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This report benefited from interviews of Tri-Met staff involved in the development, implementation and use of the agency’s automatic passenger counter and automatic vehicle location systems. The staff interviewed include Rick Gerhart, Ken Turner, Steve Callas, and Jon Lutterman. Their insights are gratefully acknowledged. Tom Kimpel and Pete Fielding also provided many helpful comments on an earlier draft.

## Introduction

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is one of about 30 metropolitan transit agencies that have deployed both automatic vehicle location (AVL) and automatic passenger counter (APC) systems (Casey, 1999). These technologies are important components of the agency's new automated bus dispatching system (BDS). The AVL and APC systems at Tri-Met recover comprehensive operations and passenger activity data at the bus stop level that is archived for later analysis. The agency has gained a reputation as an industry leader in the areas of data archiving and the application of archived data to performance monitoring and analysis.

Prior to the implementation of AVL and APC technology, Tri-Met, like others in the transit industry, relied on costly manual data recovery. During lean budget years in the early 1980s, the agency began using stand-alone APCs instead of ride checkers, and recovered very little operating data beyond what was required for Federal Transit Administration reporting. With its AVL and APC systems, Tri-Met is now automatically collecting and archiving over 500,000 stop and event data records per day. Offline analysis of this data supports a wide array of agency activities. The transformation from scarce to abundant data has contributed to a variety of functional changes that have both enhanced service quality and improved efficiency.

This report examines factors related to the development of Tri-Met's BDS that have contributed to its success in data archiving and analysis. The organization of the report includes a description of the BDS, a review of the types of analyses that have been supported by archived data, a discussion of factors that influenced decisions made on the design of the system, reflections on unrealized expectations and missed opportunities, and concluding observations.

Tri-Met's Automated Bus Dispatch System

Tri-Met's BDS became fully operational in 1998. Its main features are as follows (see Figure 1):

- Orbital Sciences Corporation's Intelligent Fleet Management System, which includes Automatic Vehicle Location (AVL) using a satellite-based global positioning system (GPS);
- Voice and data communication within a pre-existing 450 MHz Motorola mobile radio system;
- On-board computer for temporary data storage, a vehicle control head displaying schedule adherence to operators, detection and reporting of schedule and route deviations to dispatchers, and two-way, pre-programmed digital messaging between operators and dispatchers;
- Infrared beam-type Automatic Passenger Counters (APCs) installed on approximately 70% of the bus fleet and all new bus acquisitions;
- New dispatching center containing nine CAD/AVL consoles.

(Figure 1 about here)

A PCMCIA memory card containing the route schedule is inserted in the vehicle control head when an operator logs on at the beginning of each block. A vehicle's current status is related to its scheduled status to determine schedule deviation in real time, which is displayed on the control head screen (see Figure 2). When schedule deviations exceed predetermined values, an exception report is automatically transmitted to the dispatch center. Exception reports are also transmitted when vehicles deviate from their routes. Exception reports are listed on the dispatcher's CAD screen along with other attention requests (e.g., mechanical problems, traffic and on-board incidents, delays, etc.) that are transmitted by vehicle operators from the control head keypad. In addition to schedule status, the control head screen displays freeform text messages from dispatchers to operators. The AVL system also contains a covert microphone and silent alarm key, providing enhanced security.

Figure 2 about here)

Data generated by the BDS is written automatically on the memory card. A data record is written at each bus stop, producing approximately 500,000 stop records per day. In addition, a data record is written at each location where an operator-initiated text message is generated or a schedule exception occurs, producing about 25,000 event records per day. Stop records contain the following information: route number, direction, trip number, date, vehicle number, operator ID, bus stop ID, stop arrival time, stop departure time, boardings, alightings and passenger load (on APC-equipped vehicles), door opening, lift usage, stop dwell time, maximum speed since the prior stop, longitude, and latitude. An example is shown in Table 1.

(Table 1 about here)

When vehicles return to the garages at the end of each day the data are transferred from the memory card to a PC and then uploaded to a server on Tri-Met's LAN. A post processing operation then matches the stop data records to the schedule database. About 97 percent of the stop records are successfully matched to the schedule database. The matched data is organized in an Oracle 8.1 database and stored on an eight processor Sun 4501 computer with 500 gigabytes RAID, 8 gigbytes RAM, and 1 gigabit Ethernet connection. Presently, the BDS data warehouse contains more than 120 million stop and event records, along with the related schedules. Summary tables have been designed to report at the stop, time point and trip levels.

Applications of AVL-APC Data at Tri-Met

Archived AVL and APC data support a variety of regular reporting activities at Tri-Met. The data are also used to support analysis of specific needs and problems that relate to both short and long term planning, scheduling, and operations. Tri-Met has dedicated one staff position to reporting and analysis of AVL and APC data. In addition, the agency has engaged Portland State University researchers in a series of projects to evaluate the effects of its BDS on service performance and to help identify potential applications of the data. The projects have been jointly sponsored by the USDOT Region 10 University Transportation Center.

Detailed quarterly performance reports represent the most prominent use of AVL and APC data at Tri-Met. The report provides performance data at the trip, route, and system levels. An example of the trip level report for the Winter 2001 quarter is shown in Table 2. The table covers afternoon and evening outbound trips for the 4-Fessenden, an interlined route extending north from downtown Portland. The columns in the table report the scheduled trip departure time, block number, and departure location. This is followed by six indicators related to passenger activity: average boarding rides per trip, average maximum load per trip, the average maximum load factor (average maximum load divided by seating capacity * 100), the percentage of trips exceeding 130% of seating capacity (a service standard), the number of pass-up events reported by operator-keyed messages, and the number of trips generating valid APC data. In any given quarter there are between 60 and 70 scheduled trips. In this example, valid APC data were recovered on about 75% of the trips.

(Table 2 about here)

The columns on the right side of Table 2 report indicators of operating performance: scheduled running time, median actual running time, running time ratio (median divided by scheduled running time * 100), the observed running time coefficient of variation, median speed, headway adherence (the percentage of stops in which the actual headway ranges from 50% to 150% of the scheduled headway), the scheduled recovery time, the median actual recovery time, and the recovery ratio (median divided by actual recovery time * 100). The final three columns in the table report stop level on-time performance, where early is represented by departures more than one minute ahead of schedule and late is represent by departures more than five minutes behind schedule.

Trip level data is also aggregated in the quarterly performance report to provide summary indicators. Table 3 is an example of weekday performance reporting by service period for the 4-Fessenden. Several new indicators are reported in Table 3, including (in the top half of the table) boarding rides per revenue hour and the percentage of trips with passenger loads exceeding seating capacity due to deviations in headways. This latter measure is based on a regression relating passenger loads to headway deviations.

