Estimating Light-Rail Ridership from APC Data

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The Denver RTD

The Regional Transportation District (RTD) serves Denver and surrounding communities. Our region is the country's 21st largest metropolitan area with a population of 2.5 million. Annual boardings are 20.1 million. The agency provides both a bus and light-rail service.

The RTD started rail service in 1994. The 5 light-rail lines connect 36 stations with 775 weekday trips. RTD has 125 light-rail cars of which 24 have automatic passenger counters (APCs).

This paper discusses the use of APC data of the light-rail system in service evaluation and transit planning. The figures presented in this paper illustrates that with the right data and the right tools, RTD can provide the right solutions to provide quality service and improve ridership.

Figure 1. RTD's light-rail system serves 66,000 patrons each weekday.

Ridership Information System

The agency's ridership information system has three components – automatic passenger counters, ridership reporting software and scheduling software.

The APCs and other onboard equipment are provided by Innovations In Transportation (INIT) of Chesapeake, VA. The agency has found the onboard equipment to be dependable and the data to be accurate.

Ridecheck Plus from RSM Services of Houston, TX is the agency's ridership reporting software. The Ridecheck Plus database is a single repository for ridership information from ridechecks, AVLchecks and standchecks for light rail and bus. The data comes from a variety of sources including checkers, station masters, the APC system from INIT and an AVL system from another vendor. The Ridecheck Plus back-end database is hosted on a Unix database server running Oracle 10g. The Ridecheck Plus front-end application is hosted on various workstations running Windows XP Professional.

Trapeze Group of Mississauga, Ontario supplied the agency's fixed-route scheduling system, Trapeze FX. The scheduling information (routes, stops, timepoints, patterns, garages, divisions, blocks, runs and scheduled trips) are exported to the INIT and Ridecheck Plus systems at the start of each runboard or whenever a runboard is updated.

Over twelve months, the APC system typically gathers 63,000 ridecheck surveys (one-way vehicle trips) from the light-rail system with 1.1 million observations at stations. This is a great deal of information and, if it was not for RTD's software solution, would be unwieldy to analyze.

RTD's checker staff does not now collect, nor ever has collected, ridechecks on the rail system due to personnel resources. Rather, the checker staff does standchecks at two locations bracketing downtown. Weekday service is measured once a week. Standchecks for Saturday and Sunday service occur once a month. Standchecks are used by RTD staff for some reporting, but are a less preferred data source due to lack of precision and low volume of information. APC data is preferred.

Factoring from Cars to Trip

RTD does not have APCs on all cars. Therefore, APC data must be factored from multiple cars to the entire train. For example, the factor is 3/2 if the trip has two APC-equipped cars in a three-car train. This means 15 boardings on one car at Alameda Station and 25 boardings on another car translate into 60 boardings at the station on the three-car consist ((15+25) x 3/2). This factoring is done at each station on each trip.

RTD retains train configurations in daily manifests which are not amenable to electronic access. So, a data clerk enters the total cars in each trip on an onscreen form, illustrated in ***Figure 2***. This is the only manual step in utilizing APC for light rail. By contrast, processing of bus APC data is entirely automated.

Some agencies, like Houston METRO, have APCs by INIT on all light-rail cars, so would not need factoring, just merging of multiple cars into a single trip.

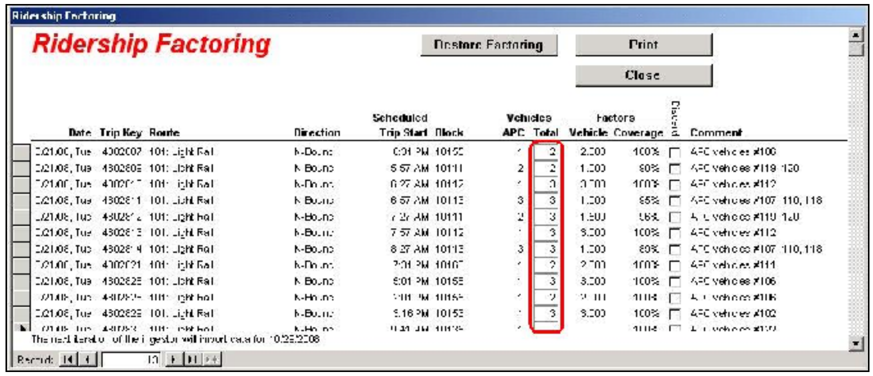


Figure 2. A RTD staff member adds the total cars in a train to the Ridership Factoring screen. This allows the software to factor data from car to trip level.

