History of Estimating and Evaluating Annual Traffic Volume Statistics

DAVID ALBRIGHT

Traffic volume summary statistics are foundational to the transportation profession. A historical perspective to estimation and evaluation of annual traffic volume statistics in the United States is provided. During the 1930s there were extensive manual count activities. In the 1940s the transition to mechanical measurement of traffic changed the approach to data integrity. In the 1950s and 1960s dominant personalities gave theoretical direction to calculating annual traffic summary statistics. The procedures developed during this period were at times questionable but became the unchallenged basis for traffic reports over the next three decades. At the end of the 1980s earlier traffic data assumptions began to be challenged. Among the historical assumptions and procedures being reexamined are the normal distribution of traffic, traffic variability, and data imputation and smoothing. In part it was awareness of problems in historical traffic volume procedures that influenced the development of national traffic monitoring standards. The history of traffic volume summary statistics provides a helpful lesson in designing the future of traffic monitoring.

Annual average traffic summary statistics are used to estimate the central tendency of vehicle demand on individual roads and road systems. The precision and bias of annual summary statistics have wide-reaching implications for the transportation profession. Traffic summary statistics affect road geometry and pavement thickness (*1,2*). When expressed as vehicle miles traveled, summaries of traffic volume influence calculations of accident exposure and mobile sources of air pollution (*3,4*). Traffic summary statistics are also used for purposes as diverse as fund allocation, benefit/cost analysis, signalization warrants, alternative route alignment, and transportation research.

The applications and impact of traffic estimates require ongoing review of the assumptions and practices that have been used to produce traffic statistics. The history leading to current procedures for estimating and evaluating annual traffic volume summary statistics are thus examined.

The study began with a comprehensive literature search. Documents relating to traffic volume were reviewed dating from 1930 to 1990. After reviewing the literature, several themes were identified that influenced current practice. Themes were also selected to help inform a more intentional future of traffic monitoring.

HISTORICAL DEVELOPMENT OF TRAFFIC MONITORING

Seminal work was undertaken in statistical analysis traffic data during the 1930s. Some of the initial work was based on manual traffic counts taken in 5-min intervals. The objective was to quantify highway capacity analysis and volume/speed relationships. For example, in 1932 Johnson (*5*) published an article on capacity analysis. Kinzer (*6*) presented a related paper in 1934 on the relationship of probability theory to highway traffic data. Kinzer's paper influenced subsequent national and international discussion of the assumption that traffic is a random series. In 1936 Adams (*7*,p.122) analyzed manually collected hourly traffic flows to demonstrate that, under free-flowing conditions, traffic generally corresponds to a random series of events.

An early statistical analysis concerned with the adequacy of base data for estimation of traffic summary statistics was presented by Shelton (*8*,p.347) in 1938. Shelton designed his study on the basis of concern for complete data sets:

> Most studies of time periods of highway traffic volume have been devoted largely to averages in the form of trends, or patterns, and have been confined to incomplete data.

Shelton (*8*) examined the grouping of traffic volume by hour, day, and month at two sites in Iowa. For the two sites, hourly manual traffic volume observation was conducted for 1 year. The analysis of variability at these sites specified that "there are no additional hours of wider variation not included." Shelton sought to identify the optimal number of manual count hours at a site. Within 3 years there was widespread development and implementation of mechanical traffic-recording devices, and the urgency of Shelton's findings diminished. What did not diminish was the concern for unadjusted data sets for statistical analysis. The value of Shelton's work is not so much in his findings as in his approach to ensuring the integrity of base data.

In 1939 Shelton (*9*) prepared a followup analysis concerned with the variability of traffic volumes. He analyzed observations of traffic volume at nine locations in Michigan. The traffic volume summary statistics were based on hourly manual volume counts for every hour of the day, for 366 consecutive days. Shelton found that some sites were more variable than others and that there tended to be "greater constancy" during work hours than at other hours of the day. He calculated that one of the nine Michigan sites would require seasonal counts, rather than a count in any single month, to estimate annual traffic accurately. Shelton's commitment to unadjusted and complete data for analysis and his observation that at some sites traffic was more variable and would therefore require more than one count annually were important contributions to traffic monitoring.

