# Accuracy and Precision of TriMet's Transit Tracker System

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November 15, 2006

Word Count: 6,900

## ABSTRACT

This paper presents an analysis of the accuracy and precision of TriMet's Internet- and telephone-based real-time arrival information system referred to as Transit Tracker. Although Transit Tracker provides estimates of the arrival times of both bus and rail vehicles, this analysis is limited to bus vehicles. Archived data from TriMet's automatic vehicle location (AVL) and automatic passenger counter systems was used to compare actual bus arrival times with Transit Tracker estimates drawn from logs created in the estimation process. Accuracy was evaluated primarily by calculating the mean of the difference between the actual bus arrival times and the Transit Tracker-estimated arrival times. Precision was determined largely by the degree of variation in the estimates, and measured by the standard deviation of the difference between the actual bus arrival times and the Transit Tracker-estimated arrival times. Finally, an arrival estimation error model was developed to test the effects of a series of factors on the degree of estimation error.


## INTRODUCTION

### Extent of Real-time Transit Information Systems in Industry

According to TCRP Synthesis 48, as of 2000, 88 transit agencies in the United States had operational AVL systems and 142 were planning AVL systems. In addition, there were 291 operational automated transit information systems in the United States, with 48 planned. Real-time bus arrival information systems accounted for some of these automated transit information systems, in addition to other pre-trip, wayside, and in-vehicle systems.(*1*) It is likely that by 2006, many more agencies had deployed AVL and real-time bus arrival information systems.

The majority of real-time bus arrival information systems are based on the use of data from Global Positioning System (GPS)-based AVL systems. Other types of AVL systems, such as signpost and transponder systems, are also being used to generate real-time arrival information. The location data generated from AVL systems are used together with other information, such as current and historical traffic conditions, and real-time operations data (e.g., travel time between specific stops) from the last several buses that passed a particular stop, to predict the arrival time of the next bus at that stop.(*1*)

### Previous Studies

As part of an FTA Field Operational Test conducted in Blacksburg, Virginia, Lin and Zeng developed four GPS-based bus arrival time estimation algorithms. In addition to GPS-based bus location data, other information was used as input data, including bus schedule information, bus delay patterns, and bus stop type information (e.g., a timepoint vs. a regular stop). Whereas all these algorithms used GPS-based bus location data, the level of other information used in each algorithm varied. Lin and Zeng measured the performance of each algorithm using the following criteria: overall precision, robustness, and stability. The precision measure determined the average deviation of the predicted arrival from the actual arrival. Robustness measured the extent to which the algorithm gave a prediction far off the actual arrival time. Stability gauged the degree of prediction fluctuations. They determined that the dwell time at timepoints is most significant to the performance of each algorithm. In particular, because the arrival and departure times of a bus occurred within a small time window, it was assumed that the arrival time was equal to the departure time. But at timepoints, a bus could have dwelled for up to five minutes. The estimation algorithm that took this dwell into account experienced the best performance.(*2*)

Mishalani *et al* pointed out that methods to evaluate the benefits of real-time bus arrival information are limited. However, in their modeling of three bus arrival information system alternatives reflecting different real-time AVL data availability, they found that the type of data as well as operations characteristics--such as variations in headways and dwell time--significantly affect the value of real-time arrival information to passengers.(*3*)

Hickox reported on a real-time bus arrival pilot project conducted by the Delaware Transit Corporation in 2000. The transit system used headway management instead of scheduled timepoints, and did not publish a timetable--only a range of headways. An arrival estimation method was needed that could provide real-time information without schedule adherence as an input. A predictive arrival system was then developed that calculated expected arrivals based on historical transit performance. A database of transit operations “experience” was developed over several months preceding the implementation and used as the basis for the decision making process of this predictive algorithm. Tests conducted following implementation revealed a degree of accuracy of plus or minus 30 seconds.(*4*)

## TriMet’s Transit Tracker System

Transit Tracker is the name given to TriMet’s real-time customer information system, which provides rail and bus arrival estimates via the Internet, telephone, and light-emitting diode (LED) displays at a limited number of rail platforms and bus stops. TriMet’s AVL system is the basis for the availability of real-time arrival information. The system tracks each bus (via GPS) and rail vehicle (via electronic signals in the track), and receives an update of the early/late status of each vehicle approximately every 90 seconds. The arrival estimation algorithm relies on both the current location of the vehicle as well as its current early/late status.

Demand for the Internet and telephone components of Transit Tracker have shown significant growth. Figure 1 shows the number of Transit Tracker site visits by month from June 2005 through June 2006, along with the number of calls for telephone-based arrival information.

An arrival estimate is calculated by applying a correction to the scheduled running time of the vehicle between its current location with that of the desired stop by the amount of time the vehicle is reporting to be early or late. For example, if a bus that is scheduled to arrive at a stop at 3:00 is exactly on time a distance prior to the stop that is scheduled to take ten minutes to traverse (i.e., at 2:50), the arrival estimate would be ten minutes at that point (i.e., arrival at 3:00). If the bus becomes delayed five minutes later (i.e., at 2:55), and then reports its early/late status as three minutes late at that point, that three minutes is then added to the remaining five minutes of scheduled running time, resulting in a revised arrival estimate of 8 minutes (i.e., now estimated to arrive at 3:03, compared to 3:00 previously). It should be noted that these estimates are not generated upon user demand, but are constantly being calculated and appended to database tables created in the estimation process. A user seeking an arrival time estimate is essentially querying the existing set of estimates for their specific bus stop.

