

**TRAVEL ESTIMATION PROCEDURES
FOR THE LOCAL FUNCTIONAL SYSTEM**

**Office of Highway Information Management
Federal Highway Administration
U.S. Department of Transportation**

October 1994



INTRODUCTION

Nationally, the local functional system contains about 75 percent of the road mileage, but accounts for only about 16 percent of the travel. In the past, the relative unimportance of the local system at the national level (when compared to higher systems such as the Interstate) have resulted in the absence of national guidelines for traffic monitoring. However, as States and local governments focus on new issues such as reduction of emission pollutants, fuel conservation, urban infrastructure congestion, areawide safety exposure, and intermodal analyses; national recognition of the need for this information has grown.

The extensive size of the local system makes it prohibitively expensive and impractical to apply the traffic counting procedures used on the higher functional systems, and the relatively small amount of total travel on the local system acts to reduce the need to achieve high accuracy for the vehicle kilometers of travel (VKT) estimates produced.

Several States maintain counting operations on local systems, usually spread out over a number of years. Most States count only as needed for project development or delegate the responsibility to lower jurisdictions. Practical and cost-effective traffic counting procedures for local roads are needed to estimate local system VKT. A sampling approach is advanced to accomplish the objective while minimizing the effort and resources required.

The objective of the local system procedures is to estimate VKT, not AADT. AADT is the basic estimate used for higher systems because of its use for many transportation purposes (for example, AADT is the volume estimate reported to the Highway Performance Monitoring System). Once AADT is estimated for the higher systems, VKT is computed by expanding based on length. However, higher system AADT estimates are based on short counts (the Traffic Monitoring Guide¹ [TMG] recommends 48-hours), which require expansion based on seasonal factors. The development of AADT seasonal factors is dependent on an adequate base of permanent counters. Due to the low traffic, extensive mileage, and limited importance of the local highway systems, hardly any permanent counters are currently installed in the local system. Without a permanent counter base, the development of objective seasonal factors is not possible. Even if factors could be developed, the high variability of traffic in the local system would still make AADT estimation highly inaccurate.

On the other hand, reasonably accurate, statistical VKT estimation based on unadjusted short counts is quite feasible, if the counts are randomly distributed spatially and temporally. The random distribution, however, complicates the scheduling of counting operations and increases the cost.

From an equipment perspective, the low traffic in most of the local system simplifies the use of automatic counters. With limited exceptions, the high volume multi-lane conditions which complicate traffic monitoring in the higher systems are not found in the local system.

The higher system VKT is estimated by the Highway Performance Monitoring System (HPMS). The HPMS covers the National Highway System (universe reporting) and the remaining functional systems (sample) with the exception of the rural minor collector and local systems. The HPMS excludes the rural minor collector and local functional class road systems.

The procedures presented in this guide complement and closely follow those presented in Appendix S of the Highway Performance Monitoring System (HPMS) Manual², which covers minor arterial and

collectors within the non-attainment area boundaries. The hierarchical procedural development allows traffic program continuity and maintains a direct estimation linkage to meet the desired VKT needs.

SCOPE

The outlined approach for estimating VKT for rural and urban roads functionally classified as local and/or rural minor collectors may be applied as described below:

1. Sample as individual areas all urbanized areas with a population equal to or greater than 200,000 and urbanized areas that are a part of an NAAQS nonattainment area regardless of population size. Sample the remaining urban areas (small urban) and the rural areas on a statewide basis.

2. The counting program can be designed to provide annual estimates of local VKT for each of the individual urban areas, the small urban areas, the rural system, and by aggregation statewide totals.

Since the HPMS excludes roads classified as rural minor arterials or local, it may be appropriate to include the rural minor arterials in these procedures to provide coverage of all the road systems.

Multi-State urbanized areas have the option to do a combined analysis that incorporates the system extent within the urbanized area boundaries as a whole. The sample size would be distributed to the jurisdictions within the urbanized area proportionally to the size of the system in each strata. This option would necessitate the development of sets of expansion factors to allow expansion for each State, and, of course, requires agreement and coordination between the involved highway departments.