(Table 3 about here)

In the bottom half of Table 3 are three indicators of excess passenger waiting time associated with deviations from scheduled headways. These measures are based on work by Wilson et al.(1992), and assume a constant rate of passenger arrivals at bus stops. The three measures shown in the table are average excess wait times per passenger and per trip, and excess wait time over the quarter. The wait time measures are intended to reflect service quality from the passengers' perspectives.

The quarterly performance report serves a variety of functions at Tri-Met. For example, service planners sort the data on boarding rides per revenue hour to identify instances where service is greatly underutilized, and focus their efforts on changes that will either improve utilization or reduce the amount of service provided. At the other end, they identify instances of heavily utilized service and consider options such as adding trips or improving schedule and headway adherence. Schedule writers evaluate observed running and recovery times to determine whether adjustments in the schedule are needed. The operations staff assess schedule and headway adherence to identify routes (and, after further analysis, locations) where field supervisors can better focus their control efforts.

APC data are also compiled to produce a quarterly passenger census report by stop. Prior to the extensive deployment of APC's in the bus fleet, passenger census data was collected manually every five years at a cost of about $250,000. Table 4 provides an example of quarterly passenger census reporting for selected bus stops on the 4-Fessenden. The columns in the table report the stop location and ID, average daily boardings and alightings, and lift activity. This data is useful in identifying opportunities for stop consolidation or the need for additional stops.

(Table 4 about here)

Analysis of archived AVL data is also undertaken in response to specific issues that arise related to service design, delivery and use. For example, customer complaints about lateness or excessive speed can be checked against the data. Patterns of fare evasions (as reported by operator event messages) can be mapped to target locations for enhanced fare inspections. Patterns of early departures or excessive layovers can be identified to aid field supervisors in focusing on problem operators, while patterns of high on-time performance can be used to identify meritorious recognition. Data are also used in evaluating special projects. For example, Tri-Met has initiated a project ("Transit Tracker") to provide real time bus arrival information to passengers on selected routes. Predicted arrival times are posted on the web as well as on variable message boards installed at a limited number of stops. Arrival predictions are based on the scheduled running time from the current bus location, with updates provided on an approximate 90 second interval. Archived AVL data are being used to evaluate the accuracy of arrival predictions. In another example, an analysis of dwell and running time data has been undertaken to determine whether a fleet of recently-acquired low floor buses reduces boarding, alighting and lift times compared to standard buses. In another case, the additional running time associated with a route deviation was estimated. Another example concerns an evaluation of the reduction in running time means and variances due to signal prioritization on selected routes. A final example is a project to redefine service standards for vehicle capacity utilization focusing more generally on morning and evening peak hour periods rather than individual trips.

To date, the primary applications of archived AVL and APC data at Tri-Met have been dedicated to improving service quality and ensuring maximum effective utilization of resources. However, there is increasing interest in using this technology directly to reduce costs. Two examples of cost-motivated opportunities are the yard mapping of buses and time-slipping. Presently, the daily yard mapping process at the agency's three bus garages is the responsibility of three employees. The locational referencing of vehicles with AVL may be sufficiently accurate to generate yard maps automatically, which would yield a savings of about $150,000 annually. Secondly, time slips for operators logging overtime are currently filled out and processed manually. Alternatively, overtime could be calculated and forwarded automatically when operators log off the BDS.

The collaboration between Tri-Met and local university researchers has yielded a series of studies of the effects of the BDS on operations and scheduling. Initial efforts dealt with defining performance measures and collecting baseline data prior to the implementation of the BDS (Strathman et al., 1999). This was followed by an evaluation of the initial performance impacts of the new system (Strathman et al., 2000), which found a 9% improvement in on-time performance, an 18% reduction in running time variation, a 3% reduction in mean running time, and a 4% reduction in headway variation. It was estimated that these improvements produced a savings in passenger waiting and in-vehicle travel times valued at $3.5 million annually. It should be noted that these improvements occurred without substantive changes in practices related to service design and delivery. It was posited that they were the consequence of providing enhanced information to dispatchers and operators.

Another study evaluated efforts to improve bus spacing along the downtown bus mall (Strathman et al., 2001). In this study, dispatchers alerted field supervisors of impending delays. Field supervisors responded by imposing control actions (holding, short-turning, and switching trip assignments). It was found that these actions resulted in a 16% reduction in passenger load variation, which was maintained through the maximum load points of the study routes. Another study sought to improve Transit Tracker arrival time predictions by estimating delays related to lift activity and bridge closures (a number of east side routes serving downtown Portland must pass over draw or lift bridges on the Willamette River) (Dueker et al., 2001).

The extensive passenger data produced by the large-scale deployment of APCs provided the focus for several other Tri-Met/PSU projects. In the first project, passenger data were combined with service attributes and demographic variables in route segment corridors (using GIS to apportion data from the American Community Survey) to estimate a transit utilization model (Kimpel et al., 2000). In the second project, the validity of APC boarding, alighting and load counts was assessed relative to counterpart data obtained from on-board cameras (Kimpel et al., 2002). A framework for sampling archived passenger data was also developed consistent with NTD and internal reporting requirements. Although a sampling approach based on a limited number of APC-equipped buses had been approved by FTA a decade earlier, Tri-Met continued to rely on manual passenger counts due to difficulties in assigning APC-equipped buses to sampled trips. Extensive deployment of APCs has now mitigated bus assignment problems. Automating NTD data recovery is expected to save Tri-Met about $50,000 per year.

The precision and confidence levels required for NTD reporting can be met with a relatively small sample of bus trips. Given the extensive deployment of APCs, the NTD sampling framework was extended to provide monthly passenger boardings by route at higher levels of precision and confidence. Previously, monthly route-level boarding estimates were derived from revenues, but the growing mix of fare payment alternatives made those figures increasingly uncertain.

The final Tri-Met/PSU project focused on schedule efficiency and operator-related effects on running time variation (Strathman et al., 2002). Archived AVL data were used to construct running time distributions by route and time period. From these distributions, typical running, recovery and layover times were calculated and compared to standards recommended by Levinson (1991), as well as Tri-Met's own scheduling standards and conditions identified in the agency's labor agreement. It was found that 81 of the agency's 104 routes had excessive running, recovery, and layover times, while the scheduled times in the other 23 were inadequate. It was estimated that adjusting the schedules would potentially yield a $7 million per year savings in operating cost. The contribution of operators to running time variability was assessed with a fixed effects model. After controlling for various operational causes of running time variation, the model estimated the variation attributable to operator-specific differences. The results indicated that operator differences account for the majority of running time variation, and that running time is inversely related to operator experience. This suggests that "bus bunching" problems experienced in peak periods can be partly attributed to the mixing of operators with varying experience on a given route. The runcutting process is an important determinant of the mix of operator experience in its delineation of work assignments among part-time, split shift, and straight shift operators. Runcuts may thus generate a mix of work assignments that is optimal in terms of cost-effectiveness, but sub-optimal in terms of headway maintenance.