If the AVL system loses contact with a bus and does not receive timely early/late status updates, arrival estimates are then replaced with a display of scheduled arrivals until contact is restored. In addition, when a bus is out of service between trips (i.e., laying over or traveling to its starting point "deadheading" ), arrival estimates are based on the schedule until the bus enters service and begins providing early/late status updates. Thus, the system depends on buses departing the layover location on time; buses that have not yet departed the location are ignored until early/late updates are provided once the bus actually departs the location.

The arrival estimation algorithm is the same for the three dissemination modes, although the architecture differs. The arrival estimates for both the Internet and telephone components are computed within TriMet's central server, while for the LED display components, the estimates are computed by processors housed in the displays themselves. This analysis is limited to the Internet and telephone Transit Tracker components of the system.

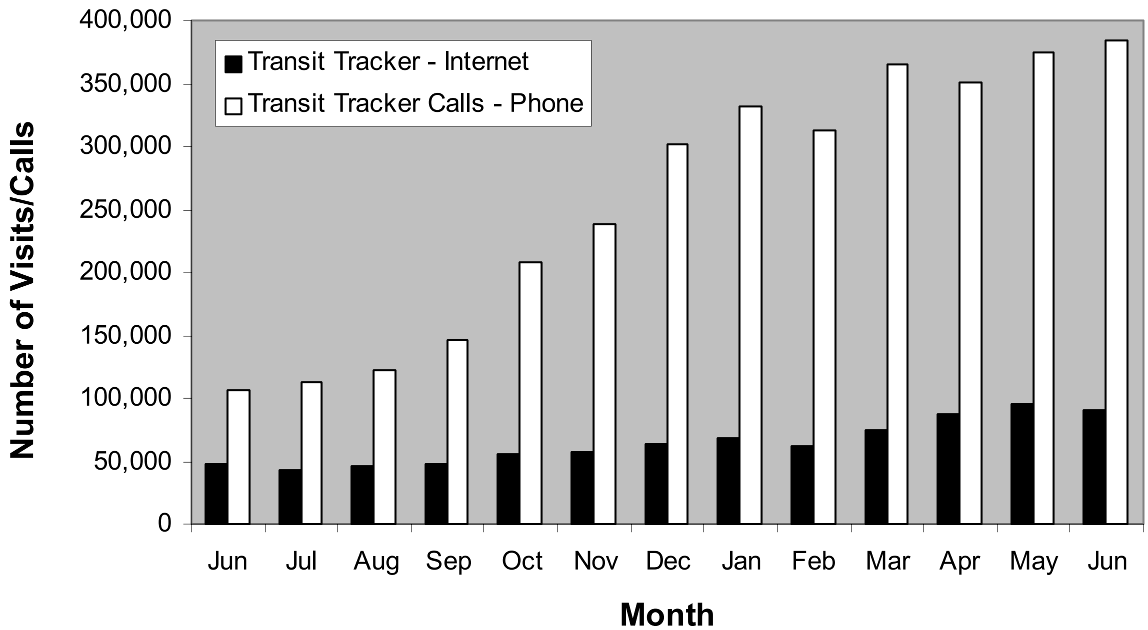



**FIGURE 1 Number of Transit Tracker Visits/Calls, June 2005 to June 2006.**

## METHODOLOGY

In this analysis, archived data from TriMet's automatic vehicle location (AVL) system was used to compare actual bus arrival times with Transit Tracker estimates. Although archived rail arrival data is also available, the bus data has historically proven to be much more useful for analysis purposes. Rather than utilizing a GPS-based AVL, the rail arrival data is a byproduct of a rail control system based on track circuits that contains relatively few data points. Thus, the bus AVL data has shown to be richer and more complete than the rail data. Hence, this analysis excludes rail vehicles.

Arrival estimation accuracy (or error) was examined primarily by calculating the mean of the difference between the actual bus arrival time (per the AVL) and the Transit Tracker-estimated arrival time for a set of estimates drawn from logs created in the estimation process. If the calculated confidence interval around the mean error includes the value zero, it can be concluded that the estimates are reasonably accurate.(*5*) It is expected that a number of factors may affect the accuracy of arrival estimates, including the number of minutes until the estimated arrival, where on a particular route the stop for which an estimate is made is located (i.e., how far from the route starting point), the on-time status of the bus, the time of day, and different levels of operator experience.

Precision was determined largely by the degree of variation in the estimates, which can be measured by the standard deviation or the coefficient of variability of the difference between the actual and estimated bus arrival times. The estimates can exhibit a high degree of accuracy (i.e., the mean error equals zero) while still being imprecise if the range of observations of error about the mean is great.(*5*) It is expected that a number of largely random factors may affect the precision of arrival estimates, including variations in passenger activity, traffic conditions, and weather.

Passengers' perceptions of estimate reliability or predictability is likely related to the degree of precision. If a set of arrival estimates is consistently or systematically incorrect but with little variation over time (i.e., inaccurate but precise), a passenger may associate that set of estimates with a higher degree of reliability than one where the estimate varies significantly over time (i.e., imprecise). In addition, inaccurate estimates can be mitigated through the application of correction factors.

Seven routes were selected based on their representation of the different types of bus routes in TriMet's system (Table 1). Routes classified as regional trunk, urban radial, and crosstown are characterized by high frequency service and a large number of boardings; note the relatively large number of trips and observations (one observation for each successive arrival estimate made for each stop) for those routes. Peak express routes operate primarily in the morning and afternoon peak periods, while feeder and secondary radial routes are characterized by less frequent service.

