Development of Cost-Effective Sampling Plans for Section 15 and Operational Planning Ride Checks: Case Study for Madison, Wisconsin

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More cost-effective procedures for Section 15 ride check sampling are developed and integrated with the overall planning and operations analysis data needs of Madison Metro, a medium-sized bus system serving Madison, Wisconsin. To develop and test alternative sampling plans, data from three primary sources were used: daily electronic farebox passenger counts, 100 percent ride checks for an "equivalent weekday," and Section 15 sample data for 2 years. Analysis of the primary data suggested that a boardings-based ratio estimate of passenger miles with stratification by week with round trips as the sample unit provides the most cost-effective Section 15 sampling plan. For Madison Metro a sample of only two round trips per week will meet the 10 percent precision requirement. Extension of the sampling plan for operational planning is possible by expanding the sample unit to two consecutive round trips. The resulting expanded sampling plan would update the equivalent weekday ride check data base in only 3 years.

The Madison Metro transit system is a medium-sized bus system serving a population of 244,000 in the Madison, Wisconsin, urban area. In 1990 Madison Metro ran 118 peak-hour buses on 5 primary and 15 secondary, circulator, and express routes attracting 32,000 passengers per weekday and 9,900,000 a year. In response to downward ridership trends, Madison Metro contracted with a consultant for a comprehensive operations analysis (COA) study that was conducted in the spring of 1990 (*1*). The data collected in the COA included a 100 percent ride check of all vehicle (bus) trips for an "equivalent weekday." The ride check data were used extensively in the comprehensive route restructuring that was implemented in the fall of 1990.

Because the COA (100 percent ridecheck) data were found to be so useful, Madison Metro would like to keep the COA data base up to date through a modest expansion of its current field data collection program. Currently, the Section 15 ride check data collection required by FTA is conducted independent of other field data collection and is not used by Madison Metro for system monitoring or planning. One possibility for reducing the costs of maintaining the COA data base would be to integrate the COA ride check updates with the Section 15 data collection requirements.

The purposes of this research are (a) to develop more cost-effective Section 15 ride check sampling procedures and (b) to determine if Section 15 and COA update data collection can be integrated effectively. The ordering of the purposes with the initial focus on Section 15 is deliberate. The FTA Section 15 samples must be random and distributed throughout the year. Because of the difficulties and cost of scheduling manual ride checks to cover all days of the week and all service hours, the first priority should be to minimize the Section 15 sample requirements. In contrast, the COA update need not be based on random samples. In fact, a highly systematic 100 percent data collection effort may give more useful data.

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PRIOR RESEARCH

The *Bus Transit Monitoring Manual* provides the most comprehensive consideration of field collection of bus system operating data (*2*). The report recommends a route-level two-stage cluster sampling plan for collecting both ride check and point check data. Route-level data are then aggregated to meet Section 15 requirements. Preliminary samples (pretest) are proposed to estimate data variation, which is used to identify the primary survey sample size requirements. The methodology is not designed to generate 100 percent COA ride check data.

Damm surveyed 30 U.S. transit systems to determine their information needs for transit management and their interest in computer-aided tools (*3*). Review of Section 15 data collection efforts revealed that these data are not often used by transit managers. Some systems, however, have integrated Section 15 into their overall operating data collection program with data disaggregated by route and time of day.

McGrath et al. reviewed several innovative Section 15 sampling plans, both actual and proposed (*4*). The review led to general suggestions for reducing Section 15 sampling requirements by tailoring stratified sampling and cluster sampling techniques to the operating conditions of individual transit systems. The authors recommended use of actual Section 15 ride check data for the design of improved sampling strategies.

In a 1983 study funded by FTA, Smith conducted an inventory of the Section 15 sampling procedures used by 58 of the largest U.S. transit systems (*5*). A wide range of sampling methods was found including many nonstandard methodologies. Detailed analysis of alternative sampling plans for several transit systems revealed many opportunities for reducing the sample size required to obtain a precision of 10 percent. The potential for a dramatic reduction in sample size on the basis of a ratio estimate of passenger miles per passenger was demonstrated using actual Section 15 data for Madison Metro. The ratio estimate, however, requires an independent estimate or actual count of total passengers.