## The APC-AVL Chronology at Tri-Met

The chronology of APC and AVL planning, deployment and use at Tri-Met covers a 20 year period. A 1980 visit to OC Transit in Ottawa, Canada, left Tri-Met staff impressed with the potential of APCs. Ten units were acquired and installed in the bus fleet in 1982. However, the initial experience with APCs was plagued by equipment malfunctions and data problems. More than 80% of trip-level assignments of APC-equipped buses either failed to return any data or generated data records that were screened out due to inconsistencies in passenger counts, time/distance tolerances, and trip assignment information.

While it was clear that APCs were not initially delivering on their potential at Tri-Met, a series of severe budget cuts in the early 1980s spared them from elimination. A 1984 budget cut led to a lay-off of Tri-Met's entire staff of traffic checkers. Passenger counting for FTA Section 15 reporting was contracted out and, for several years, virtually no additional data were collected for planning and performance monitoring. At that time, a commitment to "force the APCs to work" was made, and a person was appointed the task as his only responsibility. His efforts ranged from hardware maintenance to programming, data processing, and reporting.

A major challenge with the APCs involved trip and time point referencing the passenger data. The basis for referencing the data stream were time clock and odometer readings.

Operator radio log ins were used to identify work assignments, trips were identified by time breaks in the data associated with scheduled layovers, and time point location was determined from odometer readings.  Post processing of the data included a comparison of total daily boardings and alightings, and day records were screened when the difference between the two exceeded 10% of the total passenger activity.  The resulting data reports on time point level passenger activity and on-time performance served as input for two in-house developed programs, Interactive Schedule Maintenance (ISM) and Schedule Writers Analysis Package (SWAP), which were used to monitor and adjust bus schedules.

By 1986, the number of APC-equipped buses had grown to 50 (about 10% of the fleet) and passenger data collected from these units was used for Section 15 reporting for the first time. Continuing problems with equipment malfunctions and screening of data, coupled with difficulties in assigning APC-equipped buses to routes selected for data recovery, led to uncertainty about the compatibility of the resulting sample data with the recommended Section 15 sampling procedure (UMTA, 1978).  A subsequent review of the system led to the development of a cluster-based sampling approach (Strathman and Hopper, 1991), which was approved by FTA for Section 15 reporting.

Tri-Met's involvement with AVL technology can be traced to the late 1980s.  A feasibility study assessing signpost and Loran-C systems was completed in 1988.  However, subsequent internal budget proposals for a stand-alone AVL system with a projected cost of about $3 million failed to gain support for five consecutive years.  In the early 1990s, an operations control plan (Tri-Met, 1991) identified a critical need to replace the agency's bus dispatch computer.  An AVL component was recommended as part of the upgrading of the dispatching system.

The proposed replacement of the bus dispatch computer was approved by Tri-Met management, and tentative approval, subject to cost, was also given to specifying AVL capability in the request for proposals (RFP). A Bus Dispatch System (BDS) RFP was issued in late 1993, and generated 5 qualified responses. The proposal by Orbital Sciences Corporation was selected in mid-1994. Orbital's bid of $6.5 million included $.5 million for adding AVL functionality to the BDS. A contract was awarded in mid-1994. The shake down of the BDS began in 1997, and the transition to full operation was completed by early-1998.

## Keys To Success

Based on its experience with APCs, Tri-Met concluded that it was important to take a "hands on" project management approach in designing and implementing the BDS. The main reason given for this assessment was that the transit industry market for APTS technologies was fairly small and, as a result, vendors typically lacked both experience and key insights related to transit operations and planning/analysis environments.

Probably the most critical organizational factor contributing to success was that the person selected to manage the BDS project had diverse and substantial operations experience, including service as an operator, trainer, and data analyst for FTA Section 15 reporting. Management of the BDS project from the development of the RFP through final implementation was his only responsibility. He was familiar with Tri-Met's experience in archiving APC data, and was aware of the value of this data to service planners, schedule writers, and operations managers. He thus assembled a project team that represented dispatching, scheduling, information systems, maintenance, operations analysis, and service planning. Because dispatchers were primarily interested in real time applications of the BDS, it was the presence of the other interests on the project team that ensured substantial attention to data recovery and archiving issues in the design of the system.

Another important consideration was that the vendor selected for the project was strongly motivated to deliver a successful product. The Tri-Met project was the company's first AVL job in the transit industry, and the client's satisfaction was seen as important for subsequent work with other transit properties. In turn, there was a talented resident staff of programmers, database specialists and data analysts at Tri-Met who worked closely with the vender to ensure success.

Tri-Met brought valuable prior experience with APCs to the BDS project. It was recognized that an APC-AVL interface would provide a much-improved basis for locational referencing of the APC data, which would allow passenger activity reporting to be upgraded from the time point to the stop level. It was determined that an AVL-APC interface producing stop-level records would require on-board data storage, given capacity constraints on radio transmission. The decision to stop-reference the AVL-APC data thus shifted attention away from an archiving framework based on data generated from a "location-at time" polling cycle.

Synergistic economic considerations are also worth noting. Tri-Met might not have acquired an AVL system had it not been linked to the necessary upgrade of its bus dispatch computer system, which substantially reduced AVL's cost by compared to a stand-alone system. Similarly, with on-board location referenced data storage already in place to serve the AVL system, the cost of adding APCs declined from about $5,000 to $1,000 per vehicle.

Retrospective Considerations

Overall, Tri-Met managers are pleased with the performance of their AVL/APC system. The data recovered and archived by these systems has allowed them to conduct detailed analysis and reporting of bus operating performance and passenger activity, which is increasingly contributing to improvements in dispatching, operations control, service planning and scheduling. At the same time, potential opportunities were untapped in the design and implementation of the AVL/APC systems. In addition, there were expectations that were not realized. Untapped opportunities and unrealized expectations include the following:

- Instrumentation for monitoring major vehicle components was not included in the AVL system specifications. A recent review of maintenance-related digital messages between operators and dispatchers found a frequency of about 35 per day, or about 6% of vehicles in peak service. Also, records show that in a recent month 235 vehicles (35% of the vehicle fleet, with an average age of 7.5 years) required a road call. Maintenance needs thus involve considerable expense and result in service disruption. Instrumentation of vehicles would have provided a means for creating an automated maintenance log, which may have provided a means for detecting some problems before they deteriorated to the point of failure. Maintenance staff did not actively participate in the development of the BDS specifications. This may have been the result of experiences with the pre-existing Motorola radio system, which was capable of monitoring and reporting engine temperature and oil pressure. The radio system produced numerous “false positives” (e.g., reporting low oil pressure because the engine had been shut down during layover), and the monitoring function was disconnected. Tri-Met is now exploring the addition of drive train monitoring hardware that would provide operating data to the AVL system that could be reported to maintenance at the end of each day.