The analysis sample was also limited to weekday trips in order to gauge the performance of the estimation process during the greatest amount of transit system activity. Due to the large number of records created when matching AVL data with the Transit Tracker log file, five weekdays in May 2005 were chosen. May generally corresponds with the largest amount of passenger activity on TriMet's bus and rail system. The same days were used for each of the

**TABLE 1 Routes Selected for Analysis**

| | | | Number in Sample | | |
|---|---|---|---|---|---|
| **Route Number** | **Route Name** | **Route Type** | **Trips** | **Stops** | **Observations** |
| 12 | Barbur Blvd. | Regional Trunk | 141 | 161 | 408,187 |
| 14 | Hawthorne | Urban Radial | 190 | 117 | 558,299 |
| 51 | Vista | Secondary Radial | 51 | 122 | 48,303 |
| 66 | Marquam Hill-Hollywood TC | Peak Express | 5 | 37 | 1,689 |
| 72 | Killingsworth-82nd Ave. | Crosstown | 215 | 235 | 1,198,710 |
| 88 | Hart-198th Ave. | Feeder | 16 | 140 | 32,021 |
| 96 | Tualatin I-5 | Peak Express | 45 | 94 | 50,954 |
| | | **TOTALS:** | **663** | **906** | **2,298,163** |

seven routes. Finally, only estimated minutes until arrival from 0 to 15 were selected, with the expectation that most passengers find estimated arrival times of 15 minutes or less the most useful, and that inclusion of larger values in the analysis could skew the results. Note that the case of 0 minutes until arrival corresponds with a display of “Due” on the Internet interface or an indication of “Due Now” from the telephone system.

## RESULTS

Table 2 displays a set of descriptive statistics for the arrival estimation error by route and direction. As described previously, arrival estimation error is the difference between the actual and estimated arrival time of the bus. Thus, if the bus arrives 30 seconds later than the estimated time, the error would be +30 seconds; if the bus arrives 30 seconds earlier than the estimate, the error would be -30 seconds.

The data indicate that both the overall mean and median error are greater than zero, suggesting that error is biased toward the condition where the bus arrives after the estimated time, or where the arrival estimate is “early.” This could be a reflection of the bus “losing time” before an update of its early/late status has been received by the AVL system, and subsequently making an estimate based on “stale” early/late data. The bus could be losing time because of an insufficient allocation of running time on its route and/or between the current and previous stops.

Note the variation in degree of error from route to route, and between inbound and outbound trips. The limited number of observations for Route 66 may be partially responsible for the large variation in error values, although it should be noted that this route along with others that serve the Oregon Health & Science University area are known for poor AVL tracking performance. This area is characterized by steep terrain and heavy forest cover, which together can significantly impact the quality of GPS reception.

Table 3 displays the same descriptive statistics by the estimated number of minutes until arrival (up to 15). The largest mean error appears to occur with estimates of 11 minutes until arrival, and then decreases as the estimated arrival time approaches, except for a slight increase where the bus is designated as “due” at zero minutes. The standard deviation of error shows a similar pattern.

One explanation for the slight increase in error at zero minutes could be related to variation in the amount of time a bus remains at a stop. This can depend on the number of passengers boarding or alighting, whether or not the wheelchair lift is deployed, or if the bus even stops there. An explanation for the decrease in error beyond 11 minutes could be related to more buses being in layover situations at the time those estimates are provided, and, thus, the estimates being based on the schedule instead of the actual early/late status. Perhaps starting at the 11 minute mark, a large number of buses are beginning to report their early/late status, and subsequently estimate error decreases.

Figure 2 shows the frequency distribution of arrival estimation error, with the median, mean, and 95th percentile denoted. Again, the positive skew of the distribution indicates that more often buses are arriving later than their estimated arrival time.

Table 4 contains the analysis variables used in the error estimation model and their descriptions along with their expected effects on the model. Figure 3 shows the mean error and the coefficient of variability of error by accumulated distance from the beginning of the route (for all routes), aggregated into arbitrary distance classifications. The mean error turns out to be