The *Bus Transit Monitoring Manual* was updated in 1985 and published as the *Transit Data Collection Design Manual* (*6*). The design manual included sampling methods for using ratio estimates to reduce sample size requirements. The statistical basis for using ratio estimates was documented in a 1987 paper by Furth and McCollom (*7*). Using a ratio estimate of boardings to revenue for the Pittsburgh transit system, they found that the Section 15 sample size could be reduced to 149, whereas a ratio estimate of passenger miles to revenue required a sample size of only 129.

In a 1988 paper Furth et al. evaluated several cluster sampling techniques for collecting Section 15 ride check data that would make the data more useful for operational planning purposes (*8*). Both ratio estimates and stratification were incorporated into the sampling alternatives and tested using data from the Southern California Rapid Transit District (SCRTD). The SCRTD data present a particular challenge because SCRTD did not have registering fareboxes and the drivers did not count passengers. The relatively simple stratified ratio-to-cluster-size sampling strategy was the optimum for SCRTD requiring only 38 half-runs (clusters of bus vehicle trips) to meet Section 15 precision requirements. The usefulness of the resulting Section 15 data base for other purposes was not discussed in the paper.

FTA SECTION 15 SAMPLING REQUIREMENTS

The first Section 15 sampling plan was documented by UMTA Circular 2710.1, which specifies a two-stage cluster sample based on a systematic sample of days followed by a random sample of one-way bus trips within each sample day (*9*). The formula for the relative variance (coefficient of variation squared) of passenger miles per one-way trip is

$$CV^2_{\mathrm{PM}} = \frac{N-n}{N}\frac{CV^2_b}{n} + \frac{M-m}{M}\frac{CV^2_w}{mn} \tag{1}$$

where

CV^2_b = between-day relative variances,
CV^2_w = within-day relative variances,
n = number of sample days,
N = number of population days,
m = number of one-way trips per day in sample, and
M = number of one-way trips per day in population (*10*).

Note that the number of one-way bus trips per day in the population is assumed to be constant. Thus, variation in service between weekends and weekdays is not accounted for, but since m is much less than M, the ratio $(M - m)/M$ is essentially equal to 1. Thus, the assumption of constant M is reasonable. The minimum sample size under Circular 2710.1 is 549 trips on the basis of sampling three trips every other day ($n = 183$, $m = 3$). This sampling plan was based on the Wells memorandum (*11*), which assumed that $CV^2_b = 0.1$ (or $CV_b = 0.316$) and $CV^2_w = 1.0$, so that for the 95 percent confidence level the precision, r, is

$$r = t_{.025549} \times CV_{\mathrm{PM}} = 1.96 \times 0.0458 = 0.090 \tag{2}$$

Because many transit systems found the requirement for sampling 549 trips per year burdensome, UMTA developed an alternative revenue-based sampling procedure, UMTA Circular 2710.4, that requires a sample of only 208 trips (*12*). The key to the smaller sample size is the use of a ratio estimate. Total annual passenger miles are estimated on the basis of the sample estimate of the ratio of passenger miles to farebox revenue multiplied by the actual farebox revenue for the year. For a simple random sample (SRS) the relative variance of a ratio estimate of passenger miles (PM_R) is given by

$$CV_{\mathrm{P\hat{M}}_R} = \frac{\left(1 - \frac{n}{N}\right)}{n} \times \left(CV^2_{\mathrm{PM}} + CV^2_{\mathrm{REV}} - 2\rho CV_{\mathrm{PM}}\, CV_{\mathrm{REV}}\right) \tag{3}$$

where

CV_{PM} = coefficients of variation for passenger miles,
CV_{REV} = coefficients of variation for revenue,
ρ = simple correlation between passenger miles and revenue,
n = sample size, and
N = population size.

For any sample observation i the passenger miles are estimated as

$$\mathrm{P\hat{M}}_i = \hat{R} \times \mathrm{REV}_i \tag{4}$$

where $\hat{R}$ equals $\overline{\mathrm{PM}}/\overline{\mathrm{REV}}$ from the sample.

The Circular 2710.4 sampling procedure, however, is not an SRS from the entire year; instead, the sample is stratified by week and an SRS of four one-way trips is selected each week. This complicates the precise estimate of the variance of the ratio estimate. It can be argued that stratification is likely to increase the precision of the estimate of passenger miles. Thus, Equation 3 can be used as an upper bound on the precision of the ratio estimate. The same basic equations are also used to estimate total annual passengers (boardings) from a ratio estimate of boardings to revenue.