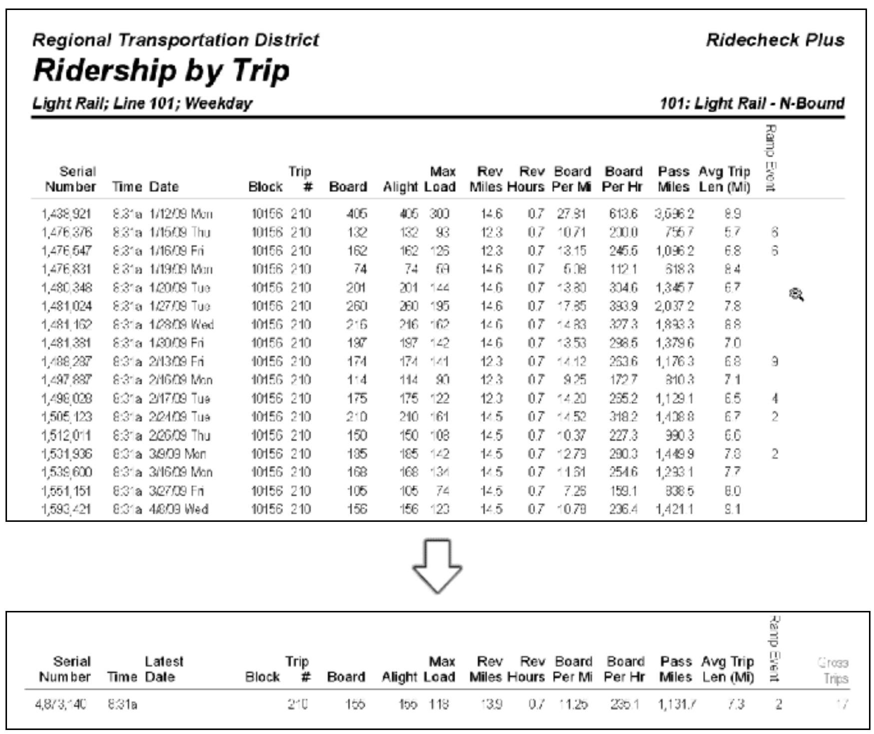
Validation of Data

The primary use for the APC data is in-house ridership estimation for service evaluation, planning and scheduling and, in particular, for recommending changes in routes and service frequency. Consequently, the agency requires, and Ridecheck Plus provides, measures to ensure high quality in the APC data that reach planners and schedulers.

Ridecheck Plus has forty-some validation and adjustment routines. RTD uses twenty of these routines to eliminate incomplete and questionable data. The result of these routines is the discard of 9% of the trips submitted by the APC system.

One validation test compares the stations within a trip of APC data against the stations in the Trapeze pattern. The test discards the trip's data if the discrepancy is great. This validation step accounts for 30% of the discards, or 3% of the data.

Another test compares the odometer distance submitted by the cars against the official pattern distance in the agency's scheduling system. A substantial discrepancy results in the discard of the trip's data. Here's the underlying logic. APC systems rely on GPS readings to identify the station, but also the measured distance from the last known location when GPS is unavailable due to storms and the downtown canyon effect. So, this test's logic rejects survey data in which the latter dead-reckoning method uses questionable vehicle odometer readings.