**TABLE 2 Descriptive Statistics for Arrival Estimation Error, by Route and Direction**

| | | Error (sec.) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Route | Dir | Mean | Median | 95th Percentile | Min | Max | Lower 95% CL | Upper 95% CL | Standard Error | Standard Deviation | CV | N |
| 12 | 0 | 25.27 | 11 | 215 | -427 | 1171 | 24.78 | 25.77 | 0.25 | 112.55 | 4.45 | 197221 |
| 12 | 1 | 20.25 | 6 | 208 | -914 | 787 | 19.79 | 20.70 | 0.23 | 106.99 | 5.28 | 210966 |
| 14 | 0 | 29.49 | 17 | 205 | -956 | 1136 | 29.12 | 29.86 | 0.19 | 101.59 | 3.44 | 291638 |
| 14 | 1 | 7.43 | -2 | 161 | -936 | 869 | 7.09 | 7.77 | 0.17 | 89.71 | 12.07 | 266661 |
| 51 | 0 | 29.42 | 16 | 197 | -809 | 739 | 28.16 | 30.68 | 0.64 | 94.86 | 3.22 | 21709 |
| 51 | 1 | 11.05 | 1 | 142 | -524 | 999 | 10.04 | 12.07 | 0.52 | 84.35 | 7.63 | 26594 |
| 66 | 0 | -73.05 | -71 | 248 | -385 | 315 | -86.33 | -59.77 | 6.76 | 143.50 | -1.96 | 451 |
| 66 | 1 | 27.02 | 2.5 | 248 | -534 | 384 | 21.10 | 32.94 | 3.02 | 106.20 | 3.93 | 1238 |
| 72 | 0 | 34.18 | 17 | 214 | -946 | 1185 | 33.91 | 34.44 | 0.14 | 106.23 | 3.11 | 610787 |
| 72 | 1 | 21.47 | 8 | 192 | -952 | 1153 | 21.23 | 21.71 | 0.12 | 94.84 | 4.42 | 587923 |
| 88 | 0 | -2.83 | -7 | 148 | -856 | 522 | -4.16 | -1.49 | 0.68 | 89.49 | -31.67 | 17275 |
| 88 | 1 | -1.23 | -9 | 120 | -226 | 1141 | -2.64 | 0.18 | 0.72 | 87.40 | -70.91 | 14746 |
| 96 | 0 | 38.01 | 20 | 241 | -892 | 616 | 36.64 | 39.39 | 0.70 | 112.05 | 2.95 | 25517 |
| 96 | 1 | 37.98 | 23 | 267 | -892 | 896 | 36.41 | 39.54 | 0.80 | 127.44 | 3.36 | 25437 |
| | **Overall** | **24.43** | **10** | **201** | **-956** | **1185** | **24.30** | **24.56** | **0.07** | **101.84** | **4.17** | **2298163** |

**TABLE 3 Descriptive Statistics for Arrival Estimation Error, by Estimated Minutes until Arrival**

| | Error (sec.) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimated Minutes until Arrival | Mean | Median | 95th Percentile | Min | Max | Lower 95% CL | Upper 95% CL | Standard Error | Standard Deviation | CV | N |
| 0 | 18.49 | -1 | 104 | -94 | 1185 | 18.10 | 18.87 | 0.20 | 90.24 | 4.88 | 210736 |
| 1 | 13.93 | 2 | 114 | -140 | 1122 | 13.59 | 14.27 | 0.17 | 67.08 | 4.82 | 147321 |
| 2 | 17.28 | 5 | 139 | -187 | 1005 | 16.89 | 17.66 | 0.20 | 75.51 | 4.37 | 146914 |
| 3 | 20.06 | 7 | 159 | -259 | 999 | 19.62 | 20.50 | 0.22 | 85.41 | 4.26 | 145303 |
| 4 | 21.56 | 10 | 172 | -300 | 909 | 21.10 | 22.03 | 0.24 | 90.15 | 4.18 | 143806 |
| 5 | 23.99 | 12 | 186 | -375 | 868 | 23.49 | 24.49 | 0.26 | 96.67 | 4.03 | 143428 |
| 6 | 26.21 | 15 | 199 | -452 | 814 | 25.69 | 26.73 | 0.27 | 100.91 | 3.85 | 143998 |
| 7 | 28.08 | 16 | 210 | -476 | 764 | 27.54 | 28.63 | 0.28 | 104.82 | 3.73 | 142031 |
| 8 | 29.27 | 18 | 219 | -526 | 698 | 28.70 | 29.83 | 0.29 | 107.90 | 3.69 | 140212 |
| 9 | 30.00 | 19 | 228 | -594 | 633 | 29.42 | 30.59 | 0.30 | 111.76 | 3.72 | 139257 |
| 10 | 31.07 | 20 | 236 | -646 | 573 | 30.46 | 31.67 | 0.31 | 114.65 | 3.69 | 137849 |
| 11 | 32.42 | 22 | 243 | -710 | 521 | 31.80 | 33.04 | 0.32 | 116.89 | 3.61 | 136816 |
| 12 | 31.66 | 23 | 240 | -772 | 478 | 31.04 | 32.29 | 0.32 | 117.13 | 3.70 | 135220 |
| 13 | 29.52 | 23 | 234 | -838 | 409 | 28.89 | 30.15 | 0.32 | 116.93 | 3.96 | 133108 |
| 14 | 24.71 | 21 | 218 | -894 | 350 | 24.08 | 25.34 | 0.32 | 114.96 | 4.65 | 128728 |
| 15 | 16.54 | 17 | 190 | -956 | 293 | 15.93 | 17.16 | 0.32 | 110.77 | 6.70 | 123436 |
| **Overall** | **24.43** | **10** | **201** | **-956** | **1185** | **24.30** | **24.56** | **0.07** | **101.84** | **4.17** | **2298163** |

