Effects of Automated Scheduling and Dispatch Technology on Paratransit Schedule Adherence in Southeastern Michigan

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ABSTRACT

Among the paratransit performance indicators likely to be affected by automated scheduling and dispatch (ASD) is schedule adherence. Schedule adherence refers to a variety of measures, such as on-time arrival at a trip pickup point, associated with how well paratransit buses adhere to daily trip schedules. Such measures, then, serve as indicators of how well the transit operator adheres to trip times promised to customers during the trip reservation process. This study evaluates the Suburban Mobility Authority for Regional Transportation's (SMART's) performance on several key schedule adherence measures based on a sample of paratransit trips selected from their daily paratransit trip logs. More specifically, this paper characterizes SMART's schedule adherence performance on eight measures, with a particular emphasis on evaluating their ASD's effects on schedule adherence.

To isolate effects due to SMART's ASD system (Quo Vadis), the evaluators employed multivariate linear regression analysis, which allows for statistical control over other factors influencing service outcomes. The results of this analysis indicate that, holding constant for other changes and events affecting SMART paratransit operations, Quo Vadis-based schedules are associated with declines in per trip travel time, earlier than scheduled arrival at scheduled trip pickup times, later than scheduled arrival at scheduled drop-off times (as a whole suggesting some underestimation of required trip times in schedule creation), and fewer intermediate pickups and drop-offs during trips. Furthermore, the analyses also indicate that Quo Vadis has improved the scheduling of intermediate pickups, making those that are scheduled less burdensome in terms of time costs. On the other hand, Quo Vadis as used does not appear to allocate enough time for intermediate drop-offs, contributing to lateness relative to scheduled travel times. In sum, with Quo Vadis actual travel times have improved (suggesting better ordered schedules and resulting in faster trips for customers, on average), but Quo Vadis has been underestimating required travel times.

INTRODUCTION

Through the addition of automated scheduling and dispatch (ASD) technology to its Community Transit operations, the Suburban Mobility Authority for Regional Transportation (SMART) of southeastern Michigan has sought to improve its paratransit operations along several dimensions. Among these potential improvements, SMART hopes to improve its schedule adherence, meaning that it seeks to do a better job of having Community Transit buses arrive when customers are told that they will arrive.

From the paratransit customers' perspective, both early and late arrivals can be problematic, as the former may mean that a customer is not prepared to leave when the bus is, and the latter means that the customer may well arrive late for some other appointment. The latter situation may be even worse for late arrival at the destination. Thus, adherence to the daily schedules represents an important measure of service quality. This paper provides a quantitative basis for evaluation of the performance of SMART's ASD (a product called Trapeze™-QV, or simply Quo Vadis; Trapeze™-QV is a registered trademark of Trapeze Software Inc. The most recent version of this software, which SMART will soon obtain, is marketed under the name Trapeze™-PASS.) in the area of schedule adherence, including measures of pickup arrival time, destination drop-off time, and on-board travel time, especially deviations of these from daily trip schedules.

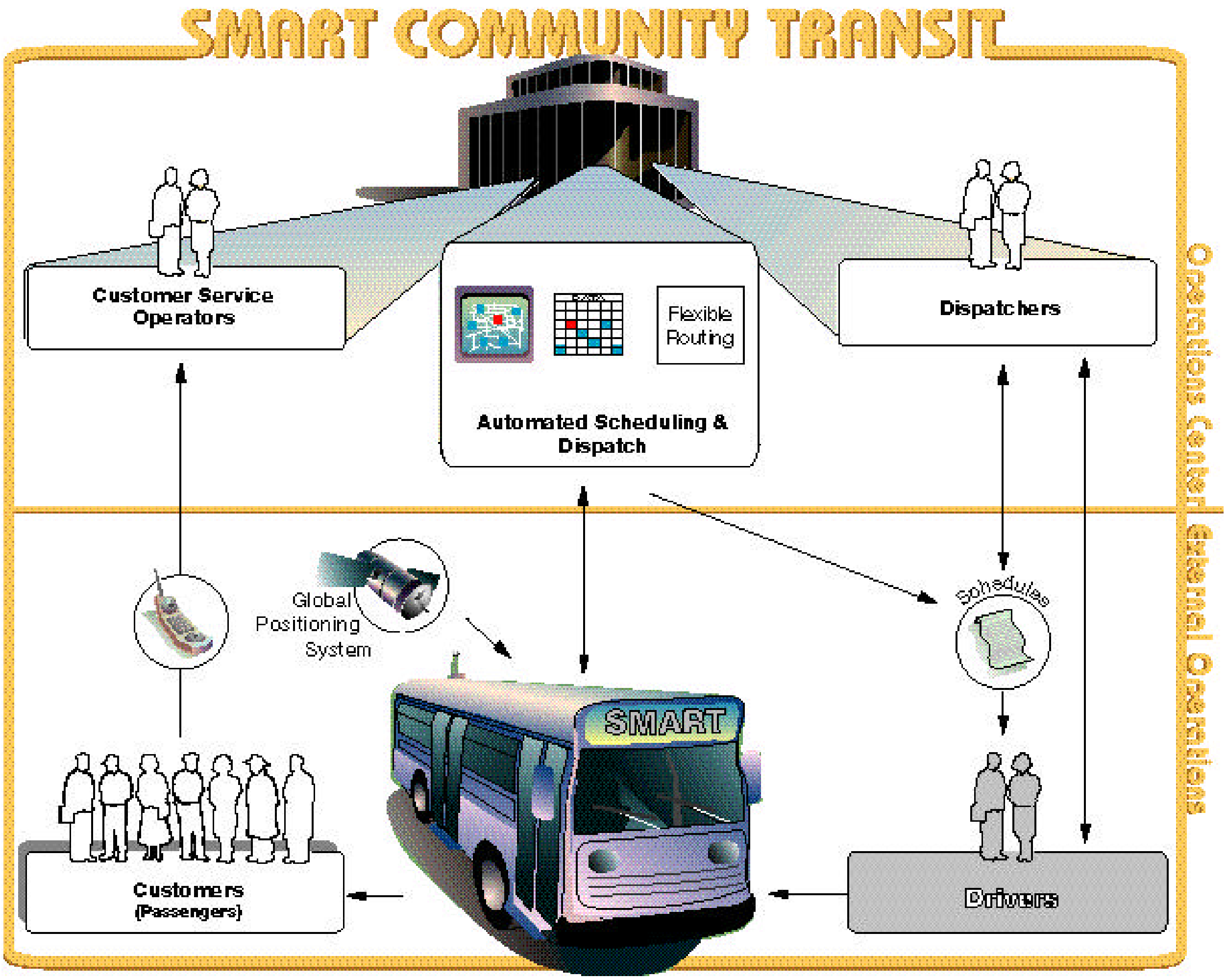
Paratransit Scheduling at SMART

To receive paratransit service from SMART, customers typically call a SMART customer service operator (CSO) several days in advance to arrange for a trip--usually two to six days in advance. Other customers have standing orders, meaning that they are picked up by SMART at a predetermined time and place on a weekly, monthly, or other regular basis. Still other customers request same-day (or ASAP) trips. Regardless of the method of trip reservation, however, customers are told by SMART CSOs (dispatchers in the case of ASAP trips) when the bus will arrive to pick them up and when it will drop them off at their destination. Furthermore, SMART informs customers that the bus will arrive within a twenty-minute window around the scheduled time (i.e., up to ten minutes early or late). (SMART instructs Community Transit drivers to wait at least three minutes before leaving without a passenger, but this three-minute period begins only at the onset of the twenty-minute window, meaning that early vehicles may need to wait more than three minutes. Furthermore, drivers require permission from the dispatcher to leave without completing a scheduled pickup.) For its own records, SMART considers all pickups that occur within this twenty-minute window to be on-time, while those arriving before the window are early and those arriving afterward are late. In keeping with this convention, for the purposes of this study, we will also examine twenty-minute intervals around scheduled drop-off and on-board times. Other important characteristics of the customers's paratransit experience are that all paratransit service is operated on a curb-to-curb basis and all CSOs are located at a single terminal (though all customers are given a local number for their area to reach these operators).