In 1940 the national traffic volume emphasis shifted from intensive manual counts to mechanical traffic recorders. Rather

Research Bureau, New Mexico State Highway and Transportation Department, P.O. Box 1149, Santa Fe, N.Mex. 87504-1149.

than short-term manual counts adjusted to represent an annual traffic summary statistic, 48-, 72-, and 96-hr continuous mechanical traffic counts were taken. These short-term mechanical counts were, in time, adjusted to represent annual summary statistics from permanently operating traffic-recording devices. From 1940 to the mid-1950s, the traffic monitoring emphasis was on short-term mechanical counts and the use of geographically based, permanent counter adjustment factors to adjust these counts to mean annual statistics (10).

In 1954 Petroff (*11*) first published an article concerned with estimating the error of short-term counts compared with permanent count data. Petroff continued this emphasis and in 1956 wrote what was to become a pivotal traffic monitoring article (*12*,p.110). As in his previous traffic analysis, Petroff was concerned with estimating the error of traffic counts. The data for Petroff's analyses were from permanent counters in New Mexico, Florida, Colorado, Idaho, and West Virginia.

An important contribution of Petroff's 1956 work (*12*) was to identify the deficiency in the approach of geographically proximate sites for adjustment of short-term counts. Two years later, Burggraf et al. (*13*) used Minnesota data to confirm Petroff's observation that adjustment factors based on similar road use were more accurate than those based on similar geographic location. The result of Petroff's work was that, typically, short-term count adjustment factors were based on one permanent counter on a same-use facility. The subsequent development of mean traffic adjustment factors by functional classification of roadway described in the FHWA *Traffic Monitoring Guide* (*14*,p.3-3-4) can be traced back to Petroff's work.

There were other consequences of the 1956 article that had as important, but not as positive, an impact on traffic monitoring. Petroff (*12*) defined the task in traffic summary analysis in one sentence:

> Then the task is to find ways of measuring the errors in the estimates of ADT (average daily traffic) when the estimates are derived by different methods of sampling traffic volumes.

The task definition assumes that the variability in ADT is the result of different sampling techniques.

Petroff (*12*) did not address the issue as one of both the inherent temporal variability of traffic at a site over the period of a year and the additional variability introduced by alternative sampling and estimation methods. Concerning permanent counter data collection he noted:

> The error of estimate of ADT due to a specific method of sampling can be determined only at a few stations where there are permanent machine installations because only there is the true ADT known. Even at permanent installations, the ADT is not absolutely true because of machine failures; the error is comparatively small, however, and is ignored.

The observations of a so-called "true ADT" states clearly the search for a single number rather than the question of whether and to what extent the mean statistic is indicative of the central tendency of traffic volume when summarized over the period of a year. The assumption of a true ADT led Petroff (*12*) to use purely descriptive statistics in determining an approach to the problem of estimating ADT.

In Petroff's quote there is an assumption concerning the impact of machine failure at permanent count stations. This assumption would lead in Petroff's work, and in subsequent state highway agency practice, to techniques for completing or filling in missing data measurements. This practice of completing missing data is termed "imputation." Because the assumption was made that the error would be small and could be ignored, no assessment was made in subsequent work of the impact of imputation and mixed data sets between measurements and imputed values. Or, as Petroff (*12*) wrote,

> At the continuous count stations the true ADT is always known. The difference between the estimated and true ADT value is termed the error.

Some of Petroff's writing concerning traffic estimate accuracy and precision may have been influenced by the interest of the data users. In one section of his 1956 article, Petroff (*12*) wrote the following:

> Experience shows that the estimates of ADT with errors measured by standard deviation of about 10-12% for high-volume (over 500 vehicles per day) roads are satisfactory to the users of the data.

There is a concern with emphasizing the users' interest in precision. What might be satisfactory variation to users in fact may be less than the inherent within-year variation of the traffic on the road. For example, in the data analysis of the 1956 article, Petroff (*12*) calculated the coefficient of variation (the standard deviation divided by the mean and multiplied by 100) for New Mexico short-term-count ADT and true ADT. The calculations were for primary rural road systems and were based on a sample of 172 counts of 7 days' duration. The coefficient of variation was calculated as 8.0 percent. The New Mexico data comprised one of the largest samples in Petroff's study and had one of the lowest coefficients of variation. This calculation was used to support the conclusion that the ADT estimate would be accurate with a coefficient of variation of no more than ±10 percent.

