Trip Time Analyzers: Key to Transit Service Quality

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ABSTRACT

A trip time analyzer is a system for gathering and analyzing, off-line, data on transit operations. It consists of a location system; an on-board computer that logs events such as doors opening and closing, stamping each event with time and location data; software that interprets the event logs to reconstruct vehicle trajectories; and a database for storing and analyzing historical data. A trip time analyzer provides data from virtually every trip on running time by segment, schedule and headway deviation by timepoint, and delay by segment. Providing a high quality operation requires this kind of data. Benefits and capabilities of trip time analyzers are described, using examples from the TriTAPT system in use in Eindhoven, the Netherlands. Those benefits include monitoring operational quality; improving the schedule; diagnosing operational problems and evaluating countermeasures; supporting operators; supporting implementation of priority at traffic signals; and supporting research and innovation in operations management. Trip time analyzers are distinct from, but can share many components with, automatic vehicle location systems and automatic passenger counters.

In any service industry, a prerequisite to offering high quality service is data. The transit industry is no exception. However, for various reasons, the American transit industry as a whole has very little data with which to evaluate the quality of the service it offers. Where efforts have been made, often the emphasis has been on real-time location monitoring or on passenger counting. While real-time information is useful for managing service disruptions and passenger data is valuable for service planning and for evaluating benefits, data on operations – information derived from knowing each vehicle's trajectory in time and space – is the key to monitoring service quality. We use the term "trip time analyzer" to describe a system that collects and analyzes this kind of operational data.

Components of a Trip Time Analyzer System

A trip time analyzer is a system that logs time and location data all along the trip of a transit vehicle, and later (off-line) reconstructs bus trip trajectories, allowing one to analyze operational measures such as trip time, schedule adherence and headway deviations. If data is available about boarding and alighting passengers, also vehicle loads can be determined. The system can be broken into four components:

1. A vehicle location system. It may be based on beacons or global positioning, supplemented with dead reckoning. Radio data transmission to a control center, however, is not necessary.

2. On-board computers on every transit vehicle that track vehicle status and log events such as doors opening and closing, passing a speed threshold, and operator/ route changes. System software and interface hardware is also needed for the on-board computers to upload daily logs from the on-board computers to a computer at the garage, to download schedules from the garage onto the on-board computers, and to interface with the operator console and other on-board equipment.

3. Trip reconstruction software that converts the event logs into vehicle trajectories, breaks the trip time into components, and loads the refined data into a database.

4. Software for analyzing operations and service quality using the database.

The four components are modular, allowing efficient integration and competition among suppliers. For example, the first two components might exist as part of an automatic vehicle location system or a stop announcement system. The examples we report on come primarily from Eindhoven, a city of some 300,000 inhabitants in the south of the Netherlands. In that application, the vehicle location system uses underground two-way communication loops installed at signalized intersections to make them capable of providing priority for transit vehicles. Later the on-board computers were added to gather data and to provide information. The last two components are part of the software package TriTAPT (Trip Time Analysis in Public Transport) developed at the Delft University of Technology (1). TriTAPT was originally developed in the late 1970's to do research on operational control in public transport, using students with hand-held devices in place of on-board computers and a location system to gather data. Now, with data supplied by on-board computers, it serves as both a research tool and a transit management tool.

The Need for Trip Time Analysis

Manual data collection, using ride checks and spot checks by supervisors, has long been practiced to provide management with the minimal information it needs to make schedules. However, only automated data collection can provide the extensive data needed to monitor service quality. Where the U.S. transit industry has invested in automatic data collection, however, its focus has been either on passenger counting, or on real-time automatic vehicle location (AVL) systems that typically lack a data analysis capability. In contrast, transit systems in European countries such as Germany and Switzerland have a long tradition of gathering operational data using mechanical devices located in wheel hubs from which one can reconstruct vehicle trajectories. Not coincidentally, these are nations with a reputation for on-time performance.

A recent survey and synthesis of data analysis practice in large North American transit agencies undertaken by one of us (2) underscores the paucity of operations data available to support service quality in bus operations. Many large transit agencies adjust their weekday schedules once a year based on a single day's observation of running time.

Everyone agrees that on-time performance is a major component of service quality that affects traveler mode choice. However, because of the large number of observations needed, agencies without automated data collection have no chance of statistically monitoring on-time performance except at the system level. The sample size formula for proportions using the 95% confidence level is

$$tol = \frac{1.96\sqrt{p(1-p)}}{\sqrt{n}}\sqrt{1-\frac{n}{N}}$$

where n = necessary sample size, N = population size, p = fraction of trips that are on-time, and tol = tolerance (e.g., 0.03 means a $\pm$3% tolerance). The final term in this equation, called the finite population correction, can be ignored when the sample is small compared to the population from which it is drawn. However, it has a large effect when the sample size is a significant fraction of the population size, which is exactly the case with a trip time analyzer – the tolerance shrinks to near zero. For example, with 200 randomly selected observations from a large population, if 85% of the trips are observed to be on time (p=0.85), the tolerance is 5%. This means that one could be 95% confident that the on-time performance of the population of trips from which the sample was drawn was in the range [80% to 90%]. This is a rather broad range; for example, a management effort that improved on-time performance by 3% – not a trivial amount – would not be distinguishable from statistical noise. Until the sample size becomes a significant fraction of the population size, the necessary sample size increases steeply with a reduction in desired tolerance; for example, to achieve a tolerance of $\pm$3%, a sample size of 544 randomly selected observations would be needed. 'Randomly selected' means that it will not do for a checker to be stationed at a busy timepoint and observe all the buses that pass in a 2-hour period, or for an on-board checker to observe all the timepoints a bus passes. Those kinds of sampling have huge clustering effects that greatly increase the necessary sample size.