At the end of each day, all scheduled trips for the following day are distributed across the various work blocks and assigned to specific vehicles and drivers. At the start of each shift, most drivers leave their home terminal (Macomb, Wayne, Troy, or Pontiac) with a list of scheduled trips for the day (see Diagram 1 for a graphic depiction of the trip scheduling process). Drivers handling only ASAP trips, of course, may leave with a blank schedule to be filled in as the day proceeds. Even for drivers handling mostly advance reservation trips, however, schedules may change over the course of the day, as some customers cancel and others call for ASAPs; in general, ASAPs are handwritten into the day's schedule. Together, these drivers provide service over a roughly 2,000 square-mile area that includes both urban, suburban, and rural areas, though suburban predominates.

While this study seeks to measure the overall effects of Quo Vadis, and not the effects of specific components of the software, a brief description of some of the general features of the system, especially as they differ from CARDS (SMART's former scheduling system) are in order. Both systems are built on a database of customers, including home addresses and accessed destinations, and in both systems CSOs must type in desired trip information when a new reservation is made. Perhaps the major difference between the two systems is that Quo Vadis provides a geographical interface, through which CSOs can locate pickup and drop-off points through the software. With CARDS, CSOs had to resort to paper maps (map books) to pinpoint locations. Of course, the two systems also differ in terms of algorithms used to project travel times and arrange schedules. Furthermore, Quo Vadis appears to have stricter rules regarding CSOs' ability to violate these algorithms than does CARDS. Finally, Quo Vadis also allows the user to indicate if a rider is in a wheelchair and therefore requires additional boarding time (5 minutes by default, but alterable), which is built into the itinerary. The purpose of this study is to determine, all things considered, whether or not Quo Vadis produces schedules that drivers can adhere to better.

Diagram 1. SMARTs Community Transit Trip Reservation System



METHOD

Ideally, SMART maintains a record of all Community Transit trips for all drivers for all days at all terminals; until SMART's AVL system is fully operational, this data is a product of daily schedules (produced by the scheduling software) and handwritten, driver additions to these. This amounts to an enormous quantity of data available only on paper, suggesting the need for a sampling approach. Furthermore, sampling produces better results than a complete enumeration in cases in which missing data are not randomly distributed. That is, if certain terminals have more trips sheets that cannot be located, or if certain time periods (or seasons) experience more missing trips sheets, then results based on all available trip sheets may be biased; sampling can eliminate this bias. For these two reasons, we chose to sample from available trip sheets for an identical time period within each year.

Four primary concerns drove design of the sampling plan: (1) the need to establish differences between pre- and post-Quo Vadis measures, (2) a desire to control for seasonal variation in transit service, (3) a need to sample from all four SMART Community Transit terminals, and (4) statistical power. After the evaluation began another concern emerged--the need to distinguish Quo Vadis effects from the effects of SMART's 1995 millage election, which led to the shrinking of SMART's service area.

To control for seasonal variations in paratransit operations, the evaluators sampled trips during an identical time period (summer) for each of three years (1994, 1995, 1996). To account for different amounts of paratransit service provided from each terminal, we randomly sampled trips at each terminal in proportion to each terminal's contribution to the total amount of service provided by SMART. For example, if 25 percent of the paratransit trips in the summer of 1994 were provided from Terminal A, then we selected 25 percent of 1994's sample from Terminal A's trip sheets. This approach was particularly important in the wake of the millage, because some terminals lost more service than others with the reduction in service area.

The overall sample size, in turn, was driven by concerns for statistical power--i.e., the ability to identify significant differences where they exist; thus, we settled on a desired sample size of 600 (200 per year) to obtain a sampling error of approximately 0.05. In the end, we chose a somewhat larger sample (705) due to a desire to mitigate the effects of missing data at some terminals.

With this sampling plan, data from 1994 represent both the pre-Quo Vadis service and the pre-millage service. Data from 1995 are post-millage at all terminals and post-Quo Vadis at Macomb only. Finally, 1996 data are post-Quo Vadis for all terminals.

Field Sampling

Because past schedules are kept at each SMART terminal and cannot be removed from the terminals due to risk management concerns, evaluation staff were required to develop an approach for selecting specific trips in the field. Essentially, given a certain number of trips per terminal to be sampled, we selected specific pickup trips by first randomly selecting a month (June, July, or August), then a day within the month, and then a specific trip within a day. This procedure, therefore, treats all months in the study as equal. To arrive at a single trip for the database, we selected only lines in the schedules referring to pickups; cancellations also were not included, as essentially these are non-trips from the customer perspective. To aid this procedure, field data collection was accomplished with a laptop computer in hand for selecting random numbers and for immediate data entry.

At all terminals (except for Macomb), we encountered missing data for at least one month for the years 1994 and 1995. Because data storage methods required a sampling procedure in which a month was selected first in selecting specific trips, missing data resulted in a lower sample size than desired. For this reason, we extended our initial time period for each year (June through August) to also include September, which had the positive effect of maintaining the total sample size at desired levels. The resultant sample sizes by year and terminal are displayed in Table 1.

Table 1. Schedule Adherence Sample Sizes

	Year[a]		
Terminal	1994	1995	1996
Macomb	49	60	70
Wayne	68	95	68
Troy	40	54	74
Pontiac	45	35	47

[a]A year includes June through September. Data were missing for:

Wayne: August 1994, September 1994, July 1995
Troy: June 1994
Pontiac: August 1994

For all of the analyses discussed below in the Results section, month is not considered as a variable. That is, all analyses are based on the assumption that service does not differ significantly between these four months, and each year is treated as a single unit (i.e., month-by-month comparisons are not made). The primary rational for this assumption is that these four months are roughly grouped within a single season (summer); therefore, all four of these months experience similar weather and traffic conditions. To verify the validity of this assumption, we performed analysis of variance (ANOVA) tests for the key outcome measures listed in Table 2 and found no significant differences (even at the 0.25 level) by month in any year for any of these measures. Thus, the assumption of treating each year's worth of data as a single period is supported empirically and should not hinder further analyses.