- Tri-Met has installed electronic registering fareboxes in their bus fleet. However, these fareboxes are not connected to AVL/APC system. Farebox, AVL, and APC data were not integrated for several reasons. First, a farebox interface with the BDS was considered to be too expensive. Second, an interface would have added to the complexity of the system, and there was a desire to limit potential complications while allowing for future expansion. Tri-Met is now considering a shift to smart cards, and an integrated system yielding origin-destination data would be very useful in service planning and marketing. A number of buses also include cameras that are not AVL-integrated. Discs containing digital video images must be physically removed. The images are time referenced, but not location referenced.
- It was expected that the new BDS would not only yield more effective dispatching, but also result in an extension of the responsibility of dispatchers into the area of operations control (Tri-Met, 1991). The monitors displaying real time vehicle location, schedule and route deviation reports, and prioritized digital messages from operators has added a substantial amount of information to the dispatching environment. Dispatchers state that their workload has grown to deal with the increase in information and, consequently, operations control responsibility takes a low priority. Operations control remains the responsibility of field supervisors, but these individuals still lack access to the real time information available to dispatchers. To overcome this shortcoming, Tri-Met is planning to acquire mobile data terminals for field supervisors' vehicles. There is also an interest

in elevating the importance of operations control among the various responsibilities vested in field supervision.

- It was intended that the data warehouse structure would allow for data to be conveniently imported into a geographic information system (GIS) to facilitate mapping and spatial analysis of operations at the stop, segment, and route levels. The data warehouse structure allows for AVL and APC data to be queried using structured query language for purposes of operations planning and performance monitoring. While all AVL and APC data are archived, only the most current data are available in disaggregate form. Disaggregate data from previous time periods are archived on removable storage media and can be reconstructed if the need arises. The limiting factor for permanent storage of data on the database server is storage capacity.

The integration of Tri-Met BDS data with a GIS has been steadily evolving over time. A distinction should be made between visualization and mapping capabilities, and spatial analysis applications. At present, the capabilities for undertaking project-specific spatial analysis are excellent due to the disaggregate nature of the data. One of the principal advantages of data for spatial analysis is that information is collected at the bus stop level, allowing for aggregation to higher levels. The data can be assigned to point locations such as stops, time points, and transfer points or linear features such as routes and route segments. The data can be further summarized according to logical divisions such as block, trip, direction, and time period. In most instances, it is first necessary to summarize information on the database side prior to linking it with corresponding geographic features in a GIS. The signal prioritization project at Tri-Met made extensive use BDS data within a GIS in the early project planning stages for locating priority intersections and analyzing the potential impacts of stop location (nearside/farside) on bus performance. Another use of GIS for spatial analysis involved allocating socioeconomic data to transit service areas in order to create spatial variables for use in econometric models. This technique was applied in a recent study involving an analysis of passenger demand (Kimpel et al., 2000).

One area that needs increased attention concerns the use of GIS as a visualization tool to aid in decision making. BDS information is often displayed on maps. For the most part, this information tends to be descriptive in nature. As an example, service planners might display passenger boardings and alightings at bus stops in order to determine candidates for consolidation. The visualization of bus performance information is presently underexploited. There are a number of summary reports generated at Tri-Met on a regular basis such as route performance reports and passenger censuses. It would be advantageous to be able to visually display information on performance measures at alternative levels of aggregation as they vary over time and space.

Some of the issues discussed above, including integration of fareboxes and drive train monitoring, were the result of an overall intent to minimize the complexity of the BDS. Tri-Met's goal was to design and implement a system that was relatively simple and straightforward, while allowing for future expandability. Limiting the complexity of the system helped to insure that it worked as intended, in contrast with other experiences in the transit industry where adoption of new technology has been problematic (Hall,1980). Presently, four years into successful implementation of the BDS, Tri-Met is exploring a variety of upgrades and extensions to address the needs and opportunities discussed above.

## Conclusions

Tri-Met has over 20 years of experience working with APC technology and data, and about 4 years of experience with AVL technology. It appears that much of the agency's recent success with data archiving and analysis can be traced to its previous efforts to obtain useful data from APCs. It was recognized that problems associated with identifying trips and referencing of passenger activity to time points in the APC data stream could be remedied by integrating APC and AVL technologies. A consequence of APC-AVL integration was the decision to define data records on the basis of "time-at-location" rather than "location-at-time," which could only be achieved through on-board data storage.

The role of the project manager was vital in ensuring that the experience with APCs was reflected in the design of the data recovery and warehousing structure of the BDS. AVL functionality was not a central feature of the BDS project, and data recovery and warehousing were not priority concerns for the dispatchers that the BDS was designed primarily to serve; their interest in AVL was essentially limited to real time use. Having a project manager who was experienced in transit operations and in analyzing operating data was a key to success.

Given the fairly rapid evolution of AVL technology from signpost to satellite-based systems, Tri-Met clearly benefited from being a relatively recent adopter. Although the agency could have developed a data recovery and archiving system with the earlier generation technology (following the experience of King County Metro, for example), the near-exact locational referencing of the current technology was ideally suited to its needs. In contrast, Tri-Met was a fairly early APC adopter, but this technology has not changed as much over time.

Thus Tri-Met's experience with APC systems can be seen as an important element in explaining the success they have had with data recovery and archiving in the BDS environment.

Archived AVL-APC data support a variety of regular performance reporting functions and specific evaluation needs at Tri-Met. The agency employs analysts who bring a high level of skill and initiative to these tasks. There are also several experienced programmers in residence, whose primary responsibility has been to maintain aging (soon to be replaced) scheduling software, who can also be called on to support AVL-APC data analysis. The existence of a talented staff can be traced to the data-poor and financially constrained era of the early 1980s, as can the collaboration between the agency and local university researchers.

The wealth of operating data recovered by the BDS has resulted in more comprehensive and valid performance reports. Automating the data recovery process has also shortened the time span and greatly reduced the costs associated with analysis of operations issues. It is unlikely that much of the analysis discussed in this report would have been undertaken in a manual data recovery environment.

As described in previous sections, the implementation of the BDS and its AVL/APC components has yielded tangible improvements in service quality and measurable savings in operating and administrative costs at Tri-Met. A number of potential benefits, however, have not yet been realized. The operations control environment and practices have changed only slightly from the pre-BDS era. In the scheduling arena, where substantial efficiency savings are potentially achievable, archived AVL-APC data are still used in an ad hoc fashion. This may change with the implementation of new scheduling software. While the agency's agreement with operators prevents the use of archived data for disciplinary purposes, its use in spotlighting or rewarding meritorious performance has gone untapped. Given the ability to comprehensively recover data on fairly unambiguous measures of performance, there is an opportunity to introduce incentives in future agreements that will subsequently improve service quality and reward those who are contributors.