One complication associated with the revenue-based ratio estimate is that if the fare changes, the correlation between revenue and passenger miles will be reduced so that the required level of precision may not be achieved. The solution specified in Circular 2710.4 is to make separate ratio estimates for each fare period. To compensate in part for the smaller sample size in each fare period, the sample size is increased to five trips per week for 12 weeks following the fare change.

An additional problem with the revenue-based ratio estimate is that if there is substantial use of passes or tickets, then the correlation between revenue and passenger miles or passengers is likely to be low, thus reducing the precision of the ratio estimate. This problem is avoided by using a passenger-based ratio estimate where passenger miles are estimated from the ratio between passenger miles and passengers. Only transit systems with an independent tabulation of passengers can use this method.

Transit systems that could take advantage of improved sampling strategies such as the passenger-based ratio estimate no longer need explicit FTA approval. Instead, the transit systems need only self-certify the methodology on the basis of analysis by a qualified statistician.

MAJOR DATA SOURCES

Three major data sets were available to this study from data collected by Madison Metro:

- 1990 and 1991 electronic farebox (EFB) summary data;
- 100 percent ride check data for an equivalent weekday collected in the spring of 1990 as part of the COA study; and
- 1989 and 1990 Section 15 ride check data.

The 1990 and 1991 EFB summary data provided the total daily ridership recorded by the EFBs and tabulated by computer. The EFB passenger data included for each bus trip segment the starting and ending times, the number of passengers by passenger type, and revenue generated. The detailed review of the EFB data showed that some bus operators did not fully follow the EFB operating rules that required them to register passenger data at designated checkpoints. Consequently, bus trip segment-level ridership could not be identified for all bus trip segments. Besides driver error, errors in the EFB data could be traced to internal EFB clock timing, mechanical, and data storage failures. These problems, in general, did not affect the reliability of the total daily ridership counts. Thus, variation in ridership from day to day could be analyzed, but variation within days could be made only after manual editing of the data.

Madison Metro's COA ride check data were collected in the spring of 1990 for 100 percent of the bus trips on an equivalent weekday. If the ride checks for a route could not be completed on a single weekday, then the remaining ride checks were collected on the same day in the following week. All of the ride checks for the entire system were completed in about 3 weeks.

For Section 15 ride checks until 1989, Madison Metro followed the standard Wells two-stage cluster sampling procedure by sampling three one-way bus trips every other day. Most of Madison Metro's one-way bus trips are "through-routed" and composed of two bus trip segments: inbound to the central business district (CBD) and outbound in the same direction from the CBD. In 1989 Madison Metro switched to the revenue-based ratio estimate sampling procedure and began using segments as the sampling unit. Madison Metro sampled an average of nine segments a week in 1989 and reduced the rate to the minimum Section 15 requirement of four segments a week in 1990.

PRELIMINARY DATA ANALYSIS

To identify Section 15 sampling strategies that may be more cost-effective than the existing standard options (Wells two-stage cluster or revenue-based ratio estimate), data on the inherent variability of passengers (boardings), passenger miles, and revenue are needed. Fortunately, much, but not all, of the required information can be obtained from the three data sources described earlier. Analysis of the total daily ridership from the EFB data for 1990 and 1991 is presented in Table 1. As expected, the average daily passengers on a Saturday or Sunday is only a third to a sixth the average for a weekday. The relative amount of variation "between days" is given by the coefficient of variation (*CV*) defined as the standard deviation divided by the mean. For all days the *CV* is about 0.5, but weekdays are more homogeneous, with *CV*s of about 0.2, and Saturdays and Sundays are even more homogeneous, with *CV*s in the range of 0.1 to 0.2. As shown in Figure 1, the average daily ridership by month varies substantially over the year. The summer months' ridership is about a third lower than the peak months. The between-day *CV*s by month, however, are relatively constant—in the range of 0.45 to 0.55—except for December.

The major reduction in *CV* for stratification by day of week suggests that the sample size for the Wells two-stage cluster sample could be reduced by stratification by day of the week since Wells assumed a between-day *CV* of 0.316. Information on the other component of variation that is required for the Wells sample, the within-day *CV*, is available, in part, from the COA ride check data. One other possible stratification is summer versus nonsummer days, particularly for weekdays.