Regional Transportation District — *Ridecheck Plus*

Ridership by Trip

Light Rail; Line 101; Weekday — *101: Light Rail - N-Bound*

Serial Number	Time	Date	Block	Trip #	Board	Alight	Max Load	Rev Miles	Rev Hours	Board Per Mi	Board Per Hr	Pass Miles	Avg Trip Len (Mi)	Ramp Event
1,438,921	8:31a	1/12/09 Mon	10156	210	405	405	300	14.6	0.7	27.81	613.6	3,696.2	8.9	
1,476,376	8:31a	1/15/09 Thu	10156	210	132	132	93	12.3	0.7	10.71	200.0	756.7	5.7	6
1,476,547	8:31a	1/16/09 Fri	10156	210	162	162	126	12.3	0.7	13.15	245.5	1,096.2	6.8	6
1,476,831	8:31a	1/19/09 Mon	10156	210	74	74	69	14.6	0.7	5.08	112.1	618.3	8.4	
1,480,348	8:31a	1/20/09 Tue	10156	210	201	201	144	14.6	0.7	13.80	304.6	1,345.7	6.7	
1,481,024	8:31a	1/27/09 Tue	10156	210	260	260	195	14.6	0.7	17.85	393.9	2,037.2	7.8	
1,481,162	8:31a	1/28/09 Wed	10156	210	216	216	162	14.6	0.7	14.83	327.3	1,893.3	8.8	
1,481,381	8:31a	1/30/09 Fri	10156	210	197	197	142	14.6	0.7	13.53	298.5	1,379.6	7.0	
1,488,287	8:31a	2/13/09 Fri	10156	210	174	174	141	12.3	0.7	14.12	263.6	1,176.3	6.8	9
1,497,887	8:31a	2/16/09 Mon	10156	210	114	114	90	12.3	0.7	9.25	172.7	810.3	7.1	
1,498,028	8:31a	2/17/09 Tue	10156	210	175	175	122	12.3	0.7	14.20	265.2	1,129.1	6.5	4
1,505,123	8:31a	2/24/09 Tue	10156	210	210	210	161	14.5	0.7	14.52	318.2	1,408.8	6.7	2
1,512,011	8:31a	2/26/09 Thu	10156	210	150	150	108	14.5	0.7	10.37	227.3	990.3	6.6	
1,531,936	8:31a	3/9/09 Mon	10156	210	185	185	142	14.5	0.7	12.79	280.3	1,449.9	7.8	2
1,539,600	8:31a	3/16/09 Mon	10156	210	168	168	134	14.5	0.7	11.61	254.6	1,293.1	7.7	
1,551,151	8:31a	3/27/09 Fri	10156	210	105	105	74	14.5	0.7	7.26	159.1	838.5	8.0	
1,593,421	8:31a	4/8/09 Wed	10156	210	156	156	123	14.5	0.7	10.78	236.4	1,421.1	9.1	

Serial Number	Time	Latest Date	Block	Trip #	Board	Alight	Max Load	Rev Miles	Rev Hours	Board Per Mi	Board Per Hr	Pass Miles	Avg Trip Len (Mi)	Ramp Event	Cross Trips
4,873,140	8:31a			210	155	155	118	13.9	0.7	11.25	235.1	1,131.7	7.3	2	17

Figure 3. The ridership information system consolidates 17 distinct surveys of 8:31 am trip into one average trip..

Some tests are specifically crafted for light-rail service. For example, each car turns in data with the Trapeze trip id and an actual trip start time. If the start times differ by more than 10 minutes among cars, then the data on the "same" trip are rejected. This situation occurs when the APC system incorrectly assigns the same trip id to cars on different trips. This only happens about 50 times a month.

Average Trips

Surveys are committed to permanent storage after factoring and validation. RTD staff creates filters to retrieve particular cross-sections of rail service, and then generate an assortment of reports. RTD gathers 21,000 surveys on the rail system in a typical runboard (a four-month period). This information as a whole is not conducive to analysis by analysts, planners and schedulers, since some trips are surveyed many times and other trips surveyed a few times over the period. It is not a statistically balanced sample. RTD resolves this challenge by using “average trips”.

An average trip is the composite of several trips. ***Figure 3*** illustrates. If a line’s 8:31 am Northbound trip is surveyed 17 times in a runboard, then RTD’s software system builds one average trip. The arrival and departure times at each station are average times. The boardings and alightings at each station are averages of 17 observations.

Average trips have several advantages including (1) faster query time, (2) more trusted results than any single observation and, by definition, (3) the creation of a typical service day for weekday, Saturday or Sunday service. The service day samples are statistically balanced. RTD staff predominately use average trips, rather than distinct trips, for analysis and reporting.