Of those transit systems surveyed, one (Pierce Transit, Tacoma, WA) was found that had a statistical program for monitoring systemwide on-time performance. Each month, 220 trip / timepoint combinations are randomly selected and observed by supervisors, who plan their daily work routine around the sample. As commendable as this effort is, it can only monitor systemwide trends. To improve service quality, one needs to be able to monitor on-time performance by route and timepoint, adjusting schedules, responding to changes in traffic, and implementing operational control at the level of a route or route segment. That requires a statistically valid sample for every route – something clearly impractical for an agency relying on manual data collection.

An even more disappointing finding of the survey, however, was the lack of operational data at agencies that have automatic data collection, either with AVL or automatic passenger counting (APC) systems. In most agencies with AVL systems, analyzing data off-line seemed to be an afterthought, if it was possible at all. Few of them were able to perform the trip time analysis function we describe by capturing location data and making it available in a useful form for off-line analysis. Several AVL systems were so incapable of producing data for off-line analysis that the agencies still used traffic checkers to measure on-time performance and running time. Another agency had specified that its AVL system be able to report systemwide on-time performance. The system they got only stores exception data (creates a record only when a bus is more than 5 minutes late); other operational data is lost.

This shortsightedness of AVL implementations in North America has been criticized by others (3). Clearly, the problem is not that capturing data for off-line analysis is a major technological challenge; the problem is that trip time analysis is not clearly specified in system conception and design. Reference 2 reviews some of the difficulties inherent in using AVL data that has been radioed in real-time to a control center and stored there, as opposed to data that has been recorded in the on-vehicle computer for later uploading. A design that does not include on-board event logging – and unfortunately most AVL systems in the field lack this feature – is not capable of performing the trip time analysis function.

The best analyses of trip time and punctuality found in the survey came from agencies with APC systems, which are built for off-line analysis. Nevertheless, passenger counting is their primary function, with trip time analysis as a byproduct. Data analysis capabilities tended to be crude and inflexible, although there is a trend of migrating to modern databases that should remedy this problem. Their major limitation is their low coverage. Because of the cost of the counting units, typically only about 10 percent of the fleet is equipped. Then because the fraction of data rejected as invalid tends to be large (10 to 50 percent), and because of logistical difficulties in getting equipped buses to their specified assignment, the typical return is only 1 or 2 observations per weekday trip per month. That small a sample may be sufficient for passenger counting, but is too small to provide a good statistical estimates of running time, headway, or schedule adherence at the individual trip level. Even if aggregated to the route / direction / period level, the fact that the data is clustered (collected on a small number of days, and therefore subject to common effects of traffic, weather, and season) makes the sample still too small to exploit the full benefits of trip time analysis.

Benefits of Trip Time Analyzers

The primary lesson we have learned from our experience is that trip time analysis is valuable in its own right. It deserves to be more than a byproduct or an afterthought of an automatic data collection system. To the credit of the North American transit industry, recent "smart bus" initiatives (4) include on-board event recorders, the necessary component for trip time analysis, in their system concept. Trip time analyzers also deserve to be considered as a stand-alone system, as is the case in Eindhoven, for agencies that cannot afford an AVL or APC system. The main purpose of this paper, then, is to highlight the benefits of trip time analysis, using examples from the TriTAPT system.

Monitoring Operational Quality

Operational service quality has four components: schedule adherence, headway regularity, speed, and synchronism. Each of these measures can be monitored by a trip time analyzer.

Schedule Adherence

In Figure 1, schedule deviation at every stop for every trip on Eindhoven's Route 1 outbound on a single bad day (the signal priority system was not working) is displayed. Stop codes are labeled on the horizontal axis; deviations (positive = late) are shown on the vertical scale. Each narrow broken line represents a single trip. One can readily observe the large spread, showing the need for operational control, and the drift away from a horizontal line, showing that the scheduled running time is not realistic. Up-and-down fluctuations on such a graph indicate that scheduled running time is too short on some segments and too long on others.

In Figure 2, schedule deviations on the same route are shown for all the weekdays in a one month period. Because of the large number of trips involved, it shows a statistical summary (mean, minimum, maximum, and 15- and 85-percentile deviations at each stop) rather than displaying every trip (1213 trips). One can see, in spite of significant variations at the dispatch stop, that most schedule deviations lie in a rather tight range of [–1,3] minutes late, indicating a good schedule, good operational control, and good quality service.