The COA ride check data provide an estimate of within-day variation for weekdays. As given in Table 2, the *CV*s for boardings (passengers) and passenger miles are heavily dependent on the level of aggregation. The greatest amount of variation occurs at the segment level. Considerably less variation is found for one-way trips because a segment inbound to the CBD is combined with a segment outbound from the CBD. Particularly in the peak hours, low passenger volume in one direction will be balanced by higher volume in the other. Additional smoothing occurs in moving to the round trip and vehicle block levels. The *CV* data for passenger miles clearly indicate that collection of Section 15 ride check data at higher levels of aggregation will permit reduction of the

TABLE 1 Madison Metro Daily Passengers by Day of Week

1990	N	MEAN	STDEV	CV[a]	1991	N	MEAN	STDEV	CV[a]
SUN	51	5452	708	0.103	SUN	51	5986	987	0.165
WEK	255	32546	7477	0.230	WEK	255	33325	7348	0.220
SAT	52	9686	1572	0.162	SAT	52	10978	2156	0.196
HOL	7	2820	903	0.320	HOL	7	3270	1078	0.329
ALL	365	24933	13260	0.532	ALL	365	25745	13202	0.513

Note: <SUN> = Sundays; <WEK> = Weekdays; <SAT> = Saturdays; and <HOL> = Holidays.

[a] Coefficient of Variation (CV) = Standard Deviation/Mean

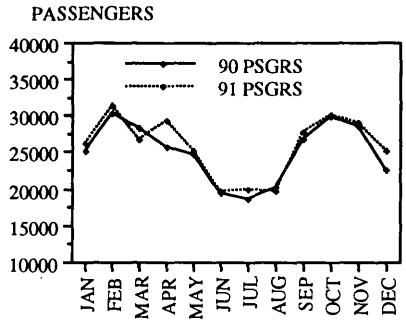

FIGURE 1 Average daily passengers by month for 1990 and 1991 from EFB data.

sample size for the Wells two-stage cluster sample. Partial Section 15 data from 1982 are also presented in Table 2 for comparison with the COA data. The Section 15 data represent one-way trips for all days rather than just weekdays. The all-days *CV*s should be somewhat higher than the *CV*s for the COA one-way trips, which is in fact the case.

Two other data items are of interest in Table 2. First, the relative variation in passenger miles compared with boardings computed as CV_{PM}/CV_B is of interest since the *CV* for passenger miles can then be estimated if the *CV* for boardings is available. This is significant since data on boardings are more generally available than data on passenger miles. As shown in Table 2, the *CV* for passenger miles ranges from 3 to 15 percent higher than the *CV* for boardings. Thus, to achieve the same precision, sample sizes for estimating passenger miles must be slightly higher than those for estimating only boardings.

Second, the correlation between passenger miles and boardings is of interest for ratio estimates. Since a 100 percent count of boardings is available from the EFB data in Madison, passenger miles can be estimated from a ratio estimate of passenger miles to boardings. A high correlation between passenger miles and boardings reduces the sample size requirements dramatically. Thus, for maximum reduction in sample size, Section 15 samples should be based on round trips or even vehicle blocks.

As discussed earlier, the 1989 and 1990 Section 15 ride check data collected by Madison Metro were nominally based on random samples of one-way trip segments with stratification by week. As shown in Table 3, the sample size was 470 (or about 9 segments per week) for 1989 and 199 (or about 4 segments per week) in 1990. The amount of variation in boardings and passenger miles is about the same for both years, with the *CV* for passenger miles ranging from 15 to 17 percent higher than the *CV* for boardings. Also, the *CV* are consistent with the COA *CV* at the segment level (see Table 2). In contrast, the correlation coefficients given in Table 3 are closer to the COA correlation coefficient for the one-way trip level, but much smaller than the 1982 correlation coefficient for Section 15 one-way trips ($\rho = 0.916$; see Table 2).