Studying the implementation of advanced transportation technology in a specific setting can identify how that technology leads to changes in practices and improvements in performance. For some of the documented changes it is also possible to monetize the corresponding benefits at this scale of analysis. However, many of the beneficial effects of new technology on performance are subtle and indirect, and are likely to be only vaguely perceived or missed entirely in case study investigations. It is also important to recognize that the changes following implementation of advanced technology may not necessarily be beneficial in every respect. Capturing overall effects resulting from the implementation of advanced technology requires analysis at the industry scale, focusing on such indicators as total factor productivity and costs. In this respect, Gillen et al. (2001), and Gillen and Haynes (2001) provide good examples of industry-level assessment of the economic consequences of advanced technology.

It is difficult to assess the effects of the BDS experience on intra-organizational performance at Tri-Met. Fielding (1987: 181) observed that "(t)ransit organizations are … hierarchically structured with little attention given to information sharing at the second and third levels of management." With respect to BDS design and implementation at Tri-Met, it was recognized at the project development stage that a variety of units in the organization stood to benefit from archived AVL and APC data, including dispatching/operations control, scheduling, planning, finance, marketing, and maintenance. Following implementation, all of these units are, to varying degrees, benefiting analysis of archived data. The benefits are most evident in the areas of planning and scheduling. Units that were less active in the initial phases of design, implementation, and analysis have now become more active contributors to possible extensions of the BDS, including farebox/smart card integration, addition of mobile terminals to field supervisors' vehicles, and addition of drive train monitoring devices. At the second level of management, there is growing utilization of the ability to directly measure factors closely associated with service quality, effectiveness, and efficiency. In addition to measurement, the ability to evaluate the causes and consequences of quality, effectiveness and efficiency problems is steadily evolving. These developments are providing senior managers with a much-improved understanding of strategic options in their efforts to advance agency performance.

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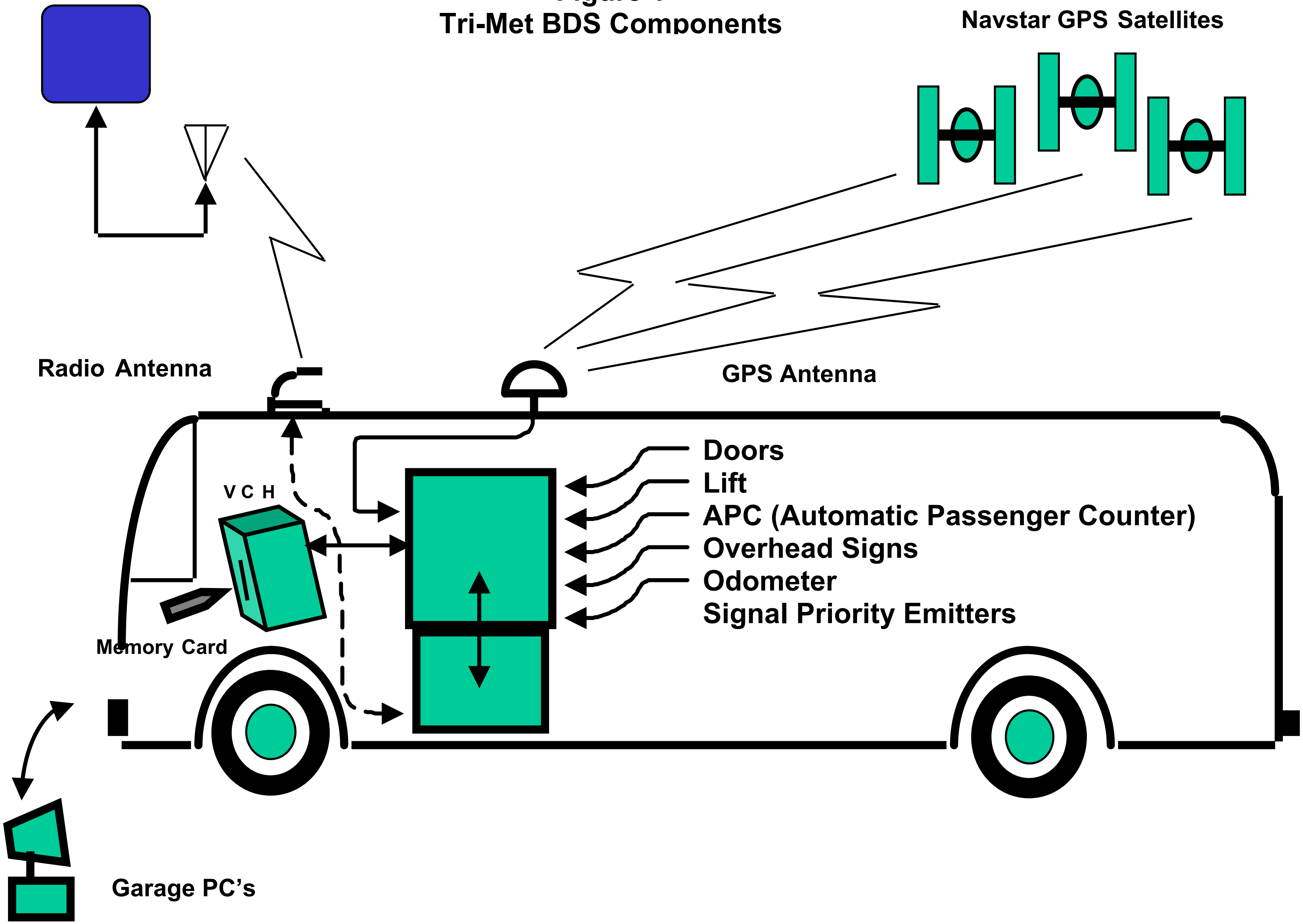
Figure 1
Tri-Met BDS Components