SAMPLING ISSUES

Unpaved Roads

A major issue related to counting on the local system is whether to count unpaved roads. The use of cables or air tubes on unpaved roads can result in equipment damage. In urban areas, the VKT needs involving the local system pertain to estimation of VKT for air quality nonattainment areas. Paved local roads carry the large majority of VKT in the local system in non-attainment areas. This guide recommends counting only on paved roads in urban areas. In rural areas, a large proportion of the local system is unpaved. Depending on the specific State situation, counting may be necessary to provide local system travel estimates. No recommendation is made for rural areas. However, the sampling procedures can be applied to unpaved roads, if desired. The only concern being the capability of road tubes to survive in the unpaved environment. New magnetometer counting equipment can operate effectively on unpaved roads.

Boundary Definition

The development of the sampling plan requires a complete and well-defined universe of roads that has been properly sectionalized. The boundaries of urbanized areas, small urban areas, and rural areas have

already been established for the HPMS based on the latest Census and EPA nonattainment area definition. The local functional system definition of roads must be complete and up-to-date. Since the plan is intended to complement HPMS VMT reporting, this guide recommends that boundary definitions be the same as used for the HPMS.

The universe of road sections within the defined boundaries as defined in the sampling frame must be accurate to select and expand the sample. Gaps in the definition will adversely affect the sample results.

Panel Sampling

A panel or fixed sample retains the sample sections over time. Panel samples are very good for assessing change over time and trends, but can be easily outdated due to the changing universe. Panel samples eliminate the need for periodic sample selection. The HPMS is a panel sample. Panel samples have proven very effective for traffic monitoring in the higher systems. A fixed sample helps to maintain the data collection schedules, allows installation of permanent equipment, simplifies the location of sites for recurring monitoring, and better addresses the dual issues of system versus site-specific data needs. Of course, road systems are constantly changing and evolving. Periodic changes are to be expected even in a fixed sample.

Random Sampling

The alternative to panel sampling is the selection of random samples of road sections. Annual sample selection would result in a totally different sample each year. The selection of different samples each year works to verify or confirm the estimates from previous years, provides traffic count information for different sections of the universe, and helps to reduce the possibility of continued dependence on a bad sample. The main drawback of an annual random sample is that it requires an annual sample selection exercise, the development of annual counting schedules, and the annual location and identification of sites for counting. Although the human aspects of traffic counting may be complicated by this approach, the equipment aspects do not present much of a problem due to the low traffic volumes in most local roads. The random sampling allows much more system coverage over a number of years and may be better suited for the typical uses of highway departments.

Length of Sections

The sample plan could be prepared based on equal or variable section lengths. Equal section length requires establishing the appropriate section length and dividing the total mileage by the selected section length to approximate the number of universe sections. For example, the use of one mile sections simplifies the approach and allows easy sample determination based on mileposts. The biggest drawback to the use of equal section lengths is the difficulty of maintaining the basic sampling assumption that traffic within a section does not change.

Variable length sections are the basis of the HPMS sampling approach. Variable sections allow better control over traffic occurring with a section, represent better the reality of traffic within road sections, and act to reduce the total number of sections needed for the sampling frame and for the corresponding sample.

Both approaches have advantages and disadvantages. No recommendation is advanced and States have the option to pick the procedure better suited to their needs and program operation.

Annual or Multi-year Sampling

The HPMS/TMG sampling approach distributes the volume sample over a 3-year cycle to reduce the annual workload and promote traffic program stability. However, since the HPMS consists of annual reporting, HPMS sections not counted during the current year must be annualized by using growth factors.

The local counting approach is designed to provide annual VKT, but lacks a factor base. Given the restrictions, these guidelines recommend implementing programs on an annual basis. The procedures are intended to support conformity and clean air regulations, which require annual interpretation of VKT. The use of an annual process also eliminates the confusion introduced by multi-year applications.