One final observation on the Section 15 data in Table 3 is that the overall ratio of passenger miles to boardings for 1989 is substantially higher than for 1990 (3.96 versus 2.85). Since the mean passenger miles are almost the same for both years, the difference in the ratios is the result of lower boardings for 1989 than for 1990. Subsequent stratification of the Section 15 data by month showed that the monthly ratios of passenger miles to boardings were quite constant throughout each year. One possible explanation for the observed systematic difference in the passenger miles per boarding ratio between 1989 and 1990 would be a difference in how passengers on board at the start of a ride check were tabulated. Fortunately, the observed systematic difference does not affect the validity of the evaluation of alternative sampling plans that is the focus of this paper.

EVALUATION OF ALTERNATIVE SAMPLING PLANS

Overview

The starting point for the development of more cost-effective Section 15 sampling plans is the evaluation of the precision of the Section 15 data collected by Madison Metro in 1989 and 1990. Although the nominal sampling plan for both 1989 and 1990 was a stratified random sample with a fixed number of segment samples to be selected randomly from each week, the number of trips actually sampled per week varied substantially. The deviations from the fixed sampling plan were taken into account in computing the actual precision of the stratified sample and the two-stage cluster sample that resulted from the 1989 and 1990 Section 15 data. For the purposes of computing the precision of an equivalent SRS, however, the Section 15 data were treated as if the samples were an SRS.

TABLE 2 Summary of COA Ride Check and 1982 Section 15 Data by Level of Aggregation

Type of Information	Bus Trip Segment	One-Way Trip	Round Trip[a]	Vehicle Block	One-way Trip (1982)[b]
Boardings	18.1	35.8	76.2	421.1	43.8
Psgr. miles	64.7	127.4	291.3	1595	157
Boarding CV	0.774	0.543	0.418	0.401	0.61
Psgr. miles CV	0.797	0.603	0.460	0.429	0.70
Ratio CV_{PM}/CV_B	1.030	1.110	1.100	1.070	1.148
Correlation[c]	0.655	0.788	0.886	0.940	0.916

[a]Based on five main routes; A, B, C, E, & J.
[b]Section 15 ride check data for 183 observations in the first part of 1982.
[c]Correlation between boardings and passenger miles, $\rho_{B,PM}$

TABLE 3 1989 and 1990 Section 15 Data Summary

Data Item	N	MEAN	STDEV	CV	CORR[b]
1989 Boardings	470	15.6	10.8	0.693	0.726
1989 Passenger Miles	470	61.7	50.0	0.810	--
Ratio PM/B (1989)	--	3.96	--	1.169[a]	--
1990 Revenue	199	4.60	4.28	0.930	0.692
1990 Boardings	199	21.1	14.5	0.707	0.783
1990 Passenger	199	60.2	48.8	0.810	--
Ratio PM/B (1990)	--	2.85	--	1.146[a]	--

[a]Ratio of CV_{PM}/CV_B.
[b]Correlation with passenger miles.

Estimates of the precision at the 95 percent confidence level of sample estimates of average passenger miles per segment for three basic sampling methodologies are presented in Table 4; these results are given initially without detailed explanation of how the estimates of precision were computed. The focus in Table 4 is on the extent to which differences in precision are possible for alternative sampling methodologies given the same data sets. The simplest sampling methodology, SRS, is shown first for comparison with the two FTA-recommended methodologies, stratification by week, and two-stage clusters (sample days first, then bus trip segments within sample days). The precision of ratio estimates based on the ratio of passenger miles to boardings is also shown for each of the sampling plans.

As given in Table 4, the Madison Metro Section 15 data for 1989 meet the required precision of 0.10 (10 percent) under all three sampling plans. Stratification by week provides almost the same level of precision as the SRS, whereas the two-stage cluster precision is substantially lower (higher numerical value). Because of the high overall correlation between passenger miles and boardings ($\rho = 0.726$), the ratio estimate improves the precision of all three sampling plans substantially.

For the 1990 Section 15 data in Table 4, the same basic patterns as for 1989 exist; however, primarily because of the lower sample size (199 versus 470), the precision of the sample is much lower. In fact, none of the basic sampling plans meets the 10 percent precision requirement; however, all of the ratio estimates based on boardings have a precision of less than 10 percent. For 1990, sample revenue data were also available. The precision of the ratio estimate based on the ratio of passenger miles to farebox revenue is much lower than for the boardings-based ratio estimate. This is explained by the lower correlation between passenger miles and revenue, which is the result of substantial pass use by Madison Metro passengers.