RESULTS

To analyze schedule adherence, numerous measures of performance are possible. In the analyses that follow we will focus on eight specific measures: on-time pickup, on-time arrival (at destination), on-time travel, actual travel time, speed, trip distance, intermediate pickups, and intermediate drop-offs. Several of these measures are based on a similar data coding strategy focusing on deviations between *scheduled* and *actual* performance. Thus, for example, a trip for which the bus arrived five minutes early for a pickup--relative to the schedule--would be coded "-5," while a bus arriving five minutes late would be coded "5." Other measures, such as actual travel time, are measured in absolute terms. Each of these eight key measures is defined in Table 2.

Table 2. Definitions of Key Study Measures

Measure	Definition
1. On-time Pickup	The difference between actual and scheduled pickup time (in minutes; negative is early)
2. On-time Drop-off	The difference between actual and scheduled drop-off time at destination (in minutes; negative is early)
3. On-time Travel	The difference between actual and scheduled on-board travel time (in minutes; negative is less than scheduled)
4. Actual Travel Time	Actual on-board travel time (minutes)
5. Speed	On-board speed for passenger (travel time divided by trip distance; miles per hour)
6. Trip Distance	Distance traversed by passenger between pickup and drop-off point (miles)
7. Intermediate Pickups	The number of pickups the bus makes between the passenger's boarding and deboarding for a sampled trip
8. Intermediate Drop-offs	The number of drop-offs the bus makes between the passenger's boarding and deboarding for a sampled trip

Tables 3a through 3d present the means for each of these eight key measures for all four terminals for all three study years. While trends vary somewhat from terminal to terminal, these tables show that numerous key measures changed significantly across years as determined by ANOVA. In fact, both millage election (interposed between 1994 and 1995 data) and Quo Vadis (between 1994 and 1995 for Macomb and between 1995 and 1996 for all the others) appear to have had significant effects on some measures. Also, the significant effects appear at different times for different terminals depending on the measure of interest. For example, actual travel time at the Wayne terminal changed little after the millage election, but fell decidedly after Quo Vadis; at Troy, however, the opposite occurred, and the millage appears to have caused the bigger change. Thus, the millage and Quo Vadis have affected the terminals differently, perhaps even uniquely.

Table 3a. Macomb Terminal Schedule Adherence Mean Results

Measure (Overall Mean--3 years)	Year (n=179)		
	1994	1995	1996
On-time Pickup (-5.26)**	0.39	-7.12	-7.59
On-time Drop-off (-5.34)*	-1.20	-4.33	-9.10
On-time Travel (-0.08)**	-1.59	2.83	-1.51
Actual Travel Time (18.1)	20.0	17.0	17.8
Intermediate Pickups (0.55)	0.41	0.63	0.58
Intermediate Drop-offs (0.35)	0.33	0.38	0.33
Trip Distance (5.52)	5.27	5.52	5.71
Speed (19.1)**	16.3	20.4	19.9

*Significantly different at the 0.10 level by year.
**Significantly different at the 0.05 level by year.

Table 3b. Wayne Terminal Schedule Adherence Mean Results

Measure (Overall Mean--3 years)	Year (n=231)		
	1994	1995	1996
On-time Pickup (-4.07)	-0.71	-4.47	-6.88
On-time Drop-off (-4.13)	-3.21	-6.00	-2.47
On-time Travel (-0.06)**	-2.50	-1.53	4.41
Actual Travel Time (32.1)***	32.3	36.0	26.4
Intermediate Pickups (2.18)	2.44	2.42	1.59
Intermediate Drop-offs (1.16)	1.03	1.29	1.13
Trip Distance (9.51)***	8.04	11.39	8.38
Speed (18.4)**	16.2	19.1	19.6

**Significantly different at the 0.05 level by year.
***Significantly different at the 0.01 level by year.

Table 3c. Troy Terminal Schedule Adherence Mean Results

Measure (Overall Mean--3 years)	Year (n=168)		
	1994	1995	1996
On-time Pickup (4.20)	7.75	4.65	1.95
On-time Drop-off (5.15)	7.50	1.85	6.30
On-time Travel (0.96)	-0.25	-2.80	4.35
Actual Travel Time (41.0)**	51.5	36.7	38.5
Intermediate Pickups (1.95)***	3.25	1.56	1.53
Intermediate Drop-offs (0.96)	1.10	0.59	1.15
Trip Distance (13.17)	14.1	13.6	12.4
Speed (19.9)	17.6	22.2	19.4

**Significantly different at the 0.05 level by year.
***Significantly different at the 0.01 level by year.

Table 3d. Pontiac Terminal Schedule Adherence Mean Results

	Year (n=127)		
Measure (Overall Mean--3 years)	1994	1995	1996
On-time Pickup (-3.75)	-2.93	-4.97	-3.62
On-time Drop-off (-4.97)	-2.82	-7.66	-5.02
On-time Travel (-1.22)	0.11	-2.69	-1.40
Actual Travel Time (20.9)**	25.3	20.4	17.1
Intermediate Pickups (0.87)	1.20	0.83	0.60
Intermediate Drop-offs (0.65)	0.62	0.71	0.62
Trip Distance (6.34)**	7.87	5.86	5.23
Speed (19.0)	19.7	18.4	18.7

**Significantly different at the 0.05 level by year.

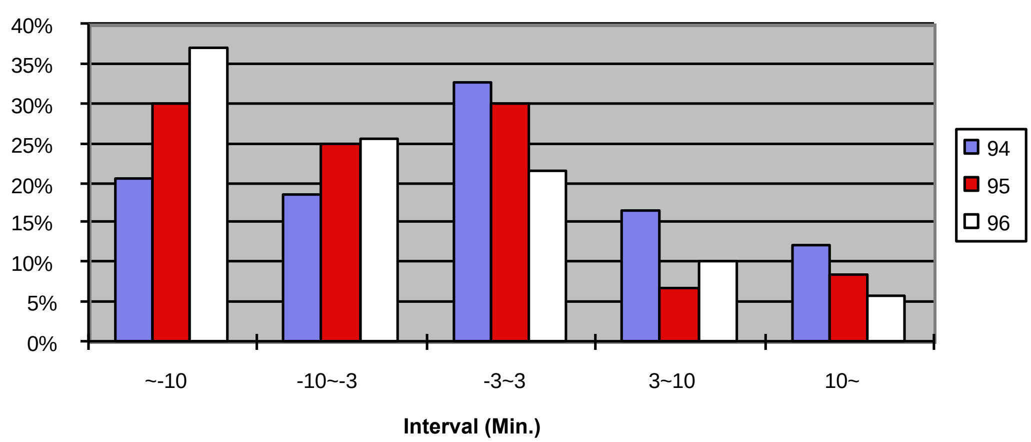
Time Window Adherence

Because SMART defines a twenty-minute window around scheduled pickup times as being "on-time," changes in percentages within and outside this window are important for analysis. In this section, we examine time-window adherence for all four terminals in the three study years. Furthermore, we extend the time-window analysis to drop-offs and on-board travel time.