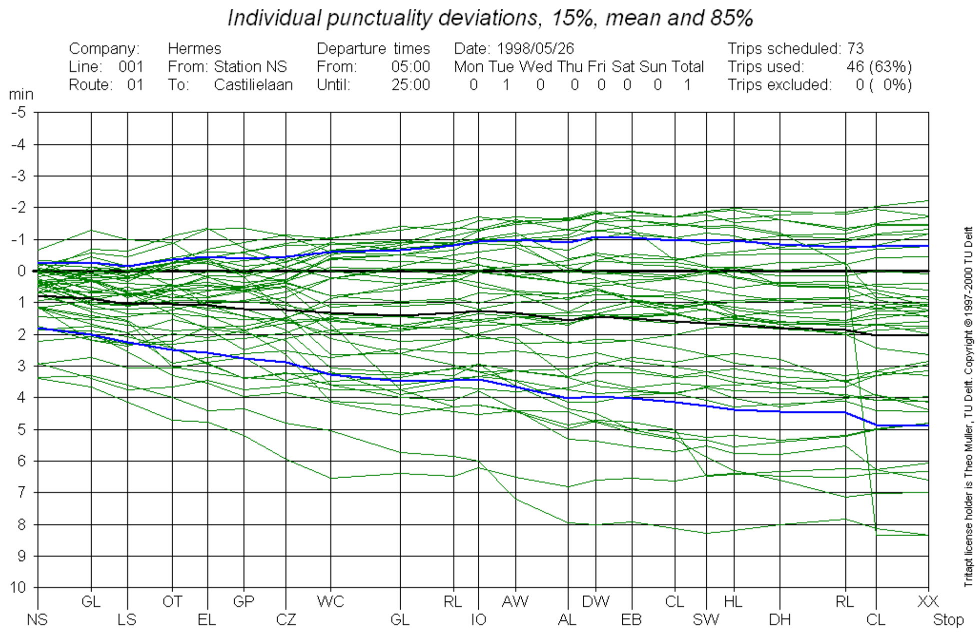

Figure 1. Schedule deviations without operational control

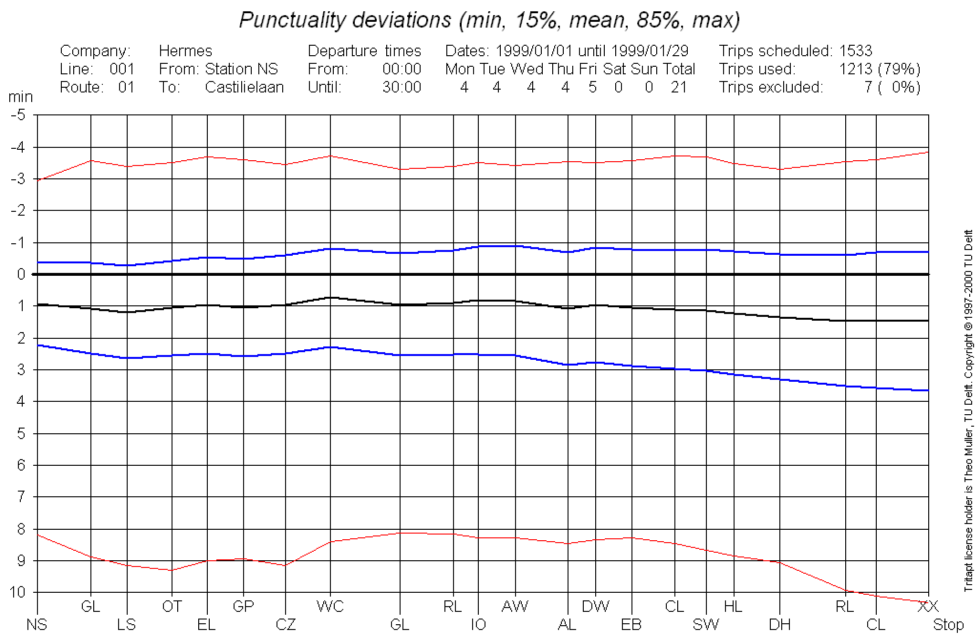

Figure 2. Schedule deviations on weekdays in January, 1999.

Headway Regularity

In short headway service, headway regularity is important to prevent overcrowding and long wait time. In Figure 3, headway deviation (absolute deviation as a fraction of the scheduled headway) at every stop on a route is displayed for a particular day.

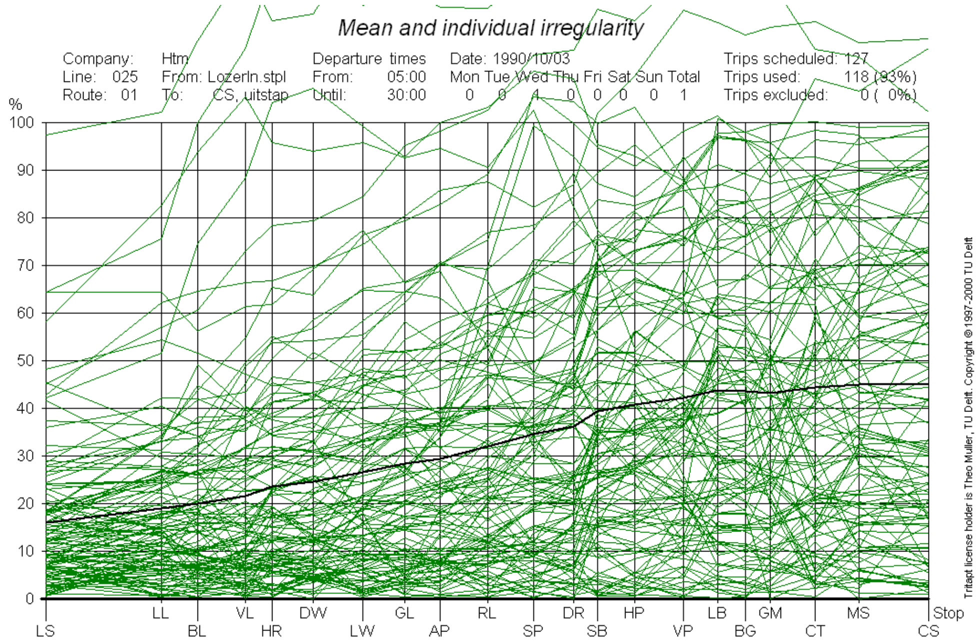

Figure 3. Proportional regularity deviations

A light rail application in Boston (5) shows further examples of headway analyses than can be done by trip time analysis.