Typical Reports from APC Data

The light rail system provides 24-hour service, 7 days a week. The rail system is generally a North-South service. Most commuters travel from the South into the central business district in the morning and return in the opposite direction at the end of the business day. Daily weekday ridership is 66,000 with demand peaks in the AM and PM rush hours. Midday ridership is reasonably strong. The left portion of ***Figure 4*** expresses

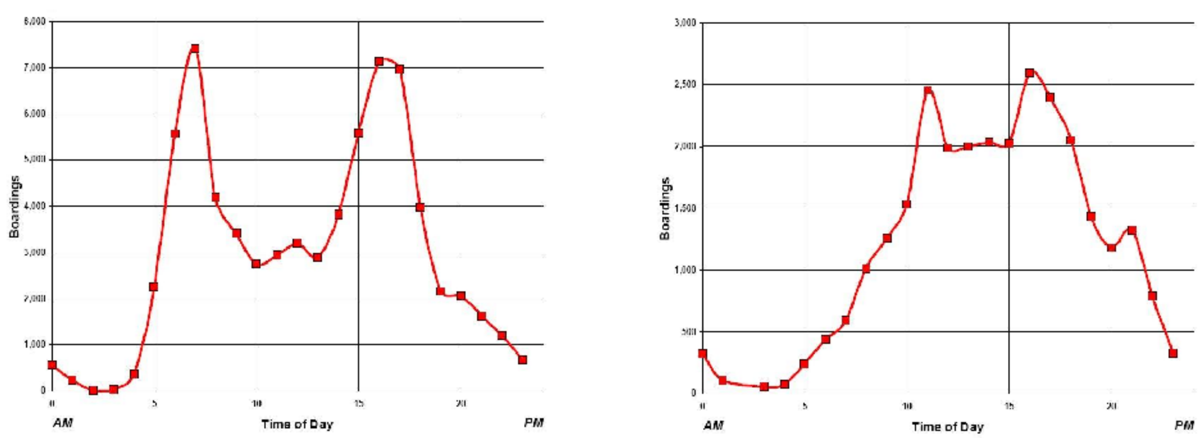


Figure 4. Weekday service is highly oriented to commuters with AM and PM peaks. On Saturdays and Sundays, most patronage occurs in the midday hours.

these characteristics as boardings in each hour of a typical weekday.

Weekend service is exemplified by low morning ridership. Boardings from 10 am to 7 pm are fairly strong, as show on the right side of ***Figure 4***.

All RTD users of the ridership information system have an interest in boardings, alightings and vehicle loads. The most popular reports show this information at the line, trip and station levels. ***Figure 5*** is a summary of stations that have maximum loads, boardings and alightings.

Figure 6 shows ridership on an average weekday by station in the Northbound direction.

Regional Transportation District | ***Ridecheck Plus***

Maximum Load, Boardings and Alightings

Light Rail; Line 101; Weekday (avg)