Sample Stratification

Stratification is used in statistical sampling because it reduces the size of the sample required. It is done by subdividing the universe of observations into strata based on a defined characteristic. If the variance of the quantity to be estimated (e.g., traffic volume) is appreciably lower within individual strata than across strata, then stratification will permit an appreciable reduction in the total size of the sample required to estimate the overall value of the quantity with a given level of precision. Previous research has shown very large gains due to stratification by traffic volume³.

Stratification by traffic volume poses a potential problem, that of obtaining the traffic-volume estimates required to perform the stratification. In theory, the amount of information needed to carry out a complete universe stratification based on traffic volume would make sampling unnecessary. In real life, the volume stratification may be based on available inventories that provide a general estimate of traffic for the universe road sections. An even more practical alternative may be to assign the universe sections judgmentally to a few relatively rough volume groupings on the basis of a relatively cursory review of readily identifiable characteristics (e.g., location, traffic, type of surrounding development, etc.) and knowledge of the road system. Such an approach will produce strata with volumes whose ranges overlap somewhat, but it will achieve the desired sample size reduction without unduly affecting the resulting VKT estimates.

This guide recommends the following traffic volume stratification:

| <u>Rural</u> | <u>Urban</u> |
|--------------|--------------|
| < 50 | < 200 |
| 50-199 | 200-499 |
| 200-499 | 500-1,999 |
| 500-1,999 | 2,000-3,999 |
| > = 2,000 | > = 4,000 |

These stratification categories correspond to the HPMS areawide reporting requirements. The urban recommendations apply equally to small urban and urbanized areas.

Monitoring Period

FHWA recommends that all short-duration traffic counts on HPMS sample sections be taken over a period of 48 hours. This recommendation is based on the need to estimate AADT, a site-specific estimate, as well as VKT (a system estimate). For the local system, the only estimate desired is system VKT. Therefore, estimation plans based on alternative monitoring periods could be effective. There are

many tradeoffs between the monitoring period alternatives and the constraints imposed by sampling theory, staffing, scheduling, equipment, and cost considerations. Sampling plans could be developed based on very short counts to emphasize visual counting operations and minimize equipment use. However, spatial and temporal randomness concerns can make this type of operation very costly.

This guide recommends the use of 24-hour monitoring periods based on automatic counting equipment. A full day count provides a direct measurement of traffic differences occurring within the day, maintains continuity with counting operations in higher systems and with the HPMS, provides a better base to examine site-specific issues, simplifies sample selection and scheduling/counting operations, allows direct estimation of daily vehicle kilometers of travel (DVKT) and makes expansion to VKT as simple as multiplying by 365.

Temporal Distribution

To maintain sampling validity, the theory of simple random sampling requires a known equal probability of selection for each highway section and monitoring period in the sampling frame. Meeting the requirement involves randomly selecting sample highway sections and randomly assigning counting periods over the 365 days of the year (including weekends). Obviously, a valid representation of annual VKT must be based on the 7 days of the week and the 12 months of the year. A totally random spatial and temporal approach presents obvious difficulties for scheduling a counting program and installing counting equipment. Efficient use of staff is a priority of public organizations. Keeping staff productive requires establishing counting schedules that minimize travel and maximize the use of counting equipment. Equipment use during the Winter months is not possible in many areas due to snow accumulation, plowing operations, use of vehicular chains/studs, etc.

This guide recommends counting the local system during the established State/MPO temporal counting cycle, distributing the counts equally to each counting month, and distributing the counts equally to each of the seven days of the week. The procedure as recommended allows continuing established counting operations, the use of current counting equipment, compensates for month and day bias, and permits efficient use of staff. Counting on weekends will not require overtime payment to staff if newer equipment with date/hour capability is installed on Fridays and retrieved on Mondays. In fact, this type of operation employs counting equipment that may otherwise lay idle over the weekend.