Speed

Speed, a prime determinant of service quality, often begins to deteriorate due to congestion before the schedule reflects it. The graph in Figure 4 shows a segment-by-segment distribution of operational speed along a route, as experienced by passengers. The graph in Figure 5 displays “passing speed” which excludes dwell time, and is comparable with the speed of private cars to evaluate traffic operations.

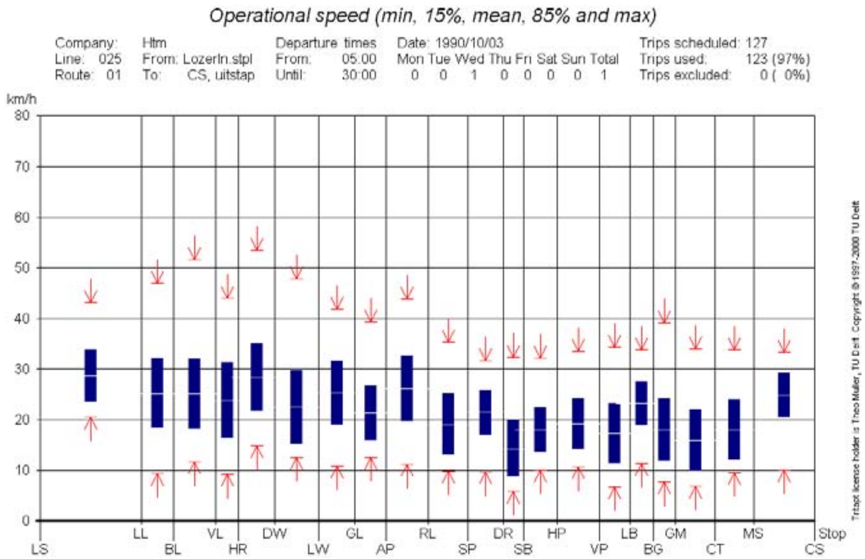

Figure 4. Operational speed

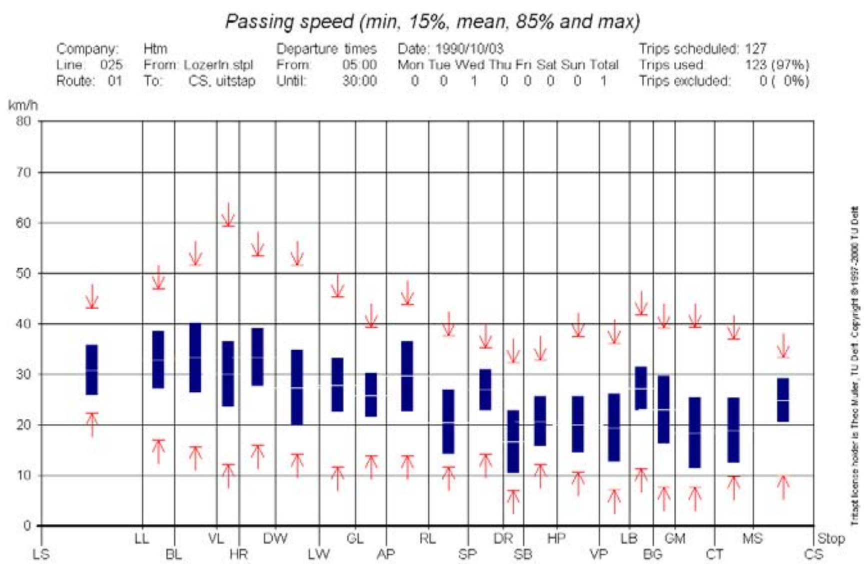

Figure 5. Passing speed

Synchronism

Synchronism is partly a matter of the schedule (are there good scheduled connections?) and partly a matter of operations (were the connections made?). The TriTAPT system does not yet include a report on synchronism. However, with operational data collected routinely on every bus, a trip time analyzer has the necessary data to monitor connections.

Improving the Schedule

Route Running Time

A statistical summary of end-to-end running time for each trip in the weekday schedule, based on many days' observation, is shown in Figure 6. Schedule makers can see not only the mean but also the variability of running time, which is important for choosing the scheduled running time and necessary layover time.