**TABLE 4 Analysis Variables**

| Variable | Description | Expected Effects on Model |
|---|---|---|
| Arrival Estimation Error | The difference between the actual and the Transit Tracker-estimated arrival time of a bus for a set of estimates, in seconds. A negative value indicates that the bus arrived before the estimated time; a positive value indicates that the bus arrived after the estimated time. | n/a |
| Schedule Deviation | The difference between the actual and scheduled bus departure time from a stop, in seconds. A negative value indicates that the bus has departed early; a positive value, late. | Little effect unless deviations change rapidly, such as from operators attempting to make up time. The estimation algorithm uses the updated early/late status from vehicles to generate the estimate, so schedule deviation should largely be compensated for. |
| Estimated Load | The estimated number of passengers on board the bus at a given stop after all passengers have boarded and alighted. | Some effect, as increased loads tend to lead to longer dwells and greater schedule deviation. |
| Minutes until Arrival | The number of minutes until the bus is estimated to arrive at a given stop. Estimates beyond 15 minutes were not used in this analysis. | Error is expected to decrease as the bus approaches a stop for which arrival estimates are being made. Since the estimates rely on updates of the early/late status of the bus, the accuracy of the estimate is expected to increase with each update. |
| Stop Distance | The accumulated distance between the beginning of a route and the bus stop for which arrival estimates are being provided, in feet. | Error is expected to be at a minimum near the midpoint of a route, and greater at the beginning and end of a route. This is likely related to the effect of layovers (which occur at trip ends) on the estimate algorithm. |
| Direction | A dummy variable equaling one for inbound trips, and 0 for outbound trips. | Little effect, other than the peak direction (e.g., outbound in PM peak) may have slightly greater error due to larger loads and greater passenger activity. |
| AM Peak | A dummy variable equaling one for estimates made for trips initiated between 7:00 and 8:59 am--or where the midpoint of the crosstown and feeder routes are between those times--and 0 otherwise. | Slightly more error than at other times. |
| PM Peak | A dummy variable equaling one for estimates made for trips initiated between 4:00 and 5:59 pm--or where the midpoint of the crosstown and feeder routes are between those times--and 0 otherwise. | Slightly more error than at other times, possibly greater than during the AM peak. |

**TABLE 4 Analysis Variables (continued)**

| Variable | Description | Expected Effects on Model |
|---|---|---|
| Regional Trunk | A dummy variable equaling one for routes classified as regional trunk routes (i.e., 12), and 0 otherwise. | Slightly more error than other types of routes, given the large amount of passenger activity associated with trunk routes. |
| Urban Radial | A dummy variable equaling one for routes classified as urban radial routes (i.e., 14), and 0 otherwise. | Slightly more error than other types of routes, but likely less than trunk routes. |
| Secondary Radial | A dummy variable equaling one for routes classified as secondary radial routes (i.e., 51), and 0 otherwise. | Little effect. |
| Peak Express | A dummy variable equaling one for routes classified as peak express routes (i.e., 66 & 96), and 0 otherwise. | More error than other types of routes, due to their operation during times of highest transit activity. Also, these types of routes tend to have a higher percentage of deadheading (operating out of service to or from the garage) than other types of routes, which can effect estimate error. |
| Crosstown | A dummy variable equaling one for routes classified as crosstown routes (i.e., 72), and 0 otherwise. | Some effect, as crosstown routes tend to be longer than many routes, and thus can accumulate larger degrees of schedule deviation. |
| Feeder | A dummy variable equaling one for routes classified as feeder routes (i.e., 88), and 0 otherwise. | Little effect. |
| Full Time | A dummy variable equaling one for trips with full time operators, and 0 otherwise. | Trips with full-time operators are assumed to have a higher percentage of experienced operators who may be able to stay on time more often than less experienced operators. Thus, these trips are expected to be associated with less error. |