<u>Pickups</u>

As shown in Figures 1 through 4, over time SMART paratransit is arriving earlier and earlier relative to the schedule, thereby increasing the percentage of pickups occurring prior to the time window. On the positive side, the percentage of late arrivals (more than ten minutes after scheduled pickup) has declined, except for trips originating from the Troy terminal, and in Pontiac nearly reached zero for trips sampled in 1996. At Macomb, the terminal least affected by the millage election, late arrivals declined monotonically after Quo Vadis implementation.

Figure 1. On-Time Performance: Pick-Ups (Macomb)



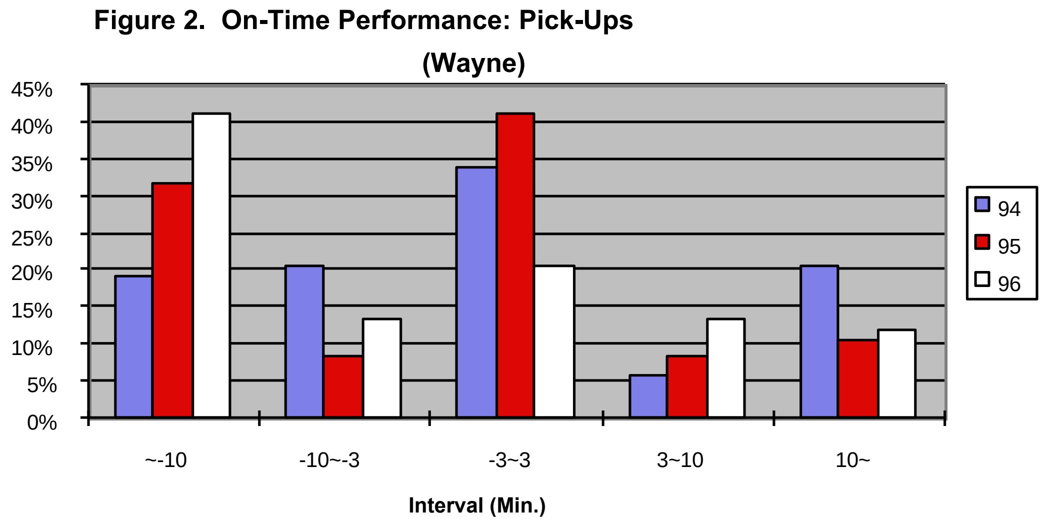


Figure 2. On-Time Performance: Pick-Ups
(Wayne)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
~-10
-10~-3
-3~3
3~10
10~
Interval (Min.)
94
95
96

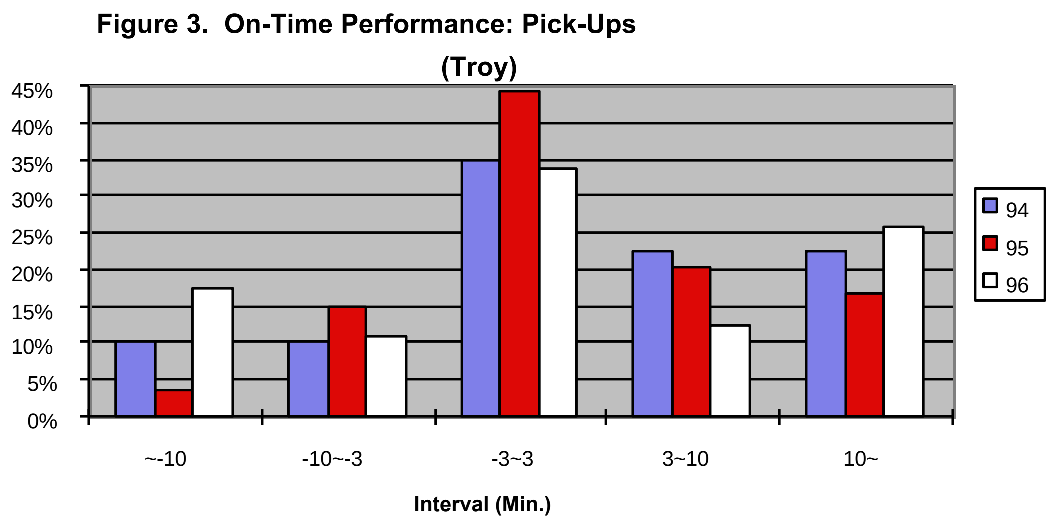
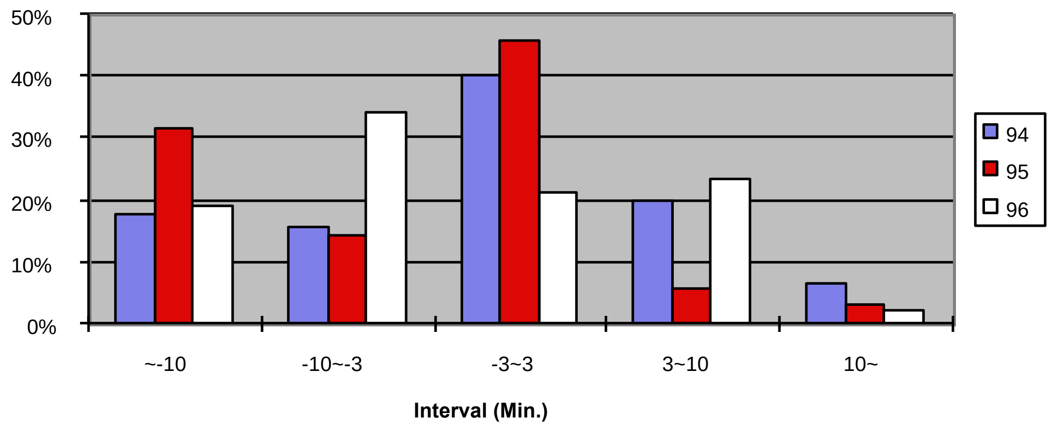


Figure 3. On-Time Performance: Pick-Ups
(Troy)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
~-10
-10~-3
-3~3
3~10
10~
Interval (Min.)
94
95
96

Figure 4. On-Time Performance: Pick-Ups (Pontiac)



Drop-offs

Figures 5 through 8 illustrate on-time performance for drop-offs in relation to the twenty-minute window. These results tend to mirror those for pickups, with the Troy terminal experiencing a surge in late drop-offs in 1996. Wayne, too, experienced an increase, while at Pontiac late drop-offs dropped to zero percent of sampled trips in 1996.