Selection of the most cost-effective sampling methodology from among the alternatives considered in Table 4 requires consideration of both the administrative difficulties of sample selection, data collection, and data processing and the potential for cost savings through reductions in sample size that are possible when the precision exceeds the 10 percent level. In general, the SRS requires slightly more administrative effort for sample selection and the staffing requirements will be slightly more variable than with stratification by week. At least for the Madison Metro data, the simplicity of stratification by week more than offsets the small reduction in sample size that may be possible with an SRS.

Because Madison Metro has an independent estimate of boardings (100 percent passenger count), it can take advantage of the substantial increase in precision provided by the boardings-based ratio estimates. Again, stratification by week

TABLE 4 Precision of 1989 and 1990 Section 15 Sample Estimates of Passenger Miles at 95 Percent Level

Assumed Sampling Methodology[a]	Precision (r)	
	1989	1990
No Stratification		
- Simple Random Sample (Sample Size-n)	0.0732 (470)	0.113 (199)
- Ratio Estimate for a Simple Random Sample[b]	0.0509	0.0708
Stratification by Week		
- Simple Random Sample	0.0763	0.127
- Ratio Estimate (Psgr. Miles/Boardings)	0.0583	0.0816
- Ratio Estimate (Psgr. Miles/Revenue)	--	0.108
Two-Stage Cluster		
- Standard Wells	0.0916	0.127
- Ratio Estimate[b]	0.0654	0.080

[a]Based on bus trip segment level sample
[b]Ratio estimate based on Passenger Miles/Boardings

appears to provide the best combination of administrative simplicity and precision.

The two-stage cluster sample has the advantage that the days for which staff must be assigned for data collection follow a regular pattern. In contrast, with stratification by week, the days sampled will vary from week to week. Also, the two-stage data collection is concentrated in somewhat fewer days, which may be easier to staff. One problem here is that more than one checker may be required for a few days in which sample trips overlap.

Stratification by Week

To identify possible improvements to the stratification-by-week sampling methodology, it is helpful to identify how the sample variance, $s^2(\bar{y}_{ST})$, for a stratified random sample can be computed. If the finite population correction factor is ignored, then

$$s^2(\bar{y}_{ST}) = \sum_{h=1}^{L} \frac{W_h^2 s_h^2}{n_h} \quad (5)$$

where

$W_h = N_h/N$ = stratum weight,
s_h^2 = stratum sample variance, and
n_h = sample size for hth strata.

The variance of $\bar{y}_{ST}$ thus is the sum of the variances of the individual strata sample means weighted by the relative size of the stratum squared. The precision of the sample can be increased by reducing the stratum sample variance, which can most easily be done by aggregating the sample from one-way segments to round trips. For stratification by week a major part of the stratum variance is within-day variance. The COA data presented in Table 2 can be used to determine the impact of aggregation from segments to round trips on within-day variance. For a given precision the CV^2 are proportional to the required sample size. Thus, an initial estimate of the reduction in sample size from sampling round trips is given in Table 2 as

$$[CV_{PM}(\text{round trip})/CV_{PM}\ (\text{one-way segment})]^2 = (0.460/0.797)^2 = 0.577^2 = 0.33 \quad (6)$$

Thus, the impact of aggregation on reducing the required sample size is likely to be substantial.

As demonstrated in Table 4, the impact of the ratio estimate on the precision of the stratified sample was substantial for the segment-level trip sample. The sample variance for the ratio estimate is calculated by substituting d_{hi}, the error from using the ratio estimate, in place of the sample value, y_{hi} (passenger miles), in the strata variance formula (Equation 5) where

$$d_{hi} = y_{hi} - Rx_{hi} \quad (7)$$

$$x_{hi} = \text{auxiliary variable (boardings)} \quad (8)$$

$$R = \sum_{h=1}^{L} \sum_{i=1}^{n_h} y_{hi} \Big/ \sum_{h=1}^{L} \sum_{i=1}^{n_h} x_{hi} \quad (9)$$

Equation 7 was applied to the Section 15 data to generate the ratio estimates for stratification by week that are presented in Table 4. Section 15 data for higher levels of aggregation (one-way trip and round trip levels) were not available to permit the direct calculation of the precision of ratio estimates as a function of aggregation level. Consequently, the ratio estimate for an SRS was used to examine the impact of aggregation. The results are presented in Table 5.