Route	Direction	Time Period	Trips	Max Load Stop ID	Max Load Stop Name	Load	Max Boardings Stop ID	Max Boardings Stop Name	On	Max Alightings Stop ID	Max Alightings Stop Name	Off	Gross Trips
101: Light Rail	N-Bound	AM Early	17	24882	Evans Station	93.4	24896	Littleton / Mineral Ave Station	43.4	23046	16th/California Station	35.6	257
101: Light Rail	N-Bound	AM Peak	51	23043	10th/Osage Station	164.6	25987	Nine Mile Station (1402)	80.6	23046	16th/California Station	75.1	642
101: Light Rail	N-Bound	Midday	97	24890	Englewood Station	66.8	24890	Englewood Station	33.0	23044	Colfax at Auraria Station	34.8	1,279
101: Light Rail	N-Bound	PM Peak	54	25971	Switch 21	69.9	24890	Englewood Station	20.3	23051	30th/Downing Station	39.6	539
101: Light Rail	N-Bound	PM Evening	31	24882	Evans Station	37.4	24890	Englewood Station	15.1	23051	30th/Downing Station	24.8	409
101: Light Rail	N-Bound	PM Late	43	23048	20th/Welton Station	20.6	24894	Littleton / Downtown Station	7.8	23051	30th/Downing Station	14.0	563
101: Light Rail	N-Bound	Other	21	24890	Englewood Station	12.0	25987	Nine Mile Station (1402)	5.2	25430	Union Station LRT Nb	5.2	254
101: Light Rail	S-Bound	AM Early	14	25991	Belleview Station	22.1	23051	30th/Downing Station	14.2	25439	Littleton / Mineral Ave Station	8.6	180
101: Light Rail	S-Bound	AM Peak	53	23053	25th/Welton Stn	73.1	23051	30th/Downing Station	44.7	25989	Dry Creek Station (2003)	16.2	702
101: Light Rail	S-Bound	Midday	95	25435	Evans Station	59.3	23051	30th/Downing Station	31.9	25436	Englewood Station	27.9	1,208
101: Light Rail	S-Bound	PM Peak	54	23058	Colfax at Auraria Station	166.4	23056	16th/Stout Station	64.8	25987	Nine Mile Station (1402)	97.1	655
101: Light Rail	S-Bound	PM Evening	33	23058	Colfax at Auraria Station	83.7	23058	Colfax at Auraria Station	36.3	25987	Nine Mile Station (1402)	39.2	389
101: Light Rail	S-Bound	PM Late	47	23058	Colfax at Auraria Station	47.3	23058	Colfax at Auraria Station	20.0	25987	Nine Mile Station (1402)	18.1	562
101: Light Rail	S-Bound	Other	20	25433	Pepsi Center/Elitch's Stn	16.2	25434	Union Station LRT Sb	14.8	25987	Nine Mile Station (1402)	3.7	331
Total			630										7,971

Figure 5. RTD's ridership information system give a concise view of the rail system, such as stations with maximum boardings, alightings or vehicle loads by time period.

The average maximum load of a trip in the AM Peak time period is 165 patrons at 10^{th}/Osage station in the northbound direction according to ***Figure 5***. The average maximum load in the PM Peak time period is 166 patrons at Colfax at Auraria station. However, some ***individual*** trips have higher numbers. ***Figure 6*** shows a maximum load for one trip of 338 patrons at the University of Denver Station.

Regional Transportation District | ***Ridecheck Plus***

Ridership by Station

Light Rail; Line 101; Weekday (avg) | ***101: Light Rail - N-Bound***

Sort	Stop	Dir	Stop ID	All Day Trips	All Day Board	All Day Alight	All Day Load Avg	All Day Load Max	All Day Load Total	AM Peak Trips	AM Peak Board	AM Peak Alight	AM Peak Load Avg	AM Peak Load Max	Midday Trips	Midday Board	Midday Alight	Midday Load Avg	Midday Load Max	PM Peak Trips	PM Peak Board	PM Peak Alight	PM Peak Load Avg	PM Peak Load Max	Bicycle Event	Ramp Event	Gross Trips
20	Nine Mile Tail Tracks (1402)	W	25975	75	644	25	6	67	618	10	154	5	15	31	23	165	5	7	22	11	124	9	10	27	.	6	1,177
30	Nine Mile Station (1402)	S	25987	78	1,996	25	27	134	2,068	11	974	3	91	134	24	518	10	22	51	12	101	4	17	35		7	1,190
40	Dayton Station	S	25974	78	353	42	36	176	2,932	11	160	4	116	176	24	142	13	33	80	12	39	11	27	40		1	1,196
60	Lincoln Tail Tracks (1401)	E	26271	1	.	.	0	0	0	.	.	.			.	.	.			1	.	.	0	0	.	.	5
70	Lincoln Tail Tracks (1401)	E	26271	102	188	36	1	5	152	19	45	7	2	5	25	49	10	2	3	18	32	8	1	3		1	1,529
80	Lincoln Station (2004)	S	25973	100	1,955	141	19	120	1,963	19	955	47	50	120	25	300	24	16	43	19	313	31	16	32	.	21	1,531
90	County Line Station (1405)	S	25988	103	496	27	24	140	2,432	19	97	5	55	140	25	126	10	21	53	19	148	7	24	41		1	1,534
100	Dry Creek Station (2003)	S	25989	100	831	42	31	187	3,221	19	307	13	70	107	25	106	10	25	59	19	200	10	38	70	.	.	1,531
110	Arapahoe at Village Center Station (2	S	25990	103	1,037	116	40	224	4,141	19	366	27	88	224	25	246	26	33	86	19	255	39	49	97		1	1,534
120	Orchard Station (1403)	S	25983	103	441	79	44	231	4,504	19	80	31	90	231	25	90	16	36	88	19	175	22	57	109	.	3	1,534
140	Belleview Station	S	25991	103	526	97	45	258	4,933	19	178	29	96	258	25	106	16	40	94	19	147	38	63	114		1	1,534
150	Southmoor Tail	N	25985	2	4	1	2	2	3	.	.	.			.	.	.			.	.	.			.	.	46
160	Southmoor Station	S	25978	180	1,173	789	46	279	8,251	29	501	121	121	279	49	385	231	40	109	29	136	206	50	101		4	2,749
170	Yale Station	S	25979	180	504	136	48	289	8,618	29	218	16	128	289	49	128	29	42	111	29	66	44	51	101	.	2	2,749
180	Colorado Station	S	25980	180	1,703	530	54	314	9,792	29	597	133	144	314	49	533	126	50	119	29	292	136	56	99		6	2,749
190	University of Denver Station	S	25981	180	1,404	463	60	338	10,733	29	515	137	157	338	49	426	114	56	131	29	209	116	59	95	.	2	2,749
200	Louisiana Station	S	25982	179	507	204	61	202	10,082	29	130	30	157	202	49	171	40	59	105	29	101	91	60	106	.	1	2,747