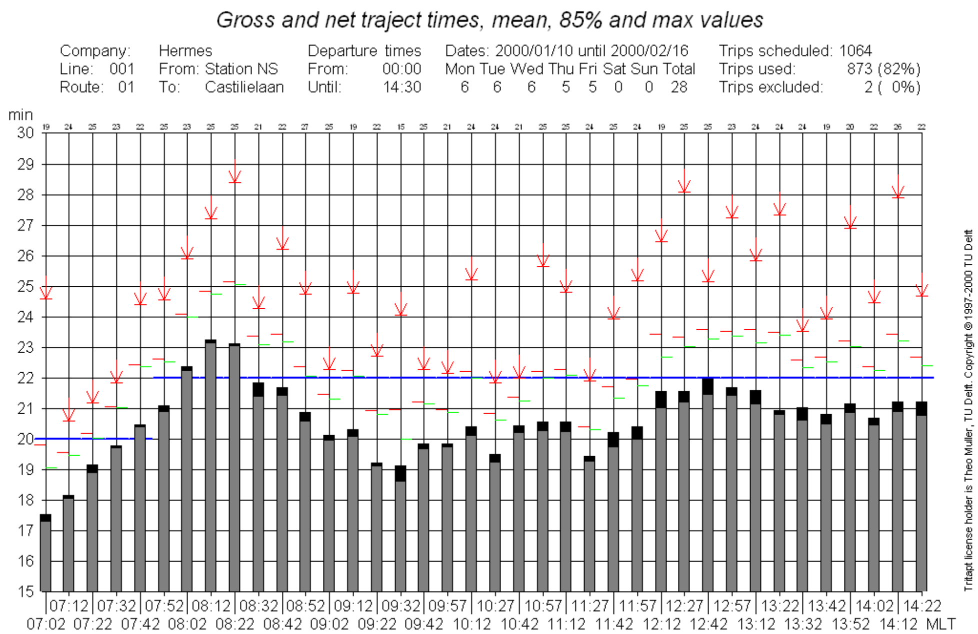

Figure 6. Trip times

A further analysis, shown in Figure 7, suggests scheduled running times. The user specifies a percentile band – e.g., give me scheduled times that lies between the 75-percentile and 95-percentile observed running time – and an algorithm breaks the day into homogeneous contiguous periods with whole minute scheduled times that meet the criterion.

Running time analyses are based on "net trip time," which is running time minus holding time (extra time spent by operators at a stop to avoid departing early). This is estimated by the analysis software based on a trip's early / late status and the distribution of dwell time at each stop. Without this correction, if operators conscientiously avoid early departures, one would never observe a running time shorter than scheduled.

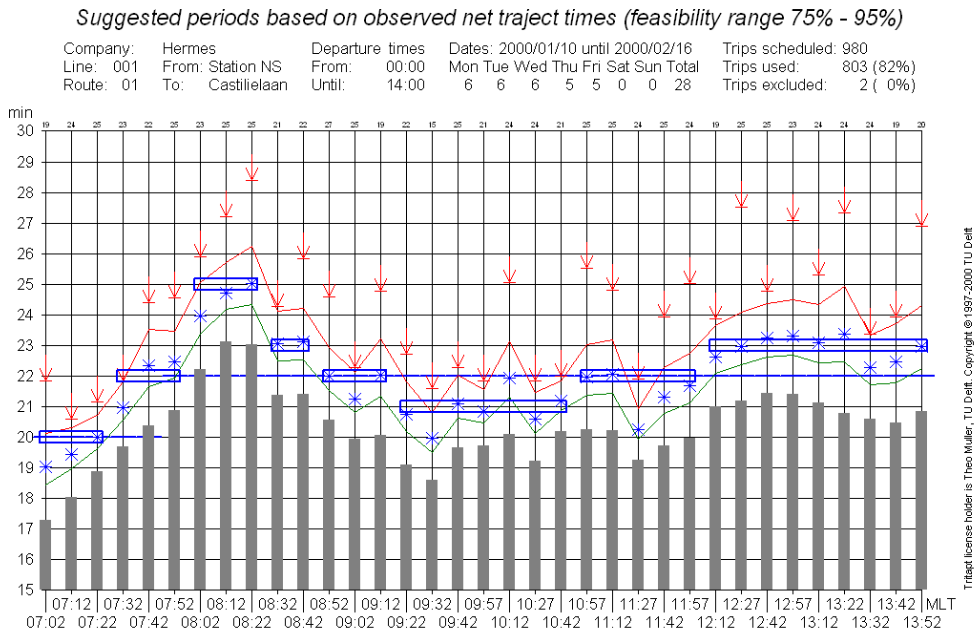

Figure 7. Homogeneous trip time periods

Segment Running Time

For operational control and good schedule adherence, it is vital that the scheduled times at timepoints be correct. Moreover, it is preferable that timepoints be located frequently – in the limit, at every stop, as is the European custom – to prevent large schedule deviations from building up. Such precise scheduling for a congested urban environment requires the kind of data provided by a trip time analysis system.

The logic used in the TriTAPT system for establishing “passing moments” (scheduled times at timepoints) is, that scheduled segment running times should be set such that a bus, that holds until the scheduled time, will reach the end of the line on time (with a high feasibility of say 85%). If this condition is not met, operators will be reluctant to adhere to the schedule. The logic of the passing moment system (6) is illustrated in Figure 8.

The scheduled time from each timepoint to the end of the line is set equal to the 85-percentile running time from that timepoint to the end of the line; segment running times are then found by repeated subtraction. The TriTAPT report that determines scheduled times at timepoints based on a user-specified set of data and user-specified feasibility condition is shown in Figure 9.