Figure 5. On-Time Performance: Drop-Offs (Macomb)

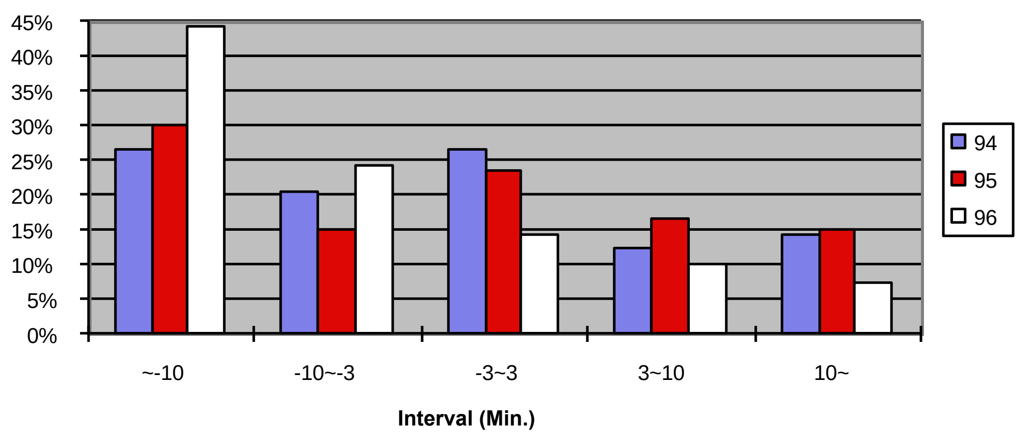


Figure 6. On-Time Performance: Drop-Offs (Wayne)

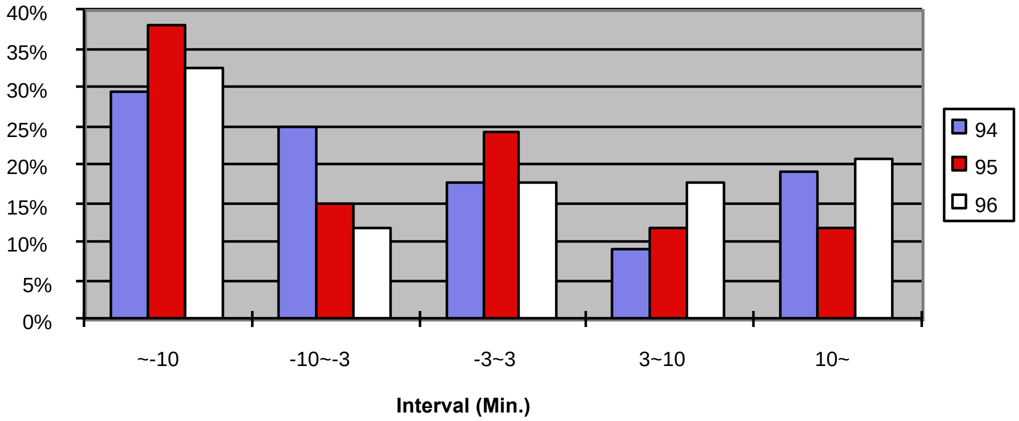


Figure 7. On-Time Performance: Drop-Offs (Troy)

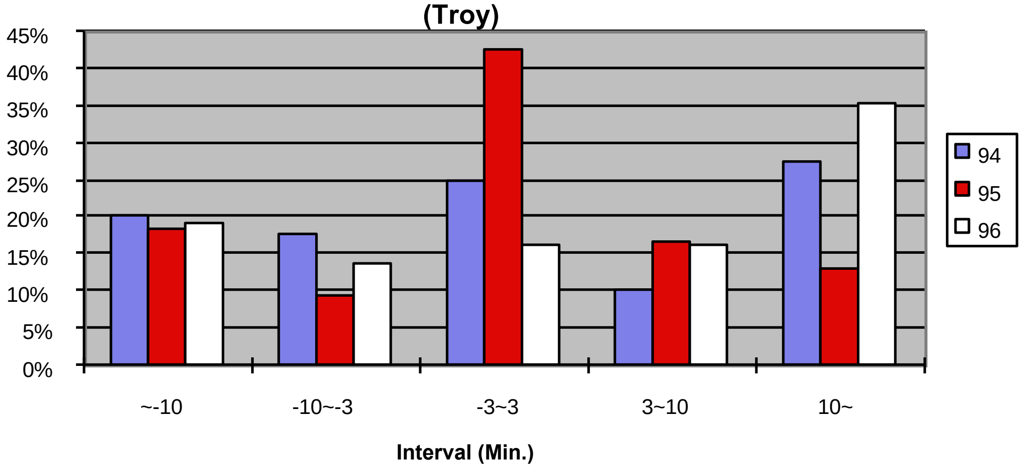
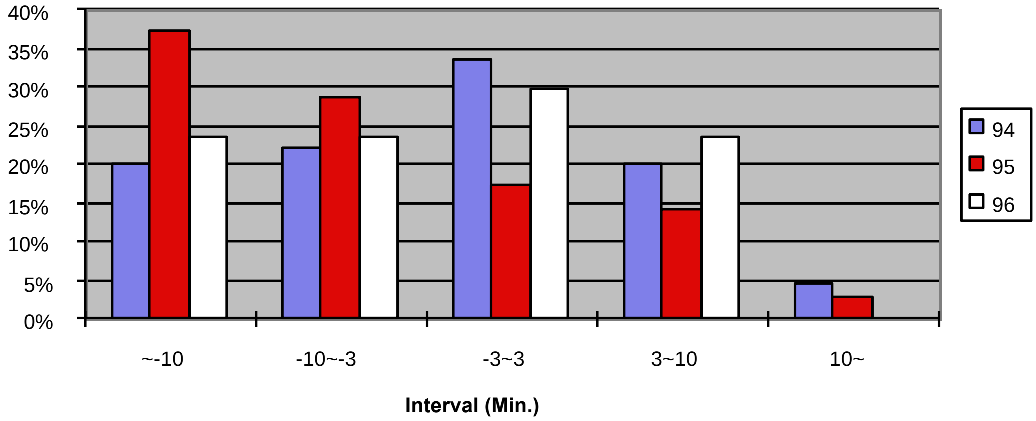


Figure 8. On-Time Performance: Drop-Offs (Pontiac)



<u>On-Board Travel Time</u>

Similar to the figures above, Figures 9 through 12 display SMART's success in keeping on-board travel time within the scheduled period. As these figures show, longer than scheduled trips have become more common at all terminals, but at two terminals so has the percentage of nearly perfectly estimated travel times (within 3 minutes of scheduled). Thus, as also visible in the figures, the percentage of much shorter than scheduled travel times (i.e., more than 10 minutes shorter) has declined since 1994, indicating a decline in the number of trips for which travel time is overestimated. These results suggest that Quo Vadis provides less of a time cushion around trips, leading to precise estimates more of the time, but resulting in lateness when conditions do not allow for precise adherence to schedules.