Figure 6. The system gives ridership breakdowns by station.

Average max loads in a time period and maximum max loads of any trip are two views of max load points. Standard deviation at max load points (not illustrated here) is another way staff view load with the agency's ridership information system.

All this information helps staff deploy the right equipment. RTD's rail cars have a nominal capacity of 114 persons. Thus, RTD usually has two cars per train, but sometimes three cars to respond to loads as reported by automatic passenger counters.

Key Performance Indicators

RTD's ridership information system provides key performance indicators such as passenger miles, revenue miles, revenue hours, boardings per revenue mile, boardings per revenue hour, passenger miles and ontime adherence. ***Figure 7*** shows these key performance indicators for light rail for typical weekday, Saturday and Sunday service. Other reports have other indicators, like a passenger's average trip length.

Running Times

Running time is the elapsed time to travel from one station to the next. Schedulers estimate the running times in creating a schedule. RTD's ridership information system provides staff with a comparison of runtimes in the Trapeze scheduling system versus actual runtimes as recorded by APC-equipped rail cars.

Shortly after the agency's ridership information system was implemented, RTD noticed scheduled and observed running times differed markedly with some station pairs.

For example, the scheduled travel times from I-25/Broadway to Alameda Station was found to be less than observed by the APC system. See the left graphic in ***Figure 8***. RTD staff subsequently increased the running time in Trapeze to reflect reality on the track, as shown in the right graphic of ***Figure 8***.

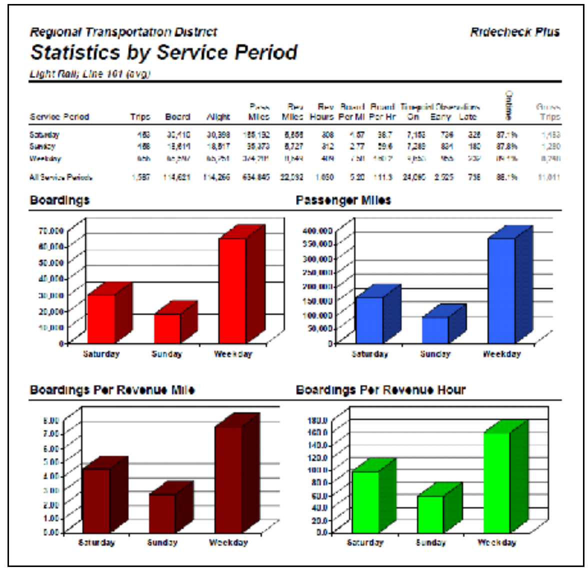


Figure 7. The ridership information system graphically portrays key information.