Axle Correction

Traffic counting equipment can accommodate a variety of detectors. Typically, air tube or pneumatic hose detectors and cables are used for this type of operation. A single tube or cable detects the passage of axles. New equipment units are capable of classifying vehicles by using two hoses or cables. Counters are also designed to allow the use of inductance loops to directly detect the passage of vehicles. Many States utilize specially designed carpet mats with measured loops, tubes, or switches for ease of installation. Other types of vehicle counters such as magnetometer counters may also be effective.

Axle counts must be converted to vehicles. This is normally done by the use of axle correction factors developed from vehicle classification data. Obviously, vehicle detectors do not require axle adjustment. The development and application of appropriate axle factors is straightforward, but requires classification data. Local roads in general have no truck travel with the exception of roads leading to gravel pits, farms, logging areas, mines, garbage dumps, construction sites, concrete producers, etc., making the estimation of these factors very difficult in those areas.

One alternative is to assume the lack of trucks and convert axles to vehicles by dividing by two (assuming all vehicles have two axles). This will not cause large errors, since as mentioned above, multi-axle trucks and other vehicles are not often found in the local system. However, multi-axle vehicles do travel local roads and ignoring them will cause an overestimation of VKT. No data exists to estimate the degree of overestimation caused by the presence of trucks in the system.

The estimation of accurate VKT is dependent on accurate vehicle counts. One of the limitations of a small random sample is its vulnerability to the introduction of bias. Axle counts may inordinately affect such a small sample. This guide recommends the use of vehicle counts. Vehicle counts can be taken by the use of loop detectors, double hoses, or cables. Magnetic detectors placed in the center of a traffic lane would also work. The recommendation restricts the use of older, less capable equipment and may raise the level of complexity; but it eliminates the need to collect classification data, to compute axle factors, and totally eliminates the likelihood of axle bias.

RECOMMENDED PROCEDURE

The local system VMT estimation procedures consist of the following six steps:

1. Preparation of the sampling frame.
2. Estimation of sample size requirements.
3. Selection of the sample sections.
4. Collection of traffic volume data.
5. Estimation of local VKT.
6. Estimation of Precision of VKT Estimates

Preparation of the Sampling Frame

All public roads functionally classified as local within the designated boundaries are to be included. This may require updating current road inventories or establishing a separate inventory of local roads. States annually report extent and travel data on local systems to the HPMS. These data are used to produce Table HM-67 in Highway Statistics. The tables imply substantial inventory and travel information available on lower road systems to guide the development of sampling frames.

The designated boundary may correspond to a non-attainment area, an urbanized area with a population greater than 200,000, an aggregation of small urban areas, or the rural areas of the State. The boundaries must be unique, independent, and non-intersecting to allow clear development of expansion factors and the aggregation of estimates to statewide totals. Using the already established HPMS boundaries is highly recommended. Since HPMS boundaries are already defined, their use greatly simplifies the plan. Also, the use of HPMS boundaries will allow the development of total VKT estimates (all functional classes) by simple addition.

Once boundary definition is completed, the inventory of local roads is used to create the sampling frame. The road inventory must be complete and as up-to-date as possible. Exclusion of any roads from the sampling frame will, of course, bias the estimates resulting from the sample.

A sampling frame is a listing or file of all road sections from which the sample can be selected. The sampling frame is created by breaking the inventory of roads into sections or links by volume group. The traffic volume within each road section should be as homogeneous as possible. This means that traffic should not change appreciably within the section. Sections in urban areas should be very short, perhaps as short as a city block. In rural areas, longer distances may be appropriate. Section definition can be difficult due to the character of local roads, but it is crucial to the development of adequate sampling plans and for the computation of expansion factors. Defects in the sampling frame cannot be compensated for by the sampling plan. Sufficient effort and discipline need to be applied during the sampling frame development and update stages.