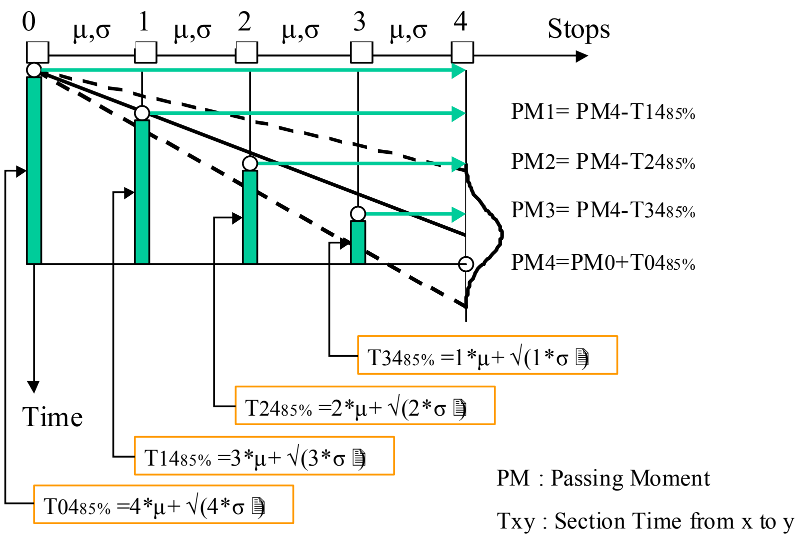

Figure 8. Passing moment calculation

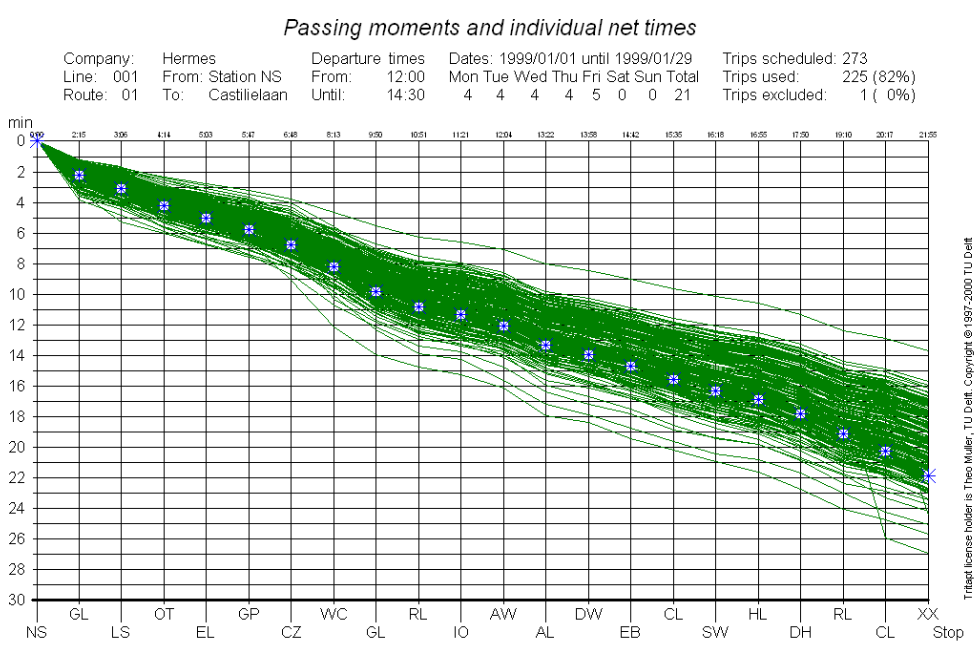

Figure 9. Passing moments presentation

A Diagnostic and Evaluation Tool

A trip time analyzer includes powerful tools for diagnosing operational problems and evaluating measures taken to correct them. One example, shown in Figure 10, is a plot of vehicle trajectories. It can help identify the cause of a bunching or crowding problem. Each operator is designated by a different color, which may help identify an operator who tends to go too fast or slow, or who was affected by a delay on an early trip.

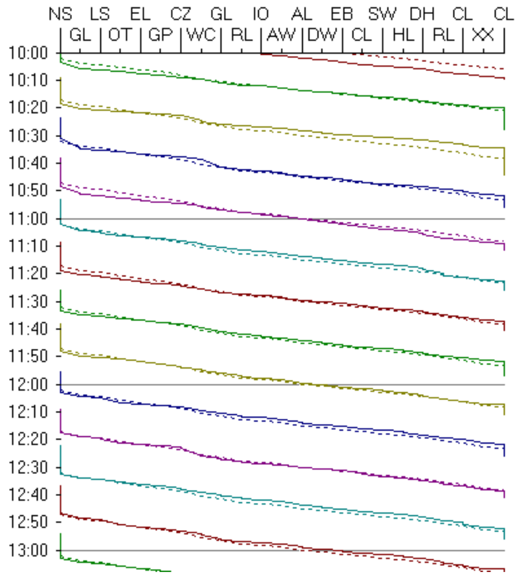

Figure 10. Vehicle trajectories

Another valuable tool is a statistical summary of delays, shown in Figure 11. The trip time analyzer defines "Delay" as time spent below a certain speed (e.g., 5 km/h) at stops and between stops (with the doors closed).