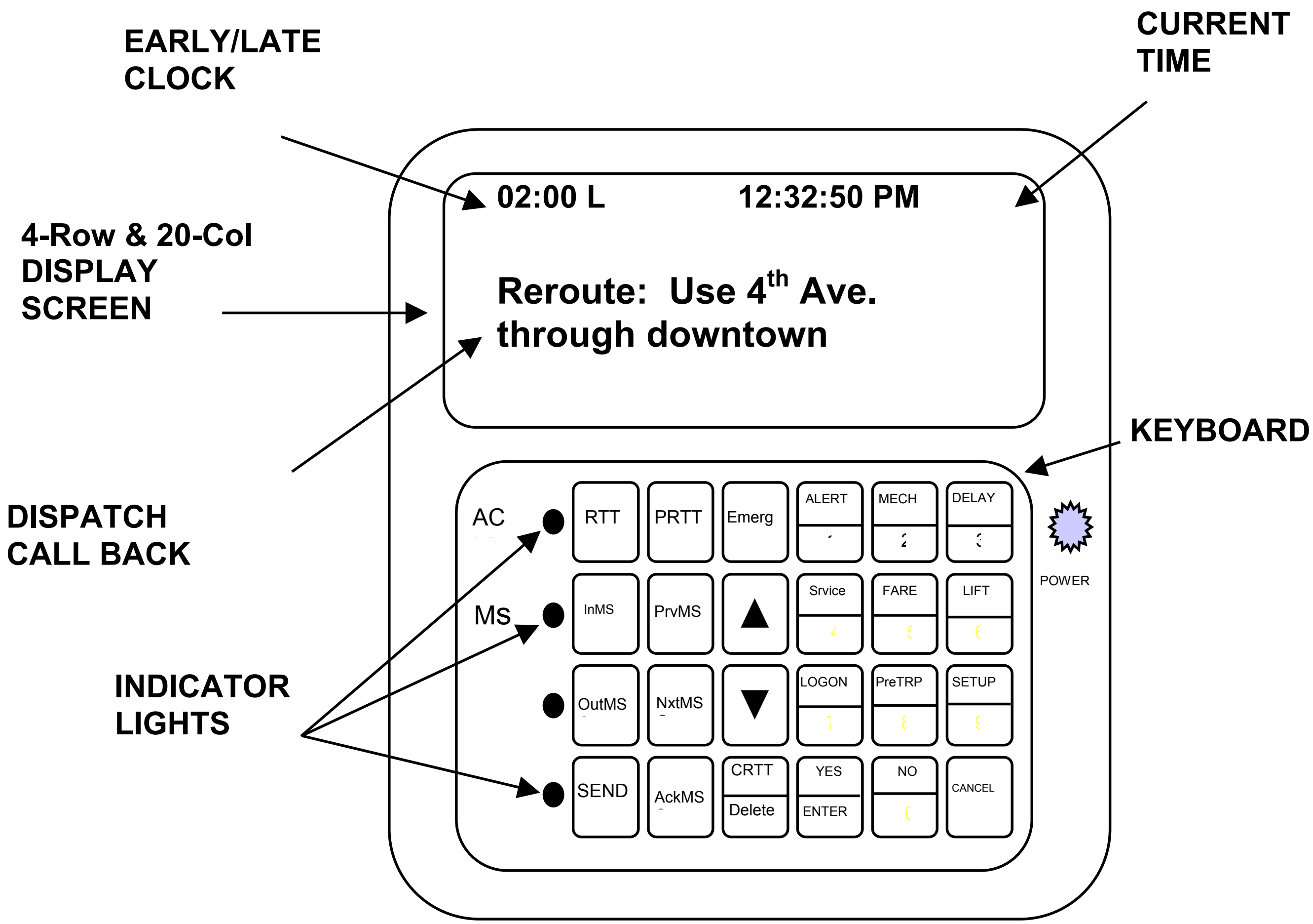



**Figure 2**
**Vehicle Control Head**

Table 1: BDS Data Records

CardRep - Notepad

File Edit Search Help

```
BUS= 2134  TRAIN=   1401  DATE=20000313

STOP ID  STOP NAME                   ARRIVE    LEAVE  ON OFF MI FT N  FT E D L DWEL SPD LOD

 9302 5TH & HOYT            (OP) 16:25:02 16:25:04  0  0  0           0 0       17   2
    0 unscheduled stop           16:25:06 16:25:08  0  0  0 -868   28 1 0    1  3   2
 9222 5TH & EVERETT         (NS) 16:25:08 16:25:52  2  0  1           0 0       18   4
 9303 5TH & COUCH           (NS) 16:26:04 16:26:40  8  0  1  -10    6 1 0   21 20  12
 7631 5TH & PINE            (OP) 16:27:14 16:28:28  4  1            5 1 0   45 19  15
       Scheduled times --------> 16:28:00 16:28:00
 7635 5TH & STARK           (FS) 16:28:30 16:29:52  3  0            2 1 0   17 17  18
 7585 5TH & ALDER           (FS) 16:29:58 16:31:26  6  2           14 1 0   24 16  22
 7645 5TH & YAMHILL         (FS) 16:31:28 16:31:46  0  0              0 0      15  22
 7633 5TH & SALMON          (FS) 16:31:50 16:33:24 15  2           80 1 0   34 20  35
       Scheduled times --------> 16:33:00 16:33:00
 3639 MADISON & 4TH         (FS) 16:33:46 16:35:24  8  0           59 1 0   22 15  43
       time=16:36:02; Fare Evasion.
 3635 MADISON & 1ST         (NS) 16:36:10 16:36:16  0  0              0 0      24  48
 2641 HAWTHORNE BRIDGE & EAST (AT) 16:37:16 16:37:38  0  2         60 1 0    7 30  46
    0 unscheduled stop           16:38:50 16:39:02  0  1          119 1 0    5 29  45
 2594 HAWTHORNE & 6TH       (NS) 16:39:02 16:39:08  0  0              0 0      15  45
 2597 HAWTHORNE & 9TH       (NS) 16:40:04 16:40:28  1  1           23 1 0    6 24  45
 2599 HAWTHORNE & 12TH      (NS) 16:41:28 16:42:04  3  5            8 1 0   18 23  43
       Scheduled times --------> 16:39:00 16:39:00
 2595 HAWTHORNE & MAPLE     (FS) 16:42:10 16:42:16  0  0              0 0      31  43
 2603 HAWTHORNE & 16TH      (FS) 16:42:22 16:42:56  0  5          -12 1 0    9 29  38
 2596 HAWTHORNE & POPLAR    (NS) 16:42:58 16:43:24  0  1         -100 1 0    4 21  37
 2607 HAWTHORNE & 20TH      (FS) 16:43:50 16:44:10  0  1              0 0      22  36
 2608 HAWTHORNE & 23RD      (NS) 16:44:20 16:44:26  0  0              0 0      31  36
 2612 HAWTHORNE & 25TH      (FS) 16:44:30 16:44:56  0  2           31 1 0    5 32  34
 2614 HAWTHORNE & 28TH      (OP) 16:45:12 16:45:44  1  3           29 1 0   15 21  32
 2615 HAWTHORNE & 30TH      (NS) 16:45:54 16:46:00  0  0              0 0      28  32
 2617 HAWTHORNE & 32ND PL   (FS) 16:46:16 16:46:44  0  3           -3 1 0    6 29  29
 2620 HAWTHORNE & 34TH      (FS) 16:46:50 16:47:28  1  3           32 1 0   11 19  27
 2623 HAWTHORNE & 37TH      (FS) 16:48:00 16:48:24  0  2          -85 1 0    5 26  25
 2625 HAWTHORNE & 39TH      (NS) 16:49:16 16:50:38  1  9          -80 1 0   12 22  17
```