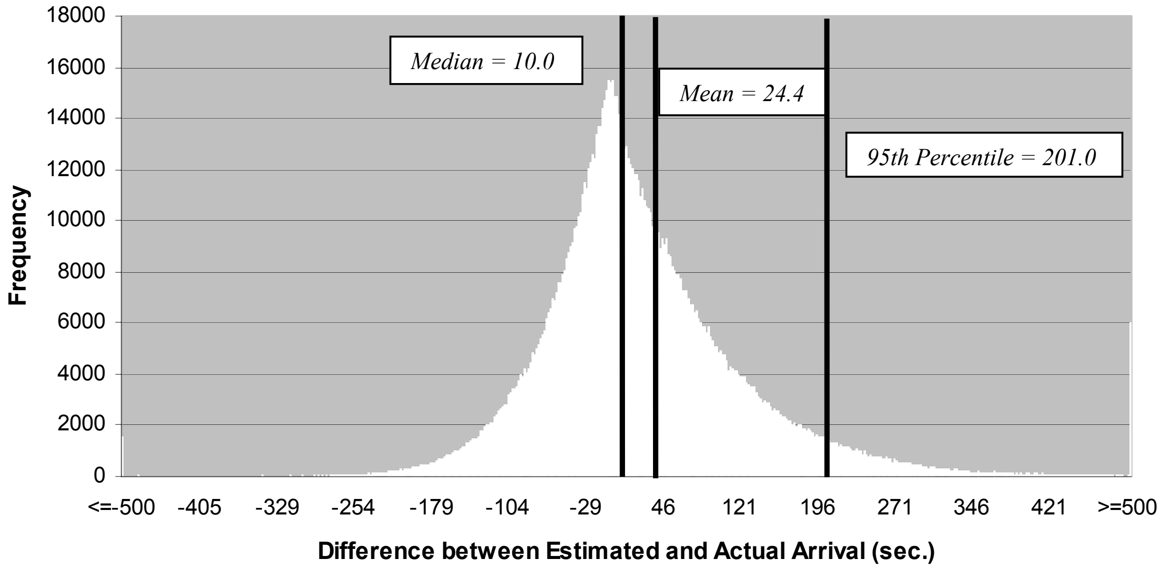



**FIGURE 2 Frequency Distribution of Transit Tracker Arrival Estimation Error.**

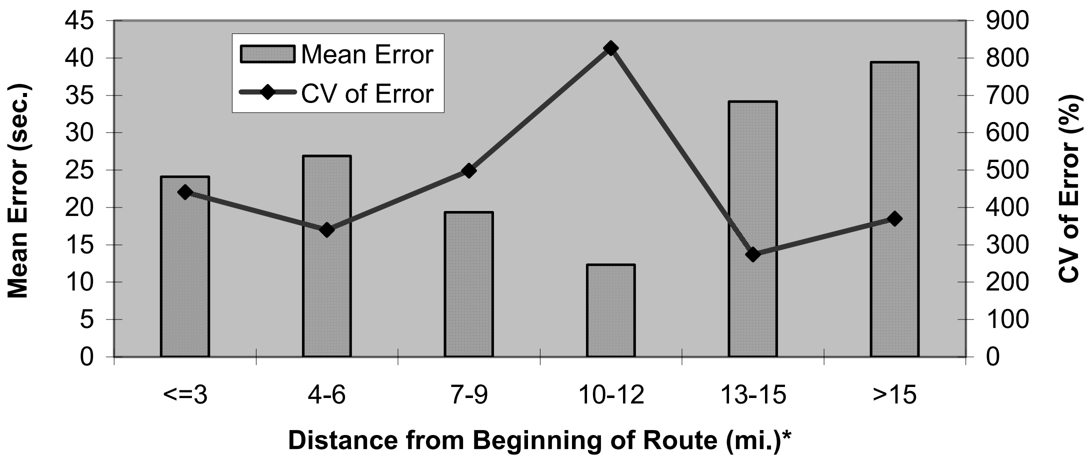
the least for arrival estimates at stops between 10 and 12 miles from the beginning of the route, while the coefficient of variability is the greatest there. Figure 4 shows the mean error by distance for all observations (stops), without aggregation into classifications. And Figure 5 shows the mean error for all stops by distance for only the route 14 outbound; a clear pattern of "late" estimates for stops from about one to four miles from the beginning of the route, and "early" estimates for the remainder of the route is evident. Note also the relatively large degree of error at the first and last stops on the route.

## Error Estimation Model

Parameter estimates for a series of variables with potential influence on arrival estimation error are reported in Table 5. The coefficients in the table are interpreted as the change in seconds of estimation error associated with a unit change in a given variable. Of the variables tested, the variable representing peak express routes (8% of trips sampled) was associated with the largest impact on estimation error, adding nearly 25 seconds to the degree of error. That is, the arrival estimates for the two peak express routes analyzed deviated almost 25 seconds from the actual arrival times.

These types of routes tend to operate during times of the highest transit activity and also tend to have a higher percentage of deadhead trips (those operating out of service to or from the garage) than other types of routes. As discussed earlier, when a bus is not reporting its early/late status (which includes when a bus is not in service, such as during a deadhead trip), Transit Tracker returns the scheduled time of arrival, which assumes the bus is exactly on time. However, if the bus is significantly off-schedule, the arrival estimates returned while the bus is not reporting will be incorrect to the degree the bus is off schedule until the early/late reporting resumes. This phenomenon is likely one reason for the larger degree of error associated with the peak express routes. In addition, as discussed earlier, one of the peak express routes examined, Route 66, serves the Oregon Health & Science University area, which is associated with poor AVL tracking performance.

The variable representing crosstown routes (32% of trips sampled) also seemed to have a deleterious effect on accuracy, adding over 12 seconds to the degree of error. Some degradation in estimation accuracy was expected for these types of routes. Crosstown routes tend to be longer and have more stops than many routes. In fact, the crosstown route analyzed is one of the



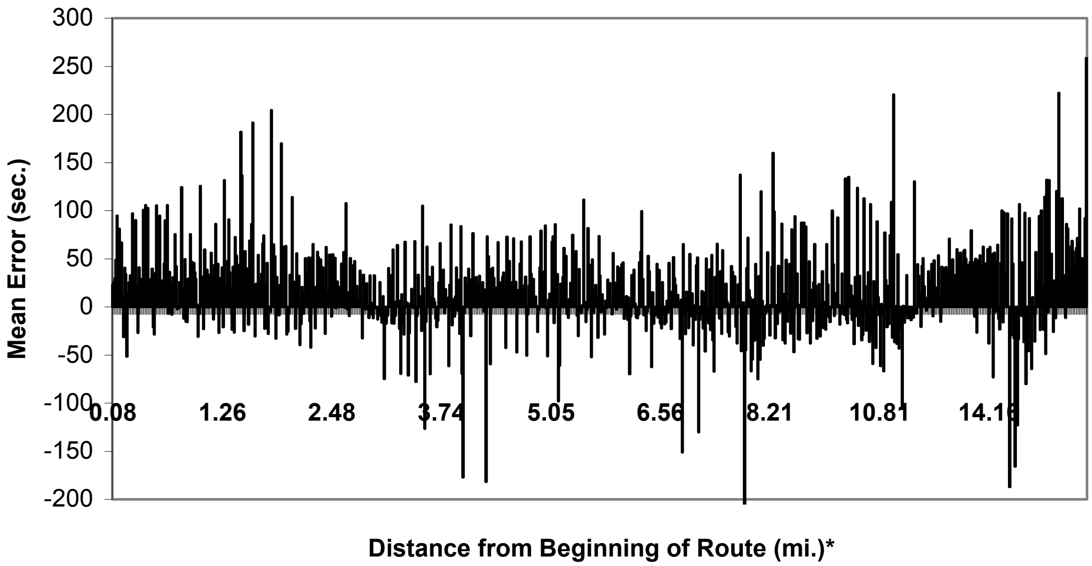

* 1 mi = 1.61 km.