As shown previously in Equation 3, the variance of a ratio estimate for an SRS is a simple function of the *CV*s of the two variables used for the ratio, the correlation between the variables, and the sample size. To obtain a conservative estimate of the impact of aggregation on precision, the results given in Table 5 are based on the one-way segment CV_{PM} and CV_B from the Section 15 data. The estimate of correlation between passenger miles and boardings (passengers) was taken from the COA data (see Table 2). Although the COA data represent only within-day variance, the correlation for the one-way segment level ($\rho = 0.655$) is lower than either of the correlations for the Section 15 data ($\rho = 0.726$ for 1989, $\rho = 0.783$ for 1990), which represent the correlation over the entire year. Thus, the COA data probably understate the increase in precision (lower r) that results from the higher levels of aggregation.

Since Section 15 requires a precision of only 10 percent ($r = 0.10$), the increase in precision resulting from aggregation can be translated into smaller minimum sample sizes that will still achieve the 10 percent precision level. As pre-

TABLE 5 Estimate of Precision and Minimum Sample Size for SRS Ratio Estimate as Function of Level of Aggregation

Level of Aggregation of Sample	COA Corr.[a] (ρ)	1989 Section 15[d] Precision[b] (r)	1989 Section 15[d] n_{min}[c]	1990 Section 15[d] Precision[b] (r)	1990 Section 15[d] n_{min}[c]
Bus Trip Segment	0.655	0.057	152	0.089	156
One-way Trip	0.788	0.045	95	0.070	97
Round Trip	0.886	0.033	53	0.052	55
Vehicle Block	0.940	0.025	30	0.039	31

[a]Correlation between passenger miles and boardings (passengers obtained from 100 percent ride check equivalent weekday COA data).
[b]Based on Equation 2 and 3.
[c]Minimum sample size required to achieve $r = 0.10$ given by $n_{min} = n^*(r/0.1)^2$
[d]See Table 3 for CV_{PM} and CV_B.

sented in Table 5, the minimum sample sizes decline to very modest levels of 53 to 55 at the round-trip level of aggregation. The minimum sample sizes are remarkably consistent between the 1989 and 1990 Section 15 data. The results in Table 5 can be extrapolated to the ratio estimate for stratification by week with some confidence since the precision of that sample for 1989 and 1990 (see Table 4) that is at the segment level, is almost the same as those shown in Table 5 that are at the segment level.

On the basis of Table 5, the best sampling plan for stratification by week involves sampling two round trips each week, for 104 round trips per year. The sample would have a wide margin of error built in since 104 one-way trips would also just barely satisfy the precision requirements for a sample of two one-way trips per week. Sampling at least two trips a week is needed in order to compute the individual strata variances and thus verify the precision of the sample.

Consideration of the cost-effectiveness of the proposed sample of 104 round trips a year must include both the actual staff costs for data collection and processing and the value of the information obtained compared with the present sample of 208 bus trip segments. Since the bus trip segments, in fact, require a return segment, the 208 segments are equivalent to about 104 round trips in terms of staff time spent on the bus. The 208 segments, however, require about twice as much nonproductive travel time to reach the starting point for the on-board data collection. Thus, we expect that the proposed sample of 104 round trips will actually require less total checker staff time than is being spent on the 208 segments. The 104 round trips will have the added benefit of reducing by about 50 percent the number of times that staff must be assigned to work outside of normal business hours. Also, total overtime hours should decrease because of the reduction in total travel time. On the basis of extrapolation from Table 5, the precision of the proposed sample size should be about 7 percent, which is in the middle of the range of precision between the 1989 and 1990 Section 15 samples. Finally, the 104 round trips will provide four times as much ride check data and provide a more useful starting point for a more comprehensive ride check data collection program. On balance, then, the proposed sample of 104 round trips is clearly cost-effective. It will provide much more useful data at a higher level of precision and should actually cost less to collect than the 1990 Section 15 sampling plan.