A sampling frame can be prepared using a microcomputer and a database program. Variables in the database should include a unique section number, the route number, beginning section milepoint (kilometerpoint) or other termini point identification, ending section milepoint, jurisdiction, rural/urban/small area location code, urban area code, AADT or volume estimate, volume group, and length of section. Other needed variables should be included as desired.

Each of the sections in the sampling frame should be assigned an AADT or volume estimate which is used to assign each section to a volume group. The volume estimate can be based on available information or be a judgment call based on knowledge of the road system.

The stratification categories have been presented earlier. In order to facilitate the sample selection and the expansion factor development, the number of sections and the kilometers in each strata should be computed. Within each strata, each sample section should be assigned a unique sequential number.

The sampling frame will have to be reevaluated annually. Changes in the boundaries, road systems, or traffic have to be incorporated as best as possible. Judgment regarding changes affecting the systems and how to track these changes will be necessary to maintain the validity of the sample and the precision of the VKT estimates.

Estimation of Sample Size Needed

The sample is designed as a stratified simple random sample. This design is easy to apply, well understood, and fully supported by theory and empirical studies. The design is the same as used for the HPMS sample, therefore, every State already has relevant experience in program development.

A sample can be designed to approximate a specified precision. The VKT estimates to be derived from the sample are intended to support the estimation of total VKT for the areas in question. Since the higher functional systems carry most of the travel, the precision of local roads VKT is not critical. The precision specification (target precision) recommended is 95-10 for each volume group strata. This means that the VKT estimates derived for each strata will be expected to deviate no more than plus or minus ten percent with 95 percent confidence. Due to the expansion (based on kilometers), the aggregation of estimates to individual urbanized or statewide totals will also be expected to approximate the target precision.

The sample can be easily modified to attain higher or lower precision targets. Precision is a difficult issue to address. Precision and sample size are inversely proportional to the second power. This means that halving precision requires four times the sample size. Traffic counting is a complex operation subject

to many pitfalls. Since this is a new program, the approach is one of caution. Precision can be computed after data collection is completed and an evaluation conducted. After the sampling program has operated for two or three years, the precision issue can be reexamined based on a far clearer understanding of the costs and efforts required. At that point, the realities of a live operation can be analyzed and decisions made. This guide recommends computing the precision achieved annually and reexamining the program every 3 years.

The sample size estimates for each strata are derived by the following formula:

$$n = \frac{Z^2 C^2}{d^2}$$

where n = required sample size,
 Z = 2, the value of the standard normal statistic for a 95 percent confidence level (two-sided),
 C = AADT coefficient of variation, and
 d = .05, the desired precision rate.

The coefficient of variation (CV) is the ratio of the standard deviation to the mean. The mean is computed as the sum of observations divided by the number of observations. The standard deviation is computed using the equation for a simple random sample available in all statistical textbooks.

For example, the sample size needed to estimate the rural local roads with a volume less than 100 and a CV of 30 percent is 144 counts [2 x 2 x .30 x .30 / .05 / .05]. To examine, alternative precision rates, the same equation applies. If the precision rate desired is lowered to 5 percent, then the sample needed is 576 counts.

The following table presents the sample sizes needed to meet a 95-10 target precision given alternative CV's:

| <u>Volume CV</u> | <u>Sample Size</u> |
|------------------|--------------------|
| .10 | 16 |
| .20 | 64 |
| .30 | 144 |
| .40 | 256 |
| .50 | 400 |
| .60 | 576 |
| .70 | 784 |
| .80 | 1,024 |
| .90 | 1,296 |
| 1.00 | 1,600 |
| 2.00 | 6,400 |
| 3.00 | 14,400 |

Theoretically, under the assumption of normality, a rough, preliminary estimate of the standard deviation

can be computed by dividing the range by 4. For example, for the urban volume group under 200; the estimated SD would be 50, the estimated mean 100, the estimated CV is .5, and the estimated sample size is about 400 counts. For the volume group between 200 and 499; the estimated SD is 75, the mean is 350, the CV is .21 and the sample size 71. For the volume group between 500 and 1,999; the SD is 375, the mean is 1,250, the CV is .30, and the sample needed is 144. For the volume group between 2,000 and 3,999; the SD is 500, the mean is 3,000, the CV is .17, and the sample size is 47. For the last open-ended volume group of greater than 4,000, the CV cannot be estimated directly. An SD guesstimate of .20 is advanced resulting in a sample of 64. A preliminary sample of about 726 section counts would approximate the specified target precision.