# Table 2. Trip Level Performance Report

**Route: 004 - Fessenden** | **Weekdays** | **December 3, 2000 to March 3, 2001**

**Direction Outbound to Lombard & Burlington**

| Start Time | Train | Start Location | Avg. Boarding Rides | Avg. Max Load | Max Load Factor | Percent Over Capacity | # of Pass Ups | APC Obs. | Sched. Run Time | Median Run Time | Run Time Ratio | Run Time CV | Median Speed | Headway Adher-ence | Sched. Recovery | Median Recovery | Recovery Ratio | On Time | Early | Late |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | h:mm:ss | h:mm:ss | | | mph | | mm:ss | mm:ss | | | | |
| 1:37 PM | 450 | SW 6th & Salmon | 62 | 31 | 79% | 0% | 4 | 53 | 0:54:00 | 0:55:37 | 103% | 9% | 11.9 | 92% | 32:00 | 26:44 | 84% | 46% | 4% | 50% |
| 1:52 PM | 451 | SW 6th & Salmon | 59 | 32 | 82% | 8% | 1 | 53 | 0:54:00 | 0:53:12 | 99% | 9% | 12.4 | 91% | 27:00 | 26:31 | 98% | 72% | 7% | 21% |
| 2:07 PM | 435 | SW 6th & Salmon | 68 | 39 | 101% | 8% | | 53 | 0:54:00 | 0:55:04 | 102% | 8% | 12.0 | 91% | 22:00 | 19:43 | 90% | 71% | 6% | 23% |
| 2:22 PM | 441 | SW 6th & Salmon | 68 | 34 | 86% | 4% | 2 | 47 | 0:56:00 | 0:56:20 | 101% | 7% | 11.7 | 98% | 21:00 | 20:21 | 97% | 75% | 7% | 17% |
| 2:37 PM | 438 | SW 6th & Salmon | 77 | 38 | 98% | 2% | 4 | 53 | 0:56:00 | 0:55:44 | 100% | 8% | 11.8 | 95% | 22:00 | 21:02 | 96% | 76% | 5% | 19% |
| 2:48 PM | 434 | SW 6th & Salmon | 76 | 39 | 101% | 9% | 3 | 45 | 0:56:00 | 0:58:20 | 104% | 8% | 11.3 | 80% | 24:00 | 18:16 | 76% | 52% | 3% | 46% |
| 3:00 PM | 442 | SW 6th & Salmon | 68 | 35 | 89% | 4% | 8 | 54 | 0:56:00 | 1:00:26 | 108% | 7% | 10.9 | 84% | 18:00 | 14:00 | 78% | 72% | 6% | 22% |
| 3:08 PM | 443 | SW 6th & Salmon | 66 | 38 | 98% | 8% | 1 | 53 | 0:56:00 | 0:56:35 | 101% | 7% | 11.7 | 89% | 17:00 | 16:20 | 96% | 79% | 6% | 16% |
| 3:15 PM | 453 | SW 6th & Salmon | 55 | 33 | 84% | 2% | | 57 | 0:56:00 | 0:55:45 | 100% | 5% | 11.8 | 85% | 20:00 | 19:05 | 95% | 82% | 5% | 13% |
| 3:22 PM | 449 | SW 6th & Salmon | 62 | 35 | 89% | 2% | | 60 | 0:56:00 | 0:55:48 | 100% | 6% | 11.8 | 62% | 26:00 | 25:16 | 97% | 65% | 4% | 31% |
| 3:33 PM | 446 | SW 6th & Salmon | 73 | 42 | 109% | 4% | | 50 | 1:00:00 | 0:56:24 | 94% | 6% | 11.7 | 86% | 21:00 | 24:22 | 116% | 71% | 19% | 10% |
| 3:47 PM | 454 | SW 6th & Salmon | 78 | 39 | 91% | 8% | 3 | 13 | 1:00:00 | 0:59:54 | 100% | 4% | 11.0 | 94% | 19:00 | 19:52 | 105% | 74% | 18% | 8% |
| 4:01 PM | 456 | SW 6th & Salmon | 98 | 50 | 117% | 19% | 3 | 37 | 1:00:00 | 1:00:10 | 100% | 6% | 11.0 | 89% | 17:00 | 15:20 | 90% | 69% | 3% | 29% |
| 4:13 PM | 448 | SW 6th & Salmon | 76 | 44 | 113% | 9% | 3 | 56 | 1:00:00 | 1:00:28 | 101% | 8% | 10.9 | 71% | 20:00 | 16:53 | 84% | 52% | 3% | 45% |
| 4:26 PM | 436 | SW 6th & Salmon | 76 | 45 | 114% | 6% | 2 | 48 | 0:57:00 | 0:57:34 | 101% | 8% | 11.5 | 80% | 26:00 | 23:18 | 90% | 64% | 3% | 33% |
| 4:38 PM | 439 | SW 6th & Salmon | 71 | 48 | 124% | 34% | 2 | 50 | 0:57:00 | 0:57:54 | 102% | 8% | 11.4 | 57% | 29:00 | 21:02 | 73% | 31% | 2% | 67% |
| 4:51 PM | 440 | SW 6th & Salmon | 65 | 36 | 92% | 0% | | 55 | 0:57:00 | 0:54:52 | 96% | 4% | 12.0 | 48% | | | | 71% | 6% | 24% |
| 5:03 PM | 445 | SW 6th & Salmon | 72 | 48 | 124% | 25% | 6 | 51 | 0:57:00 | 0:55:52 | 98% | 8% | 11.8 | 82% | 19:00 | 18:49 | 99% | 62% | 12% | 26% |
| 5:14 PM | 444 | SW 6th & Salmon | 65 | 44 | 114% | 15% | 3 | 53 | 0:57:00 | 1:02:44 | 110% | 8% | 10.5 | 82% | 26:00 | 18:25 | 71% | 52% | 2% | 46% |
| 5:27 PM | 452 | SW 6th & Salmon | 61 | 41 | 106% | 9% | | 46 | 0:57:00 | 0:56:04 | 98% | 12% | 11.8 | 86% | 28:00 | 28:28 | 102% | 76% | 6% | 18% |
| 5:39 PM | 447 | SW 6th & Salmon | 70 | 39 | 100% | 2% | | 58 | 0:53:00 | 0:52:57 | 100% | 4% | 12.5 | 63% | | | | 41% | 3% | 56% |
| 5:54 PM | 455 | SW 6th & Salmon | 55 | 38 | 96% | 6% | 2 | 48 | 0:53:00 | 0:53:14 | 100% | 7% | 12.4 | 80% | 20:00 | 19:18 | 96% | 78% | 6% | 16% |
| 6:07 PM | 450 | SW 6th & Salmon | 56 | 36 | 93% | 0% | 3 | 53 | 0:53:00 | 0:54:11 | 102% | 8% | 12.2 | 83% | 22:00 | 17:48 | 81% | 52% | 6% | 43% |
| 6:20 PM | 435 | SW 6th & Salmon | 42 | 34 | 88% | 0% | | 53 | 0:50:00 | 0:50:28 | 101% | 7% | 13.1 | 81% | 27:00 | 27:08 | 100% | 84% | 6% | 10% |
| 6:33 PM | 451 | SW 6th & Salmon | 49 | 32 | 82% | 0% | 1 | 52 | 0:50:00 | 0:51:05 | 102% | 6% | 12.9 | 95% | 29:00 | 27:18 | 94% | 77% | 7% | 16% |
| 6:45 PM | 434 | SW 6th & Salmon | 46 | 28 | 71% | 0% | | 45 | 0:50:00 | 0:48:54 | 98% | 4% | 13.5 | 82% | | | | 59% | 1% | 39% |
| 6:56 PM | 458 | SW 6th & Salmon | 34 | 24 | 61% | 0% | 1 | 53 | 0:50:00 | 0:48:11 | 96% | 5% | 13.7 | 78% | 21:00 | 22:25 | 107% | 85% | 7% | 8% |
| 7:11 PM | 443 | SW 6th & Salmon | 46 | 28 | 71% | 0% | | 52 | 0:48:00 | 0:49:06 | 102% | 8% | 13.4 | 86% | 23:00 | 21:06 | 92% | 68% | 5% | 27% |
| 7:26 PM | 453 | SW 6th & Salmon | 44 | 32 | 83% | 0% | | 58 | 0:48:00 | 0:50:40 | 106% | 6% | 13.0 | 77% | 29:00 | 20:27 | 71% | 33% | 1% | 66% |
| 7:41 PM | 448 | SW 6th & Salmon | 33 | 21 | 53% | 0% | 1 | 56 | 0:48:00 | 0:47:01 | 98% | 4% | 14.0 | 75% | | | | 69% | 4% | 28% |
| 7:56 PM | 446 | SW 6th & Salmon | 33 | 21 | 53% | 0% | | 50 | 0:48:00 | 0:44:46 | 93% | 6% | 14.7 | 89% | | | | 85% | 10% | 5% |
| 8:11 PM | 439 | SW 6th & Salmon | 40 | 28 | 72% | 0% | | 48 | 0:48:00 | 0:48:42 | 101% | 7% | 13.6 | 89% | 16:00 | 14:26 | 90% | 75% | 3% | 22% |
| 8:26 PM | 436 | SW 6th & Salmon | 40 | 26 | 66% | 0% | | 46 | 0:45:00 | 0:45:46 | 102% | 4% | 14.4 | 69% | | | | 35% | 3% | 61% |
| 8:41 PM | 444 | SW 6th & Salmon | 30 | 23 | 58% | 0% | | 54 | 0:45:00 | 0:49:05 | 109% | 9% | 13.5 | 82% | 19:00 | 13:08 | 69% | 53% | 1% | 46% |
| 8:56 PM | 445 | SW 6th & Salmon | 31 | 21 | 53% | 0% | | 50 | 0:41:00 | 0:42:15 | 103% | 5% | 15.6 | 87% | | | | 54% | 3% | 43% |
| 9:10 PM | 455 | SW 6th & Salmon | 32 | 25 | 65% | 0% | | 50 | 0:41:00 | 0:43:46 | 107% | 9% | 15.1 | 93% | 24:00 | 20:40 | 86% | 63% | 1% | 36% |