Two-Stage Cluster Sample

The two primary means of increasing the precision of the two-stage cluster samples, use of a ratio estimate and aggregation of the sample unit, were evaluated in detail using the available Madison Metro data. As was shown in Table 4, the boardings-based ratio estimate increases the precision of the two-stage cluster sample estimate of passenger miles quite substantially in the range of 29 to 37 percent. Increasing the level of aggregation to the round-trip level results in a somewhat smaller but still substantial improvement in precision ranging from 14 to 19 percent. The smallest sample resulting from the combined impact of both the ratio estimate and the round trip level of aggregation is estimated to be 98 to 144 with no margin of error. This is about twice or three times the sample size found for the SRS ratio estimate (see Table 5). Consequently, unless the regular pattern of days sampled (every fourth day, every fifth day, etc.) is required for administrative reasons, the SRS sampling plan and by extension the stratification by week sampling plan should be a better alternative.

INTEGRATION OF SECTION 15 AND COA

The update of the COA 100 percent ride check data for an equivalent weekday will be most useful if all of the data are collected over as short a period as possible. As long as ridership is not changing rapidly, a period of 1 to 3 years should still provide useful data. The data can most efficiently be collected in large groups of trips made by the same vehicle. Thus, unproductive travel time by the checkers will be minimized.

To use the proposed Section 15 sampling plan (stratification by week with an SRS of two round trips selected from each week) as the foundation of the COA update, a minor modification is needed. The sample is stratified by week, but for each week the round trips are sampled without replacement of any trips previously sampled for that year or series of years until all equivalent weekday trips have been sampled. The resulting sample should produce an unbiased estimate of passenger miles with a smaller variance than the SRS alternative since more information is being obtained.

One alternative for the Section 15 sampling plan is to sample pairs of round trips. For Madison Metro, sampling pairs of round trips would provide ride check data on more than a third (37 percent) of the equivalent weekday trips each year. Furthermore, with a 50 percent increase in the sampling rate (to three pairs of round trips per week) fully 50 percent of the equivalent weekday trips could be sampled annually, 100 percent over 2 years. Furthermore, the sample rate can be varied from week to week as long as the base rate of two trips a week is maintained.

SUMMARY AND CONCLUSIONS

Both of the standard FTA Section 15 sampling methodologies, the two-stage cluster sample and the revenue-based ratio estimate with stratification by week, were evaluated in detail. The primary alternative sampling strategies evaluated were use of passenger-based ratio estimates and increase in aggregation for the sample unit (moving from bus trip segment to one-way trip to round trip).

Because of the high correlation between passenger miles and passengers, the ratio estimate substantially increases the precision of both sampling plans. Increasing the level of aggregation of the sample unit, using one-way trips or round trips, also increases the correlation between passenger miles and passengers and consequently increases the precision of the ratio estimate. These results confirm the work of Furth and his colleagues on ratio estimates and cluster sampling. For an SRS of round trips, a 10 percent precision is achieved with only 53 to 55 trips per year. A similar sample size should also be adequate for stratification by week. Consequently, allowing for a substantial margin of error, the recommended Section 15 sampling plan is for a ratio estimate with stratification by week and a random sample of two round trips each week, resulting in a total sample size of 104 round trips per year. This sampling plan is highly cost-effective since four times as much data are obtained with a slightly smaller level of checking staff effort.

Extension of the recommended Section 15 sampling plan to update the COA 100 percent equivalent weekday ride check data requires sampling without replacement from equivalent weekdays. With an increase in the sample size to three pairs of round trips per week, the COA data could be updated in only 2 years.

Madison Metro currently allocates about 20 percent of one person's time annually (20 percent FTE) for Section 15 field data collection. With the base round-trip sampling plan recommended here, somewhat less time would be required, perhaps 17 percent FTE. With the pair of round trips sampling option, the field data collection should still require less than 30 percent FTE and would result in a fully updated COA data base in only 3 years. Thus, by allocating only an additional 10 percent FTE annually, the costly periodic intensive update of the COA data base is avoided. The stream of ride check data from the more intensive Section 15 sampling plan is potentially more useful than the periodic COA update since trends over time can be monitored more directly.

The sampling methodology proposed for Madison Metro should also apply to any transit system that has an accurate independent count of annual passengers. Existing Section 15 ride check data can easily be used to estimate the expected precision of the passenger-based ratio estimate. With the sample size reduced to only two round trips per week, Section 15 data collection should not be a burden to any transit system. In addition, by collecting round trips for equivalent weekdays the Section 15 ride check data become useful for operations planning.

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