These preliminary sample size estimates can be greatly improved based on real data, available from a counting program, from engineering estimates, or as a last resort after the completion of the counting for the first year of the plan.

The stratification gains depend on the specific sampling frame distribution, the number and volume of sections in each strata, and the actual variability of traffic within each strata. Alternative stratification categories could be examined as a means of improving the resulting sample once the program is underway.

The sample formulas present simple, preliminary approximations which do not account for strata with small number of sections. If any such cases should occur, the sample size formulas provided in the HPMS Manual Appendix G should be utilized. A discussion of sample size estimation is also provided in the HPMS Manual Appendix S.

The recommended sample stratification and sample size estimation above is one of the simplest of many possible ways to stratify and estimate sample size. More involved methodologies, such as weighing the strata depending on the proportion of VKT or system extent are quite possible and have the potential of reducing the variability and improving the precision of the resulting estimates. However, more complex methodologies will require more complex estimation techniques. Since this is a first step, the simple HPMS-coordinated sample approach is preferred.

Selection of the Sample Sections

After computing the number of sample sections needed in each stratum, the sample sections are selected using the random number generator available in most database programs or using manual procedures based on tables of random numbers. This approach assigns equal probability of selection to each highway section regardless of VKT.

For the recommended approach, each section in the sampling frame within each stratum has a unique sequential number ranging between 1 and the total number of sections in the stratum. For example, if there are 500 sections in the first volume group then each section should be numbered from 1 to 500. If the stratum number of samples is 35, then a random generator program is used to select the 35 sections, or 35 random numbers between 1 and 500 are selected from a table of random numbers. The sections selected now become the stratum sample. The sample process is continued until each strata has the required number of samples.

After the sample is selected, the sample should be plotted on a map. Any random sample selected in the

described manner is representative. However, the possibility of selecting a bad sample does exist. To insure good representation, the sections in the sample should be geographically distributed throughout the area. To assess the level of representation, it may be necessary to examine the geographic distribution of the each stratum sampling frame as well as the stratum sample. If it is found that the sample sections are clustered together rather than geographically distributed, it may be necessary to reselect some of the sections to insure a more dispersed sample.

After the spatial sample selection is completed, the temporal data collection schedule must be developed. One approach is to randomly select the day of counting for each sample section by using random procedures. This approach may be more difficult to schedule.

A second approach is to develop a systematic sample where the samples in each stratum are scheduled for counting during the counting season months and days. The purpose is to distribute the counting effort as nearly equally as possible by month and day of week to eliminate temporal bias. For example, the 35 sample sections in the first volume group would be allocated equally to the months of the counting season and the 7 days of the week. If the counting season runs for 6 months then 6 samples (5 for the last month) are randomly selected for counting each month and 5 samples are randomly selected for counting each day of the week. This distribution process is applied to each strata in the sample, then a schedule is developed for the actual counting.

Traffic Counting Data Collection and Processing

Once a schedule is developed covering the spatial and temporal frames, the counting process can begin. Counts should be attempted for all sample sections according to the schedule using standard State counting procedures. Equipment should be installed to insure that a complete 24-hour hourly count is taken for each sample section. Starting and ending times can vary as long as a 24-hour period is covered. Procedures for safe equipment installation and retrieval should be developed by the State following existing guidelines.

After the count is retrieved, the date of the count, day of the week, 24 hourly counts (if available, total vehicle count with no rounding, and equipment unit number would be entered into the database. Plots of the 24-hour hourly counts (if hourly counters are used) should be examined to determine if the 24-hour count fits the established daily pattern. General edit checks may be needed to determine if any of the counts are in error. Counts determined to be in error should be discarded, and recounts taken. Recounts should be scheduled on the same day of the week as soon as possible, preferably the week after the original count.