Locations of high delay, or recent increases in delay, can be identified, and traffic authorities can be requested to take some action to reduce delay at those locations. If a change is made, either by the traffic authorities or by the transit agency (e.g., changing a stop location), the vital question is: 'Did it help?' Even where traffic authorities are sympathetic to transit, cooperation can be hindered by the transit authority's inability to quantify the impacts of traffic system change on its operation.

Bus systems, which operate mostly in mixed traffic, should be pro-active in requesting changes to the traffic system to keep the transit system running rapidly and reliably. They should also be active in trying out improvements to their own supervision, control, and scheduling practices. However, this kind of innovation will be severely hampered if there is no system available to evaluate operational impacts. The inability of the typical American transit system to collect and analyze operational data doesn't just mean that improvements are not properly evaluated; they often aren't even tried.

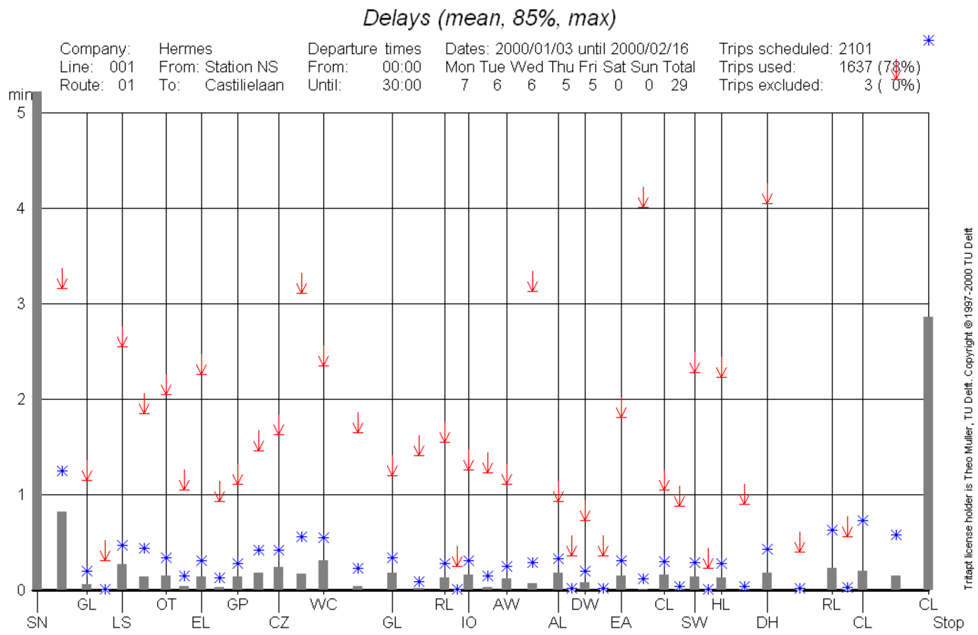

Figure 11. Time spent at stops and delays between stops

Supporting Operators

Trip time analyzers, like AVL systems, have been criticized as “Big Brother”. However, when properly implemented in a deliberate, positive process involving them, bus operators can become strong supporters of trip time analysis. It helps give them a realistically feasible schedule, reducing stress. It is a source of objective data that will support their valid demands for longer (or shorter) running times, and that reduces the uncertainty that contributes to management-labor tension.

A “window” to the Eindhoven trip time analyzer system is a small in-vehicle display of schedule deviation, visible to the operator. Instead of having to check his watch against a memorized or printed schedule, the operator can simply look at the display and see how early or late he is running, and adjust his driving accordingly. Our experience in Eindhoven is that operators are professionals who, when given a realistic schedule and the right tools, take pride in achieving high performance. For a time, operators were given each day a display of their own schedule deviation the previous day, which they viewed with pride. Until then, they had never had any feedback on their success at adhering to the schedule.

Supporting Priority at Traffic Signals

Getting priority at signalized intersections is a powerful means of improving transit service quality and improving mode share. Successful application of transit priority, however, requires trip time analysis. First, there is the need to fine-tune the bus schedule. Implementation of priority will change running times in ways that cannot always be predicted by simulation models. Fine-tuning of the priority system by the traffic engineers will inevitably cause further changes to running time, which need to be rapidly analyzed and incorporated into the schedule.

Having a well-tuned schedule is critical when implementing conditional priority (priority given to late vehicles only), as we have argued elsewhere (5, 6). Conditional priority can be a powerful means of operational control, slowing down vehicles that are early by denying them priority and speeding up vehicles that are late. However, effective results can only be achieved if there is a correct scheduled time at every signalized intersection on the route, such that about half the buses get priority and half do not. This kind of careful fine-tuning requires a trip time analyzer.

Priority at signalized intersections often puts transit in competition with traffic. Traffic engineers will be sure install detectors that enable them to carefully monitor traffic impacts, and will often be tempted to limit the amount of priority buses can get. Transit agencies should likewise be careful to have a monitoring system, so they can effectively argue their case. We know of one American city that serves as a good example of the need of transit agencies to plan for extensive monitoring as part of every signal priority implementation. When it was discovered that some transit detectors were damaged, the transit agency had no objective means of determining whether it was worth the expense to repair them. At the traffic department's control center, one could see that a green light was occasionally extended in response to a transit vehicle detection. But there was no way of knowing whether the vehicle actually made it through the green light, or arrived too late and got no benefit – or perhaps even suffered because the next green started later. Does the system improve speed and regularity? Or perhaps make it worse? Nobody knows. In order to improve traffic flow, the traffic department occasionally changes system parameters, such as the allowable green extension. How was the transit operation affected? Nobody knows.

