, travel in one direction, take recovery time, return to the original terminal and have layover in preparation for the next scheduled trip.

Half-cycle time – the duration of time between departure from a route terminal and the start of the subsequent trip assigned to the vehicle.

Headway – The scheduled time interval between successive buses on a route in a single direction.

Layover – the time at the end of a trip necessary to provide some break time to a driver and schedule recovery.

Pattern - A path defined as a specific sequence of bus stops on a route

Recovery time – The time at the end of a trip to allow for deviations in actual running time.

Running time - the travel time between successive timepoints

Segment – the path between two successive timepoints

Service – a type of schedule relating to a specific day of week (i.e. weekday, Saturday and Sunday)

Terminal – the first (departing) or last (arriving) stop on a trip

Timepoint – a location on a route where there is a specified departure time. There are many more stops than timepoints.

Trip – A bus journey on a route characterized by a start time and location and an end time and location.

REFERENCES

1. Rainville, Walter S., *Bus Scheduling Manual: Traffic Checking and Schedule Preparation*, American Transit Association, New York, NY 1947. Reprinted by the Urban Mass Transportation Administration, Washington, DC, 1982.

INVESTIGATOR PROFILE

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The principal investigator for this project is Dr. Jack M. Reilly, president of Pascal Systems, Inc. He is currently a Professor of Practice in the Department of Civil and Environmental Engineering at Rensselaer Polytechnic Institute in Troy, NY. His teaching responsibility includes courses in transportation analysis, economics and design. Prior to this, he was Deputy Executive Director of the Capital District Transportation Authority in Albany, NY.

He has done considerable work over his career in the area of transit operations analysis. He was project manager for a number of transit development studies in cities such as Charlotte, Denver and Ann Arbor. He recently completed a project to develop a guidebook on transit capacity in developing countries for the World Bank. He has also been an advisor to the World Bank on a number of intelligent transportation system projects in India and China.