* Indicates variability exceeds +/- 20% at the 80% confidence level.

Table 3. Summary Performance Report

| | Trips | Boarding Rides | Rides/ Rev.Hr | Max Load | Load Factor | % Over Capacity | % Due to Headway | # of Passups |
|---|---|---|---|---|---|---|---|---|
| ***Outbound*** | | | | | | | | |
| Early AM | 7 | 130 | 27.1 | 15 | 38% | 0% | 0% | 0 |
| AM Peak | 10 | 342 | 42.3 | 22 | 57% | 1% | 0% | 0 |
| Midday | 31 | 1,670 | 61.0 | 31 | 79% | 2% | 44% | 32 |
| PM Peak | 10 | 707 | 74.7 | 43 | 110% | 13% | 46% | 21 |
| Night | 22 | 806 | 48.0 | 26 | 67% | 0% | 0% | 6 |
| *Total by Direction* | 80 | 3,655 | 55.0 | 29 | 73% | 3% | | 59 |

| ***Outbound*** | On Time | Early | Late | Sched. Headway *hours/min.* | Headway Adhere. | Excess Wait Time *min./sec.* | Wait Time Per Trip *hours/min.* | Total Wait Time *hours/min.* |
|---|---|---|---|---|---|---|---|---|
| Early AM | 84% | 5% | 11% | 0:16 | 93% | 00:36 | 0:11 | 1:17 |
| AM Peak | 66% | 4% | 30% | 0:12 | 87% | 00:39 | 0:21 | 3:39 |
| Midday | 74% | 6% | 20% | 0:14 | 90% | 00:34 | 0:30 | 15:49 |
| PM Peak | 59% | 5% | 36% | 0:13 | 74% | 01:09 | 1:21 | 13:32 |
| Night | 69% | 5% | 26% | 0:21 | 89% | 00:51 | 0:30 | 11:19 |
| *Total by Direction* | 70% | 5% | 24% | | | | 0:34 | 45:39 |

Table 4. APC Passenger Census Report

## Tri-Met Passenger Census - Winter 2000/2001
## Weekday All-Day Ons and Offs by Route and Stop

**Route: 004 - Fessenden** **Outbound to Lombard & Burlington**

| Stop Location | Location ID | Ons | Offs | Total | Monthly Lifts* |
|---|---|---|---|---|---|
| 6TH / SALMON | 7789 | 250 | 0 | 250 | 23 |
| 6TH / YAMHILL | 7807 | 153 | 183 | 336 | 21 |
| 6TH / ALDER | 7747 | 250 | 129 | 379 | 15 |
| 6TH / STARK | 7797 | 129 | 78 | 207 | 10 |
| 6TH / PINE | 7787 | 93 | 65 | 158 | 5 |
| 6TH / COUCH | 7758 | 96 | 52 | 148 | 9 |
| 6TH / EVERETT | 9298 | 83 | 64 | 147 | 9 |
| EVERETT / 4TH | 9546 | 15 | 23 | 38 | 1 |
| EVERETT / 2ND | 1612 | 27 | 16 | 43 | 1 |
| ROSE QUARTER TC / B1 OUTBOUND | 1097 | 618 | 73 | 691 | 48 |
| WILLIAMS / WHEELER | 9547 | 7 | 5 | 12 | 0 |
| WILLIAMS / BROADWAY | 6357 | 25 | 17 | 42 | 3 |
| WILLIAMS / TILLAMOOK | 6370 | 9 | 25 | 34 | 1 |
| WILLIAMS / THOMPSON | 6369 | 17 | 31 | 48 | 2 |
| WILLIAMS / RUSSELL | 6354 | 56 | 55 | 111 | 36 |
| WILLIAMS / GRAHAM | 6362 | 24 | 70 | 94 | 25 |