**FIGURE 3 Mean and CV of Arrival Estimation Error by Distance from Beginning of Route.**

most heavily used in the system, and contains more trips than any of the other routes analyzed. The route is also characterized by stops that are served a high percentage of the time, resulting in a large number of stops being made along the route during most trips. To the extent that this activity results in poor schedule deviation and increased boarding and alighting time, arrival estimate accuracy could be affected.

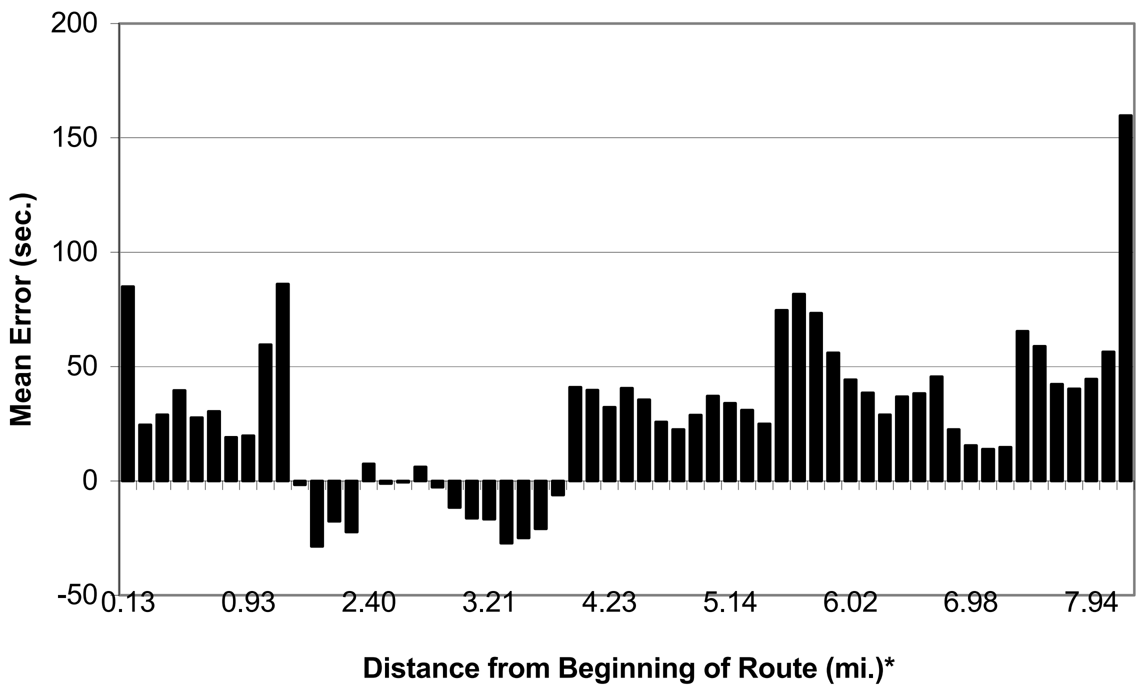
Conversely, the variable representing regional trunk routes (21% of trips sampled) was associated with a decrease in almost 10 seconds of error. This was unexpected, as these type of routes are also characterized by high passenger activity. The variables representing urban and secondary radials (29% and 8% of trips sampled, respectively) were also associated with a decrease in error, contrary to expectations that they would have little effect on accuracy. The number of observations associated with feeder routes (only 2% of trips sampled) was insufficient to determine coefficients.

Estimates made during the PM peak period are associated with slightly improved estimation, while those made during the AM peak period also show a decrease in error, although not as much as during the PM peak. It was expected that there would be more error during the PM peak, as general traffic conditions tend to be the worst and as passenger activity tends to be




* 1 mi = 1.61 km.

**FIGURE 4 Mean Arrival Estimation Error by Distance from Beginning of Route, All Observations.**




* 1 mi = 1.61 km.

**FIGURE 5 Mean Arrival Estimation Error by Distance from Beginning of Route, Route 14 Outbound.**

**TABLE 5 Arrival Estimation Error Model Parameter Estimates**

| Variable | Mean Value (Standard Deviation) | Coefficient (t-value) |
|---|---|---|
| Intercept | -- | -6.30 |
| | | (-11.96) |
| Schedule Deviation | 153.25 | 0.21 |
| | (226.50) | (754.86) |
| Estimated Load | 18.34 | -0.19 |
| | (13.19) | (-39.71) |
| Minutes until Arrival | 7.09 | 1.29 |
| | (4.67) | (100.78) |
| Stop Distance | 38074.98 | <0.01 |
| | (24011.62) | (-126.78) |
| Direction | 0.49 | -1.44 |
| | (0.50) | (-11.93) |
| AM Peak | 0.13 | -1.26 |
| | (0.34) | (-6.97) |
| PM Peak | 0.14 | -2.91 |
| | (0.34) | (-16.38) |
| Regional Trunk | 0.18 | -9.94 |
| | (0.38) | (-18.80) |
| Urban Radial | 0.24 | 6.14 |
| | (0.43) | (11.76) |
| Secondary Radial | 0.02 | 4.82 |
| | (0.14) | (7.36) |
| Peak Express | 0.02 | 24.27 |
| | (0.15) | (37.65) |
| Crosstown | 0.52 | 12.87 |
| | (0.50) | (24.94) |
| Feeder | 0.01 | * |
| | (0.12) | * |
| Full Time | 0.87 | 0.09 |
| | (0.34) | (0.47) |
| $R^2$ | | 0.21 |
| n | | 2298163 |

* Insufficient number of observations.

at its greatest during that period. The mean value of .13 and .14 for AM and PM peaks indicate that 13% of trips occurred during the AM peak, and 14% during the PM peak.