The scheduling of sample counting may leave gaps which may be filled with other duties such as taking special counts for other needs, combining the local counting work with counting done in higher systems, or other data collection activities. However, other needs should not overly influence or bias the scheduling of local road sample counts.

Estimation of VKT

At the closing of the counting season, each sample section should have a traffic volume based on an actual count and the length of the section where the count was taken. The sample DVKT in each stratum is estimated simply by multiplying the count times the length of the section and summing the sample

sections. To expand the stratum to a universe total the sample DVKT is multiplied by the expansion factor which is the ratio of the length of the stratum frame to the sample. The stratum expansion factor is computed by summing the length of all the sections in the sampling frame and dividing by the sum of the length of all the sections in the stratum sample. The stratum VKT is estimated by multiplying the stratum DVKT by 365 (or 366 in leap years). After applying the procedure to each of the strata within the area boundaries, the strata VKT are summed to an area total. Statewide estimates are developed by summing all the appropriate areas.

If vehicle classification categories have been maintained, the same procedure can be used to estimate the travel of each vehicle category.

This simple description fails to take into account many difficulties that may be encountered. For example, finding that the volume counted places the sample section outside the boundaries of the volume group. Judgment will have to be applied. Problems encountered should be documented and brought to the attention of the plan designers or the FHWA for interpretation and resolution.

The following example describes the procedure for a sample of six sections:

| <u>Sample Section</u> | <u>Volume</u> | <u>Section length</u> | <u>DVKT</u> |
|-----------------------|---------------|-----------------------|-------------|
| 1 | 55 | 1.2 | 66 |
| 2 | 40 | 3.0 | 120 |
| 3 | 85 | 2.3 | 195.5 |
| 4 | 80 | 1.1 | 88 |
| 5 | 44 | 3.5 | 154 |
| 6 | 123 | 0.6 | 73.8 |
| Total | -- | 11.7 | 697.3 |

The sample stratum DVKT is the sum of each section's volume times length and equals 697.30. The total stratum DVKT estimate is computed by multiplying the expansion factor by the sample DVKT. Assuming an expansion factor of 50, the total stratum DVKT estimate is 34,865. The annual stratum VKT is the total times 365 and equals 12,725,725.

For aggregation of strata, the total DVKT estimates of each strata are added.

Precision of VKT Estimates

The estimation of precision is complicated by the combination of the principles of sampling theory and the difficulties involved in real-life traffic monitoring.

VKT is a combination of traffic volume and length of section. The typical sampling assumption of element independence is not applicable to contiguous highway sections where volume is related to the volumes along the highway. The sample of sections was selected such that each section has equal probability of selection, the standard HPMS approach. Theoretically, the estimates of VKT should be computed as the inverse of the selection probability by expanding sample section VKT by the ratio of sample to universe sections. Instead the sample is expanded as the ratio of universe to sample length (HPMS procedure) to insure that estimates of system length match universe totals. In addition, the initial

sample size estimates were based on traffic volume variation rather than VKT variation which includes length of section.

Precision estimation will follow standard theory and will be based on VKT not volume. Previous analysis have shown that VKT and traffic volume characteristics have similar variation. However, both volume and VKT sample estimation depend on the actual volumes on the sections and the manner in which the universe was partitioned into sections based on length.

The precision level for a stratum is estimated using the following equation:

$$D = T_{1-d/2, n-1} \frac{C}{\sqrt{n}}$$

- where
- D = precision level as a plus or minus percentage of the mean,
 - C = coefficient of variation of the DVKT,
 - T = value of Student's T distribution with 1-d/2 level of confidence and n-1 degrees of freedom,
 - n = number of sample sections.

The percentage precision estimated from this equation applies both to the mean DVKT and to the total VKT.