In 1961 Petroff (*15*,p.45) wrote a response to a traffic sampling paper by Thomas Muranyi of West Germany. In the response Petroff noted the following:

> In this country the prevailing number of states base their ADT estimates on single samples. In 16 states so far, rural traffic counting procedures have built-in statistical controls. These procedures were designed to produce the ADT estimates with standard deviation 5 = ±10%. Actually, after the "smoothing out" process whereby small adjustments are made in the ADT estimates when they are examined for reasonableness in relation to the data at the adjacent stations on the map and compared with the records of previous years, the final resulting errors are probably smaller than those indicated by the "raw score" measure 5 = ±10 percent.

As this quote illustrates, by the early 1960s the process of data smoothing to reduce the variability of the estimate was accepted as common practice. Shelton's (*8,9*) concern in the 1930s for the integrity of base data was, for the time, not addressed. It would be over 30 years before analysis of data at permanently installed traffic devices in New Mexico determined that the inherent variability of traffic volume at a site produced a coefficient of variation greater than concluded in Petroff's analysis (*16*).

Petroff's observation that raw data from 1 day's sample traffic monitoring could result in an estimate of ADT that could be characterized at a 95 percent confidence level as having a confidence interval of ±10 percent was based on the experience of 16 states. One of the states that implemented the Bureau of Public Roads approach to traffic data was Georgia. In 1967 Parrish et al. (*17*,p.43) published a paper describing Georgia's automated traffic data collection and analysis program. The authors noted the implementation of the Bureau of Public Roads procedures:

> Methods for using statistical techniques to objectively design traffic-counting programs had, by 1964, progressed to the point where the U.S. Bureau of Public Roads could draw from previous research to develop firm procedural outlines.

As Parrish et al. (*17*) explain, the procedures implemented to collect and summarize traffic data were similar to those identified by Petroff:

> Accessory computer programs are being implemented to tabulate and update the hourly volumes collected from any counting station by the telemetry process. The tabulation can be scanned by a traffic analyst to insure the acceptability of all data. Based on the educated discretion of the analyst, any unacceptable recorded hourly volume may subsequently be discounted and a substitute volume mechanically estimated by the computer, or as an alternative, a volume could be estimated by the analyst.

This approach became common practice among state transportation agencies. The result was the obscuring of the difference between traffic measurements and substituted values in state traffic data bases.

In 1963 the Bureau of Public Roads (*18*) published the *Guide for Traffic Volume Counting Manual*. The method of grouping permanent counters by function of roadway to derive adjustment factors was presented for state evaluation and implementation.

In 1966 Bodle (*19*) analyzed traffic data from five states to determine if Petroff's work was still applicable. The methodology Bodle employed was based on Petroff's work. The percent error for any estimate of ADT from a short-term count was expressed as the relationship between short-term counts and an assumed absolute ADT. The variability of the traffic summary statistic was expressed in terms of the coefficient of variation of the sampling from coverage count periods within a month and the coefficient of variation of the monthly adjustment factors.

Bodle (*19*) noted that his findings were essentially the same as those of Petroff:

> One striking observation that can be made is that the coefficient of variation for 24-hour counts taken Monday through Friday is nearly always greater than ±10%. . . By taking 48-hour weekday counts, it appears that the coefficient of variation of the count can be reduced below the ±10% level to a point where ADT estimates will more closely approach the desired accuracy.

Bodle's work reinforced the importance of 48-hr coverage counts and the presumed variability of traffic based on this estimate. It also demonstrated that, by following Petroff's methodology, similar conclusions would be reached a decade later.

The 1966 comparison of reduction in error among 24-, 48-, and 72-hr counts computed by Bodle (*19*) was reprinted in the 1970 *Traffic Volume Counting Manual*. Then, with a citation to the 1970 document rather than Bodle's work, the same graphic comparison was published almost 20 years later in the 1985 *Traffic Monitoring Guide* (*14*).

The acceptance of Petroff and Bodle estimates of traffic variability was not limited to governmental agencies. In 1975 ITE Technical Council Committee 6U (*20*,p.35) published Data Collection Guidelines and Analysis Techniques, Part I, as an informational report. The report included the following comment:

> In large urban areas, the 24-hour volumes taken on typical weekdays may be considered to represent the annual average daily traffic within an accuracy range of ±10%.