Inbound trips showed lower error levels than outbound, somewhat more of a difference than expected. Outbound trips tend to have the most activity during the PM peak; however, this explanation is at odds with the results expressed by the coefficients for the variables representing the PM and AM peak periods. The mean value of .49 indicates that there were slightly more outbound trips in the sample as inbound; inbound trips were represented by a value of one, while outbound trips by zero.

As expressed by the variable Minutes until Arrival, for every additional minute prior to a given estimated arrival time, over one second was added to the level of error. This is consistent with the expectation that estimates would become more accurate as the estimated time of arrival approaches.

Schedule deviation appears to have a small effect on error. The mean value of approximately 2.5 minutes (late) seems reasonable. As the estimation algorithm uses updated early/late information from the vehicle to generate its estimate, it is expected that the effect of schedule deviation alone should be somewhat small. Contrary to expectations, the variable representing estimated passenger load was associated with slightly reduced error as the load increased. The mean value of just over 18 passengers seems reasonable. Additionally, stop distance appeared to have almost no effect on estimation error in the model. It was expected that error would be worse near the beginning and end of a route, and minimal near the midpoint, as the middle of the route is expected to be insulated the most from the effect of layovers. The mean value of just over 38,000 feet, or slightly more than seven miles, represents roughly the midpoint of a typical route.

Full Time is a dummy variable representing full-time operators. This variable was used as a proxy for operator experience, as operators with greater seniority tend to have full-time shifts. The mean value of 0.87 indicates that 87% of trips were driven by full-time operators. Although full-time operators were expected to be associated with greater levels of accuracy, the variable appeared to have a negligible impact on estimation error.

## CONCLUSION

Based on this analysis, the factors having the most influence on the accuracy of Transit Tracker bus arrival estimates are route type, time of day, and the number of minutes until the estimated arrival. Factors such as passenger load, schedule deviation, and operator characteristics appear to have little or no influence on estimation accuracy. Notable patterns are revealed, however, when the number of minutes until estimated arrival and the target stop's distance from the beginning of the route are graphed against mean error. These results can be used to focus schedule improvement efforts on routes likely to experience degraded estimation accuracy and precision with the intent to increase the perceived reliability of the Transit Tracker system to passengers.

### Suggestions for Further Research

A factor that was not examined in this analysis is the quality of the fit between the scheduled and actual running time along an entire route or a portion of a route. A reasonable expectation would be that a route with a schedule with neither too much nor too little time built in would result in Transit Tracker arrival estimations with little or no error. AVL data could be further mined to analyze schedule adherence for entire routes, while schedule writers could be asked to provide input on which route segments are known to have this limitation and which are known to fit their schedule well. Arrival estimation under both conditions could then be compared.

Although the routes selected for analysis were generally representative of the different types of bus routes in TriMet's system, further research could focus more attention on routes where the error estimation model indicated the largest apparent impact on estimation error, such as the peak express routes, or ones with an insufficient number of observations to determine coefficients, such as the feeder route. Further analysis could also help determine if the apparent poor performance of peak express routes is due more to problems with the data than with systemic causes.

Further research could also compare the performance of Transit Tracker during service disruptions due to inclement weather--and the attendant higher demand on the system--with performance during normal operations. Presently, the performance of the system during service disruptions is a known limitation that future improvements to the system are anticipated to remedy. Rather than limiting the analysis to full-time and non-full-time operators, other types of operator characteristics such as years of experience and type of service (e.g., extra board, vacation relief, etc.) could be evaluated against arrival estimation error.

The notion of assigning a penalty to arrival estimates meeting certain criteria was not examined in this analysis. As explained earlier, arrival estimation error includes situations where a bus arrives before or after the estimated arrival time. In practical terms, a passenger may find one type of situation more burdensome than another. For example, if a passenger was relying on an arrival estimate by timing their departure from their home or office to their bus stop, and the actual bus arrival was prior to the estimate by enough time that they missed the bus, that would have a much more negative impact than the situation where the bus arrived a few minutes after the estimated time. It would perhaps be useful to apply some type of weighting to the computation of mean error where this type of impact can be included.

The issues associated with providing arrival estimates when at the time of the estimate a bus is out of service (either between trips and laying over, or traveling to its starting point "deadheading") was not thoroughly explored in this analysis. Depending on the location of the stop for which arrival estimates are desired, many estimates may be provided under these conditions. The Transit Tracker algorithm includes logic to accommodate layovers and deadheads, but the effectiveness of the logic has not been thoroughly examined. As described earlier, during these conditions, the schedule is used in lieu of the early/late status updates. This assumes, however, that the bus will depart the layover or enter service on time. If, for example, a bus leaves the layover location five minutes late, an erroneous estimate will be made until the early/late status is updated sometime after the layover departure. The arrival estimate will then "jump" by approximately five minutes once the update is received. The arrival estimates for stops with scheduled times from the layover of less than five minutes would eventually be displaying "due," while the bus never appeared. And worse, if the layover departure was early, prior to the resumption of early/late status updates the arrival estimates for those stops would be indicating that the bus has not yet arrived, even though it could have passed by.

Given the expanding use of real-time transit information systems in the industry as noted earlier, an analysis that compares the accuracy and precision of various systems as well as the various methods employed to develop vehicle arrival estimates would be particularly useful.

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