Agency's Assessment

The ridership analysis package has drastically improved data availability and analysis capabilities. There is a vast amount of data available for the last runboard, but also back to 2004 for historical analysis. Users retrieve information on any cross-section of service by building their own filters. The quantity of information is conducive to in-depth study by areas, such as the Auraria Campus (30,000 students) and the central business district, as well as major facilities such as Mile High

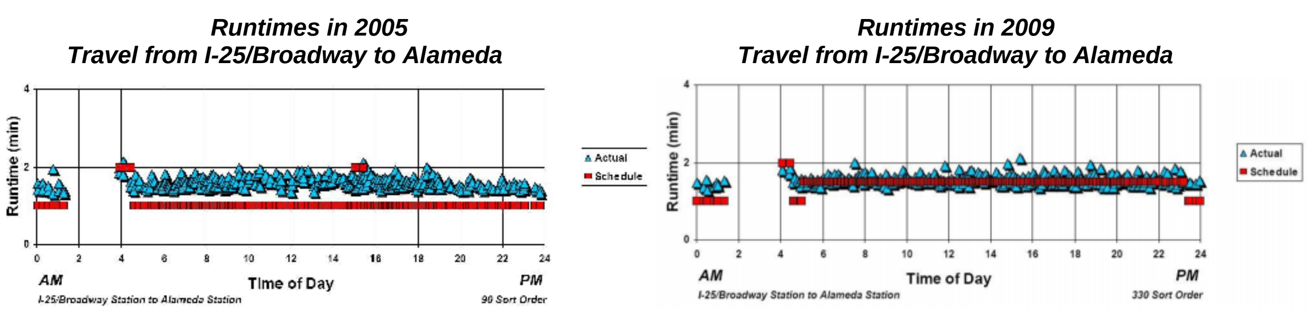


Figure 8. Observed running times were longer than scheduled running times in 2005. RTD staff adjusted the schedule. Actual and scheduled running times were nearly identical in 2009.

Stadium, Coors Field, Pepsi Center, Convention Center and various high schools.

The system allows RTD staff to make informed responses to customer complaints and suggestions. Presentations to the public about proposed changes to light-rail system are supported by current, accurate ridership information. APC data empowers the staff to be more confident when suggesting changes because of the great quantity and high quality of data at their finger tips. APC data is largely free of the "human element" that can degrade the quality.

Running time adjustments by staff are based upon information from the previous runboard. Unlike some times in the past, staff accomplish these activities quickly and easily. Prior to the current system, staff would make adjustments to running times by using less reliable data such as standchecks, operator standby cards and pass up reports. Most of this data was more than 6 months out of date which hampered timely adjustments. Running time adjustments are particularly important with a service such as light rail due to the adverse impacts of bad running times on loads.

The availability of fresh and accurate data is particularly helpful in rapidly changing areas or the early life of a new line. A large scale expansion of the light-rail system occurred in November 2006. APC data provided precise, current data that was used for adjusting equipment deployment and service frequency. The data is also used extensively for responding to the media, customers, colleagues, operators and management.

The ease-of-use of the system has made ridership information directly available to many staff members, rather then relying on a more limited number of people with high computer or analysis skills. The software has a GIS module by which users have made their own geographic maps of ridership information for the first time.

Return on Investment

The capital cost to purchase and install the APCs was $35,000 per car, or $840,000 for 24 cars. This includes associated costs like the Oracle licensing, software maintenance, data infrastructure and engineering. This one-time capital outlay allows the agency to collect 63,000 ridecheck surveys each year.

It is not practical to collect such a volume of information with checkers. Here's why. RTD would need to staff multiple doors per car for multiple cars in a train just to survey one trip with checkers. Multiply this by 63,000 trips in a year to get the same amount of data as with APCs. The theoretical manual collection program requires the expenditure of 250,000 hours by 120 checkers at a labor cost of $7,500,000 per year. There is also a burden with manual collection for data entry and validation, as well as checker oversight by several supervisors.

It is quite easy to conclude that the ridership information system with APCs provides an excellent return on the taxpayer's investment.

Figure 9. APC data indicates 2,300 customers use the Colorado Station each day. Many of commuters leave their cars in the park-n-ride lot.

Conclusion

Overall, the timeliness, quality and quantity of the data make the investments by the agency and staff worthwhile. The ridership collection and reporting system has provided a significant enhancement in the way the Regional Transportation District improves the quality service and responds to our customers needs.