Figure 9. On-Time Performance: On-Board Travel Time (Macomb)

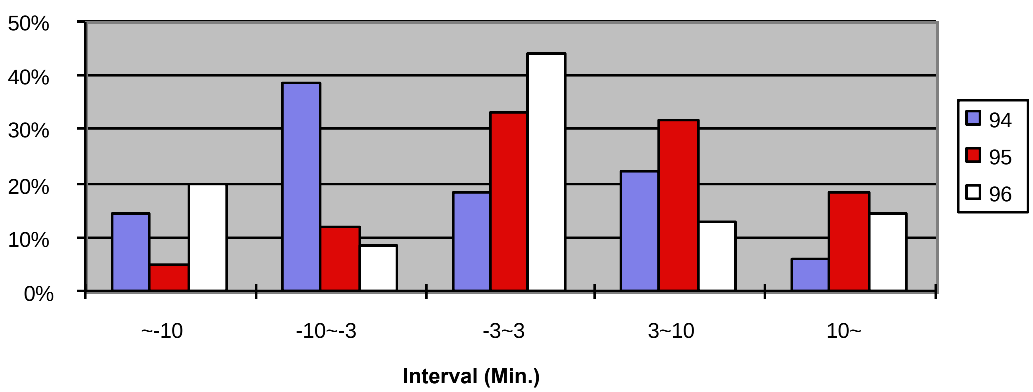


Figure 10. On-Time Performance: On-Board Travel Time (Wayne)

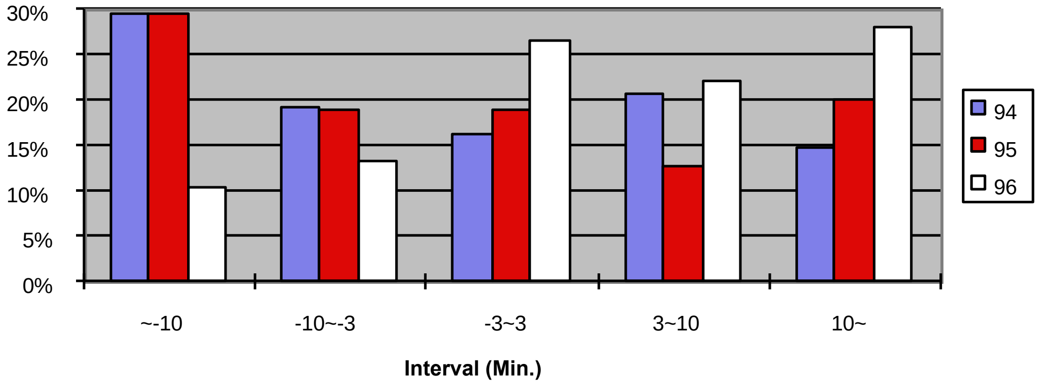


Figure 11. On-Time Performance: On-Board Travel Time (Troy)

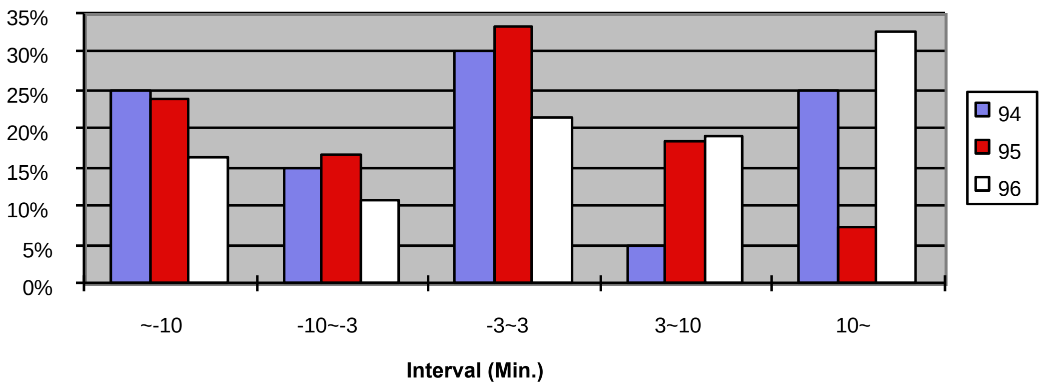
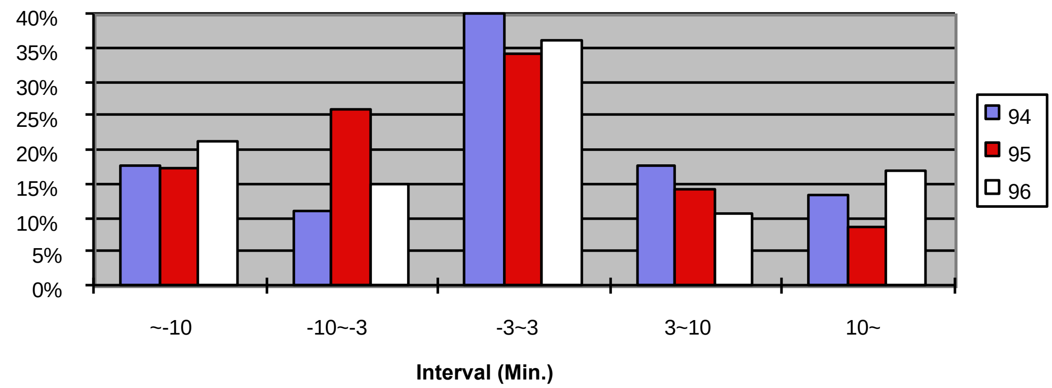


Figure 12. On-Time Performance: On-Board Travel Time (Pontiac)



Quo Vadis Effects

Given that many of the key measures analyzed in this paper are interrelated (e.g., the number of intermediate stops affects travel time), and that many changes have occurred at SMART's four terminals over the course of the study, including those associated with the millage election and Quo Vadis, the appropriate approach for evaluating the effects directly attributable to Quo Vadis is to study changes in key measures controlling statistically for other changes. Neither the means analysis nor the time window analysis above accomplishes this sufficiently.

While the available data do not allow us to control for every possible event or service change, we can approximate that level of control by including correlates of change, such as changes to other key measures, within multivariate regression models. For example, we will often use trip distance as a control variable, because many of our key measures logically should be affected by distance, even while keeping in mind that our measure of distance refers to the distance actually traveled during sampled passenger trips, and not to the distance of some theoretical best route linking the pickup and drop-off points. The number of intermediate pickups and drop-offs will be used in a similar way, as they are expected to influence on-time performance and travel time. Furthermore, we will use dummy variables for the terminals themselves to account for the variety of other changes taking place (such as the addition of new service, Job Express, the millage election, etc.) at each terminal and to account for our finding above that each terminal has some unique characteristics. These dummy variables are coded "1" for trips originating from the terminal for which the variable is formed (e.g., Macomb), and "0" for all other trips. Thus any given case (trip) contains a "1" for only one of the four terminal dummies, and "0" for the other three. (Mathematically, only three dummy variables are needed, because the fourth is perfectly defined by combinations of the other three. In the analyses that follow, we allow the statistical software to select which dummy variable will serve as the base case.)

In predicting some of our key measures, however, we have fewer control factors available. For on-time pickup, for example, events that occur after the pickup, such as intermediate pickups and drop-offs, logically should not affect the pickup time of that trip, though they may affect subsequent pickups. Because our sample was designed to produce a set of independent trips, however, such links between passenger trips will not be examined in this paper.

In the following sections, we examine each of the eight key measures in turn, with the goal of describing Quo Vadis's effect on that measure controlling for other factors. Like the terminal variables, the Quo Vadis variable is coded "0" or "1," with 0 for pre-Quo Vadis trips and 1 for post-Quo Vadis trips. For all analyses, all other predictors were entered into the model prior to Quo Vadis, thus the resultant Quo Vadis effect should be viewed as the effect of Quo Vadis after accounting for the explanatory power off all other predictors.