The mean DVKT is estimated for a single stratum as the mathematical average of the volume times the section length of each section within the stratum. The variance of the stratum mean is computed as the sum of squares divided by n-1. The standard deviation is the square root of the variance. The CV is the ratio of the standard deviation to the mean usually multiplied by 100 to provide a percentage.

Continuing with the previous example, the mean stratum DVKT is 116.2 (697.30 divided by 6). The variance is 2569, the standard deviation is 50.7, and the CV is 44 percent. The value of the T distribution with two-sided 95 percent confidence and 5 degrees of freedom is 2.571 (a table is provided on page 3-A-9 of the Traffic Monitoring Guide). The precision from this stratum sample is plus or minus 52 percent. According to the previous sample size table, a CV of 44 percent would provide the target 95-10 precision with a sample of about 300 sections.

The following table illustrates the computational procedure applicable to a sample of 3 strata.

| Stratum | n | Stratum Length | Expansion Factor | Sample DVKT | Mean DVKT | SD | CV |
|---------|----|----------------|------------------|-------------|-----------|-------|-----|
| 1 | 6 | 585 | 50 | 697.3 | 116.2 | 50.7 | .44 |
| 2 | 10 | 330 | 30 | 2,250 | 225 | 112.5 | .50 |
| 3 | 35 | 120 | 10 | 12,250 | 350 | 105 | .30 |

The aggregated DVKT is the sum of the sample DVKT times the expansion factor for each strata, 224,865 in the example.

One method to compute the precision is to compute the aggregated mean DVKT, the aggregated variance, and the CV. The aggregated mean is the weighted average, 179, computed as the sum of the stratum mean times the stratum weight $[.56 \times 116.2 + .32 \times 112.5 + .12 \times 105]$. The stratum weight is the ratio of stratum system length to total length.

The aggregated variance is computed as the sum for all strata of the squared stratum weight times the squared stratum SD divided by the stratum sample size. In the table, the aggregated variance is 268.5 $[.56 \times .56 \times 50.7 \times 50.7 / 6 + .32 \times .32 \times 112.5 \times 112.5 / 10 + .12 \times .12 \times 105 \times 105 / 35]$. The aggregated SD is the square root of the aggregated variance, 16.4. The CV for precision computation is 9.2 percent $[16.4 / 179 \times 100]$.

The estimated precision with 95 percent confidence is 2.6 percent, computed as the T value [2.0] with $n-1$ [50] degrees of freedom times the CV (9.2) divided by the square root of the sample size (51).

The final result in the illustration is a DVKT estimate of 15,197.3 with a precision of plus or minus 2.6 percent with 95 percent confidence. The 95 percent confidence interval ranges between 14,802 and 15,592.

CONCLUSION

Implementing a sampling plan in the traffic monitoring environment is fraught with difficulties. Statistical sampling thrives on rigorous control over sample selection and measurement. Traffic monitoring data collection is subject to many uncontrollable constraints. This report presents a plan to combine both theoretical and real-life conditions resulting in a reasonable and cost-effective approach to estimating VKT for the local functional system. The plan fully supports and depends on the already implemented HPMS sampling methodology.

The approach presented emphasizes simplicity and caution. It is designed as a starting point to implement a valid program while minimizing the level of effort required. It attempts to balance the rigor of a statistical sampling program with the limitations of traffic monitoring. However, quality has a price. Oversimplification of the plan and a total loss of control over monitoring operations may not produce quality results. Therefore, the recommended program attempts to maintain limited statistical rigor. Once the program is operational and the results are evaluated in terms of both meeting objectives and cost, then changes can be made to either increase precision levels, modify the program to include additional areas, or introduce more complex statistical procedures.

The plan as presented closely correlates with procedures described in the Traffic Monitoring Guide, the Highway Performance Monitoring System, and the traffic monitoring procedures of the States. Maintaining procedural consistency allows quick implementation, minimizes training needs, and simplifies coordination of results.

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