Relating Operations to Passenger Demand

In close headway service, loads are strongly related to headways. At the same time, loads affect dwell times and headways. Analyzing either one without the other can conceal the true cause of an overcrowding or reliability problem. By integrating trip time analysis with passenger counting, one can better understand and control problems of overcrowding and bunching.

Supporting Research

As mentioned earlier, TriTAPT was developed at the Delft University of Technology to support research into operational control. It continues to support university research, which in turn supports the transit industry. The arrangement with Eindhoven is that the TriTAPT database resides at Delft University. The daily uploads from the on-board computers are transmitted to Delft each night, where they are processed and added to the database, which is available both to researchers and to Eindhoven planners and officials. As part of their research, new features are added to the system in response to perceived needs. For example, one recently added feature is a display created nightly and posted on the internet at a password-protected site accessible to city and transit agency officials showing the previous day's performance. An example is accessible at the web-site http://cttrailf.ct.tudelft.nl/verkeerskunde/tritapt/index.html under Trip Extraction. One graph shows on-time performance by stop and transit speed by segment; another graph (for maintenance reasons) identifies malfunctioning detectors.

Trip Time Analyzers, AVL, and APC: Contrasts and Synergy

Trip time analyzers share many common features with automatic vehicle location and automatic passenger counting systems. It is instructive to contrast them, as well as to emphasize their potential synergy.

AVL, as traditionally defined, provides real-time information on vehicle location. This information can support real-time operational decisions, such as whether to insert a stand-by vehicle or make a temporary schedule change. If the information is disseminated to the public, travelers can also make real-time decisions that will improve the quality of their service – e.g. they can adjust their arrival times, or choose a different route if a connection will not be possible. Real-time information helps relieve uncertainty and stress for travelers as well as for transit agency personnel.

However, many of the actions that a transit agency can make to improve service are not made in real time. They include reporting on performance; improving schedules; identifying and correcting a recurring operational problem; trying a method of operational control; deciding whether an innovation that affects operations should be continued; and objecting to a traffic management change that hurts transit. Decisions like these need data to support them, but what is needed is not real-time data. They need operational data from yesterday and the day before, from last month, from last year.

This is the kind of data that a trip time analyzer is designed to supply. APC systems traditionally include off-line trip time analysis capabilities. However, the benefits are muted because of their relatively sparse coverage.

Trip time analyzers do not have the immediate appeal to elected officials that AVL enjoys. There is no glitzy control center to show off, and they offer little help for spectacular crises such as when a bus is hijacked. Unfortunately, the benefits they can offer for managing and improving operations have often been overlooked. It is telling that, in a recent synthesis of practice about AVL (7), the only concrete benefit the author could find to report was a large cost savings at Kansas City Metro due to improving schedules using running time data from the previous 6 months of an "off-line AVL system" – in other words, a trip time analyzer.

Many people have mistakenly assumed that AVL, because it tracks vehicle location, will automatically provide the benefits of trip time analysis. It won't – unless the system is deliberately specified and designed to serve both functions. Trip time analyzers pair naturally with AVL and APC – they can share a location system, on-board computers, and connections to on-board devices. It is difficult to imagine that the benefits of adding trip time analysis capabilities to either system are not worth the marginal cost.

We also believe that, for agencies that cannot afford either AVL or APC, a dedicated trip time analysis system may still be affordable while offering enormous benefits. A trip time analysis system can also be efficiently integrated with a stop announcement system that involves local tracking of vehicle location without the full capabilities of AVL.

References

1. Th.H.J. Muller and P. Knoppers. TRITAPT - TRIp Time Analysis in Public Transport. Accessed at http://cttrailf.ct.tudelft.nl/verkeerskunde/tritapt/index.html, June 23, 2000.

2. P.G. Furth. *Data Analysis for Bus Planning and Monitoring.* TCRP Synthesis 34, Transportation Research Board, 2000.

3. D. Levy and L. Lawrence. The Use of Automatic Vehicle Location for Planning and Management Information. STRP Report 4, Canadian Urban Transit Association, Toronto, 1991.

4. J.J. Schiavone. Understanding and Applying Advanced On-Board Bus Electronics. TCRP Report 43, Transportation Research Board, 1999.

5. N.H.M. Wilson, D. Nelson, A. Palmere, T.H. Grayson, and C. Cederquist, Service-Quality Monitoring for High-Frequency Transit Lines. In *Transportation Research Record 1349*, Transportation Research Board, 1992, pp. 3-11.

6. Th.H.J. Muller. Process Management and Operational Control in Public Transit. *Proceedings of the American Society of Civil Engineers Transportation Congress,* San Diego, 1995.

7. P.G. Furth and Th.H.J. Muller. Conditional Bus Priority at Signalized Intersections: Better Service Quality with Less Traffic Disruption. Forthcoming in *Transportation Research Record*, Transportation Research Board, 2000.

8. Th.H.J. Muller and P.G. Furth. Integrating Bus Service Planning with Analysis, Operational Control, and Performance Monitoring. Proceedings, Intelligent Transportation Society of America Annual Conference, Boston, 2000.

9. P.E. Okunieff. *AVL Systems for Bus Transit.* TCRP Synthesis 24, Transportation Research Board, 1997.