Trip Distance

The regression model for trip distance, which explain about 36 percent of the variance in trip distance, is summarized in Table 4a. Our analysis shows that Quo Vadis has not had a significant effect on trip distance (p=0.325). Significant effects that were found, however, include those for the Troy terminal (longer trips), intermediate pickups and drop-offs (both resulting in longer trips, with pick-ups adding more distance than drop-offs), and on-time pickup (late arrival associated with shorter travel distance and early arrival with longer). This suggests that drivers, on their own or guided by dispatchers, alter their assigned sequence of pickups or drop-offs, or follow shorter routes, when they fall behind schedule.

Table 4a. Effects on Trip Distance

	Regression Output (R^2=0.362)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-0.145	0.849
Pontiac	-0.341	0.664
Troy	4.748	0.000
On-Time Pickup	-0.046	0.002
Intermediate Drop-off	1.091	0.000
Intermediate Pickup	1.685	0.000
Quo Vadis	-0.554	0.325

*Values below 0.05 are statistically significant at the 95% confidence level.

On-Time Pickup

Because the trip pickup defines the beginning of a trip as studied in this paper, most of our key measures refer to events that occur after the pickup, and therefore should not effect the pickup time. For this reason, this measure has fewer predictors than the others, and less of its variance is explained by the regression model (less than six percent). Nonetheless, we find that Quo Vadis has significantly affected on-time pickup (p=0.004), with the post-Quo Vadis period associated with earlier arrivals relative to the schedule of about 4 minutes. Given that many trips had early arrivals pre-Quo Vadis, this result is not purely positive, and implies not only less lateness, but also a tendency toward greater earliness. Combining this analysis with Tables 3a through 3d, we see both sides of this phenomenon: Wayne terminal experienced increasingly early pickups, while Troy experienced a decline in lateness. The only other predictor significantly associated with on-time pickup is the Troy terminal, which experiences much later pickups than the other terminals. These results are summarized in Table 4b.

Table 4b. Effects on On-Time Pickup

	Regression Output (R^2=0.054)	
Predictor Variables	Regression Coefficient	Significance Level*
Pontiac	0.067	0.974
Troy	8.298	0.000
Wayne	-0.566	0.759
Quo Vadis	-4.064	0.004

*Values below 0.05 are statistically significant at the 95% confidence level.

On-Time Drop-off

On-time drop-off can be influenced by on-time pickup, intermediate stops, and trip distance, in addition to the terminal factors and Quo Vadis. The regression analysis, however, shows that terminal-specific effects are not significant and neither is the number of intermediate drop-offs. On-time arrival for the pickup and trip distance have the largest effect on on-time drop-off, but Quo Vadis and the number of intermediate pickups also have significant effects. Because the Quo Vadis coefficient is positive, this effect describes a tendency to push back the actual drop-off time, resulting from early drop-offs becoming more on time and late ones becoming later still. Intermediate stops have negative coefficients, tending to push the drop-off earlier, implying that more time is allocated to intermediates than is needed. (Due to possible interactions between Quo Vadis and the scheduling of intermediate pickups and drop-offs, we also tested a model with Quo Vadis-Intermediate interaction terms. These terms, however, failed to reach statistical significance.) Overall, the model (summarized in Table 4c) accounts for about 54 percent of the variance in on-time drop-off.

Table 4c. Effects on On-Time Drop-off

	Regression Output (R^2=0.537)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-1.571	0.322
Pontiac	-1.269	0.437
Troy	-0.008	0.996
On-Time Pickup	0.857	0.000
Trip Distance	0.397	0.000
Intermediate Drop-off	-0.303	0.371
Intermediate Pickup	-0.761	0.004
Quo Vadis	3.543	0.003

*Values below 0.05 are statistically significant at the 95% confidence level.

On-Time Travel

The regression for on-time travel results in very similar findings to that for on-time drop-off, except that the model explains far less (about nine percent) of the variance in on-time travel. Again, no significant terminal-specific effects are found, while predictors such as intermediate pickups, trip distance, and Quo Vadis are significant. The directions and magnitudes of effects are identical to on-time drop-off, except that on-time pickup has a negative effect for on-time travel, meaning that arriving late for the pickup results in a shorter than scheduled trip, while early arrival at the pickup point results in a longer than scheduled trip. Again, this implies that drivers and dispatchers effectively readjust the scheduled sequence of stops or operating speed in response to ongoing changes in schedule adherence. Quo Vadis has a positive coefficient in this model, meaning that Quo Vadis appears to be underestimating required trip times by about 3.5 minutes on average.

Table 4d. Effects on On-Time Travel

	Regression Output (R^2=0.087)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-1.571	0.322
Pontiac	-1.269	0.437
Troy	-0.008	0.996
On-Time Pickup	-0.143	0.000
Trip Distance	0.397	0.000
Intermediate Drop-off	-0.303	0.371
Intermediate Pickup	-0.761	0.004
Quo Vadis	3.543	0.003

*Values below 0.05 are statistically significant at the 95% confidence level.

Actual Travel Time

Analysis of actual travel time indicates that trips originating from Troy take longer than trips originating from other terminals, on average over six minutes longer given all the controls in the regression model. As expected, trip distance also has a significant effect on travel time, as do the number of intermediate pickups and drop-offs, with the latter, on average, adding about 3.3 and 2.6 minutes per stop, respectively. Quo Vadis, too, has a significant effect, with post-Quo Vadis trips, controlling for other factors, about 2.7 minutes shorter than pre-Quo Vadis trips. Overall, the regression model explains nearly 70 percent of the variance in actual travel time and is summarized in Table 4e.

Table 4e. Effects on Actual Travel Time

	Regression Output (R^2=0.685)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-0.468	0.739
Pontiac	-1.340	0.354
Troy	6.301	0.000
On-Time Pickup	-0.020	0.470
Trip Distance	1.236	0.000
Intermediate Drop-off	2.605	0.000
Intermediate Pickup	3.308	0.000
Quo Vadis	-2.730	0.009

*Values below 0.05 are statistically significant at the 95% confidence level.

Speed

The regression analysis for on-board speed closely resembles, in reverse, that for actual travel time, meaning that the observed effects tend in the opposite numerical direction, but in the same substantive direction. Thus, the Troy terminal is associated with lower trip speed, as are intermediate stops. Quo Vadis itself is associated with a 1.5 mile per hour increase in speed. These results are summarized in Table 4f.

Table 4f. Effects on Trip Speed

	Regression Output (R^2=0.384)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	0.389	0.666
Pontiac	0.779	0.401
Troy	-2.795	0.002
On-Time Pickup	0.009	0.627
Trip Distance	0.921	0.000
Intermediate Drop-off	-1.007	0.000
Intermediate Pickup	-1.583	0.000
Quo Vadis	1.496	0.025

*Values below 0.05 are statistically significant at the 95% confidence level.

Intermediate Pickups

A function most directly of geography, the terminals, and the scheduling package, theoretically the number of intermediate pickups should not be affected by trip distance, on-time performance, and the like. Still, given that drivers may deviate from their itinerary if they happen to be running late, as evidenced by previous findings, we included on-time pickup in the regression model. This predictor, however, proved not to be significant. We did find, however, that Macomb and Pontiac experience significantly fewer intermediate pickups than do Wayne and Troy, and that Quo Vadis schedules also contain fewer intermediate pickups--nearly 0.5 less per trip, on average. These results are shown in Table 4g, and support the general impressions of SMART staff (both managers, supervisors, and CSOs) that Quo Vadis offers CSOs less freedom to “force” trips onto the schedule if they lie outside programmed parameters of good fit. Put another way, Quo Vadis appears to offer greater protection against ill-constructed schedules.

Table 4g. Effects on Intermediate Pickups

	Regression Output (R^2=0.087)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-1.417	0.000
Pontiac	-1.273	0.000
Troy	-0.209	0.411
On-Time Pickup	0.005	0.322
Quo Vadis	-0.480	0.016

*Values below 0.05 are statistically significant at the 95% confidence level.

Intermediate Drop-offs

Even more so than intermediate pickups, the number of intermediate drop-offs is affected by many measures not included in this study, such as pickups *prior* to those in the sample. Nevertheless, though the regression model (summarized in Table 4h) explains just over six percent of the variance in intermediate drop-offs, we find that again Macomb and Pontiac experience relatively fewer. Also, the number of intermediate pickups is significantly and negatively associated with the number of intermediate drop-offs, meaning that the presence of intermediate pickups decreases the likelihood of intermediate drop-offs, controlling for terminal, on-time pickup, and Quo Vadis. Given the time cost of intermediate stops of both types, the presence of stops makes additional stops less likely in order to keep one passenger's trip within tolerable limits. Unlike for pickups, Quo Vadis is not significantly associated with the number of intermediate drop-offs. Quite likely, this is because drop-offs in the long run are paired with pickups, and Quo Vadis does affect the number of intermediate pickups, which in turn affects the number of intermediate drop-offs.

Table 4h. Effects on Intermediate Drop-offs

	Regression Output (R^2=0.061)	
Predictor Variables	Regression Coefficient	Significance Level*
Macomb	-1.001	0.000
Pontiac	-0.665	0.000
Troy	-0.289	0.096
On-Time Pickup	0.006	0.115
Intermediate Pickups	-0.104	0.000
Quo Vadis	0.045	0.741

*Values below 0.05 are statistically significant at the 95% confidence level.

Interactions between Quo Vadis and Intermediate Stops

Because we have found that Quo Vadis produced schedules contain fewer intermediate pickups than do CARDS produced schedules, we have some basis for explaining *why* it is that schedule adherence is different post-Quo Vadis. Specifically, we can examine interactions between Quo Vadis and intermediate pickups. Focusing on actual travel time as the dependent variable, in part because actual travel time showed the best improvement due to Quo Vadis, we re-run the regression model summarized in Table 4e with the addition of a Quo Vadis-intermediate pickups interaction term. This allows us to examine the possibility that the time burden of intermediate pickups is different with Quo Vadis than for CARDS. The results of this analysis, shown in Table 4i, indicate that in the post Quo Vadis period each intermediate pickup imposes a smaller time burden (by slight more than one minute) than in the CARD era. Furthermore, because the Quo Vadis variable is no longer significant, this analysis also suggests that better ordering of the sequence of pickups is the main benefit of Quo Vadis over CARDS (i.e., there is no significant Quo Vadis effect over and above that associated with intermediate pickups). Finally, these results add further empirical evidence that Quo Vadis better guards against poor schedule sequencing by CSOs and schedulers.

Table 4i. Effects on Actual Travel Time with QV-Intermediate Interaction

	Regression Output (R^2=0.688)	
Predictor Variables	Regression Coefficient	Significance Level*
Wayne	0.654	0.640
Pontiac	-0.700	0.646
Troy	7.045	0.000
On-Time Pickup	-0.022	0.437
Trip Distance	1.240	0.000
Intermediate Drop-off	2.631	0.000
Intermediate Pickup	3.580	0.000
Quo Vadis	-1.271	0.280
QV-Interm. Pickup Interaction	-1.148	0.010

*Values below 0.05 are statistically significant at the 95% confidence level.

Further analysis of Quo Vadis interaction effects reveals no significant effects on speed or on-time drop-off. Predicting on-time travel, however, the interaction analysis finds a significant and positive effect for the Quo Vadis-intermediate drop-off variable, suggesting that Quo Vadis does not allocate enough time for intermediate drop-offs (by about two minutes). Again, the main effect of Quo Vadis becomes insignificant in this interaction model, meaning that the primary cause of Quo Vadis schedules underestimating total travel time is underestimation of the time required to make a drop-off. Table 4j summarizes these results.

Table 4j. Effects on On-Time Travel with QV-Intermediate Interaction

	Regression Output (R^2=0.103)	
Predictor Variables	Regression Coefficient	Significance Level*
Wayne	1.380	0.382
Pontiac	-0.057	0.974
Troy	1.041	0.537
On-Time Pickup	-0.143	0.000
Trip Distance	0.394	0.000
Intermediate Drop-off	-1.230	0.004
Intermediate Pickup	-0.872	0.002
Quo Vadis	1.289	0.373
QV-Interm. Pickup Interaction	0.271	0.588
QV-Interm. Drop-off Interaction	2.270	0.000

*Values below 0.05 are statistically significant at the 95% confidence level.

CONCLUSION

Viewed as a whole, the above analyses revealed several positive effects of the Quo Vadis system, such as reductions in actual travel time controlling for other factors. As we have seen, however, these findings do not pertain uniformly to all terminals, and in some cases Quo Vadis appears to have aggravated schedule adherence deficiencies, such as early arrivals and late drop-offs. Encouragingly, the Macomb terminal, which has had the longest experience with Quo Vadis, appears to have benefited most from Quo Vadis. Intermediate pickups and drop-offs also are down with Quo Vadis, but there is strong evidence that this has contributed to improved travel times for scheduled passengers. Given findings from another component of the evaluation that Quo Vadis implementation has not led to a degradation in volume of service (nor an increase), this finding of shorter trips per passenger on average indicates a clear service improvement due in large part to improved trip sequencing at the passenger level. Some of this improvement, in fact, may well be due to better controls on CSOs freedom to manipulate trip orderings. At the very least, the intermediate pickups that Quo Vadis does allow to be scheduled impose a smaller time burden on average than those that were scheduled with CARDS.

While the above analyses reveal some positive benefits arising from Quo Vadis, they also indicate that some fine-tuning of system parameters remains to be accomplished. For example, the results above revealed that Quo Vadis is somewhat underestimating required total trip time, and in particular underestimating the time required to complete a drop-off. In short, SMART is not yet taking full advantage of the system, and further improvements should be obtained as Quo Vadis is optimized for SMART and its operations; indeed, SMART is currently migrating to Trapeze-PASS, which contains many of the enhancements that SMART demanded of Quo Vadis.

As our evaluation continues, the University of Michigan will continue to collect schedule adherence data and test its effects on schedule adherence. In addition, we will be interested in gauging the joint effects of ASD and automatic vehicle location (AVL); the latter, with its opportunities to better incorporate ASAPs and pace vehicles, also promises to significantly affect schedule adherence.

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