No specific reference is provided for this observation. The *Guide for Traffic Counting Manual*, published by the Bureau of Public Roads (*21*) in 1965, is cited among other titles as a general reference. This guide was based on Petroff's work. The related finding of Petroff was based on a limited number of data observations during 1953 and 1954 and was published in Petroff's 1956 article (*12*).

The ITE report (*20*) recommends that, to improve the statistical significance of before-and-after studies, two short-term counts may be taken before and after the improvement. Then the two counts may be averaged as a "close approximation of the mean" (20). The ITE report, as the work preceding it, assumes that the mean is the appropriate indicator of data's central tendency.

Petroff's work continued to influence traffic monitoring in the 1980s. It was referenced in a 1983 article on traffic count statistics by Hartgen and Lemmerman (*22*,p.11). Citing the Bureau of Public Roads 1965 manual for traffic counting, and Petroff's contribution to the manual, Hartgen and Lemmerman wrote,

> For high-volume roads (AADT > 1,500), the method produces AADT estimates that have a standard deviation of estimate of ±10%.

A limited number of observations of data by Petroff, with associated assumptions that were open to question, became the common reference for traffic variability. Although not challenging Petroff's assumption of traffic variability, a contribution of Hartgen and Lemmerman (*22*) did challenge Petroff's assumption of the insignificance of measurement error. The experimental basis for Hartgen and Lemmerman's concern with measurement error was limited, but the authors did identify that mechanical measurement error could "cloud the reliability of any count."

In the 1970s there was an effort in California to quantify traffic summary statistic variability more accurately. In 1979 the California Department of Transportation (Caltrans) completed an analysis of permanent traffic counter data. The purpose of the analysis was to estimate the confidence interval given a 90 percent confidence level. The Caltrans work concluded that the mean statistic annual average daily traffic (AADT) was highly correlated with the variability around the mean. The work completed in 1979 is still used by the agency and is published in the Caltrans annual survey of traffic volumes (*23*). The California approach to calculating the accuracy and precision of traffic volume summary statistics assumes the normal distribution of traffic volume data and homoscedasticity of the joint distribution of the means and variances. The California finding that the means and variances are correlated suggests that these assumptions are inappropriate. The assumption of the normal distribution of traffic data may similarly be questioned.

Although derived from permanent counter data, in the Caltrans presentation no distinction is made as to the basis for the AADT estimate. The estimate could have been based alternatively on a permanent traffic device; on a short-term count by length of count and by days and season, with adjustment factors applied; or on uncounted sites adjusted for annual growth. The Caltrans (*23*) report states,

> If the estimated ADT was compared to an average based on a 365-day count, it probably would be different, but for 90 out of 100 times the percent variation would not be larger than that shown above.

The approach did not identify the difference between inherent variability of traffic volume over the period of a year and the variability introduced by alternative methods of estimating the mean.

California, as other states, has an extensive procedure for imputing missing data points. If there are a few months of missing data, the data are estimated on the basis of other counts at the same site. If more than 3 months of data are missing, the previous years' data are used to impute the missing values (*24*). The California observations, as those of other states, were based on earlier assumptions concerning the importance of permanent device equipment failure and the validity of data smoothing.

The Caltrans work did not have the constructive impact it might on subsequent work in the field. Subsequent writing by authors such as Ritchie (*25,26*) did not reflect the interest in using permanent counter data to estimate same-site daily traffic variability. Subsequent work was more characteristically interested in refining the work of Petroff on estimating the variability of short-term count adjustment factors.

Such a model for estimating the variability of AADT from short-term counts was developed by Ritchie (*25*,p.14) in the mid-1980s. He began with the following equation for estimating AADT from a short-term traffic count:

$$\text{AADT} = \text{VOL}\,(F_S)(F_A)(F_G) \tag{1}$$

where

AADT = annual average daily traffic,
F_S = seasonal adjustment factor for the count month,
F_A = weekday axle correction factor, and
F_G = annual growth factor if no count was taken in the current year.

Ritchie then proposed that the coefficient of variation (cv) of AADT could be derived from the following expression:

$$\text{cv}^2(\text{AADT}) = \text{cv}^2(F_S) + \text{cv}^2(F_A) + \text{cv}^2(F_G) \tag{2}$$

The work by Ritchie (*25*) addressed the critical question of accuracy and precision of traffic volume estimates. It did not, however, address the question of the inherent variability of the traffic volume at the site. For example, omitting the variability of the traffic summary statistic can result in the computation of the variability of a summary statistic at an uncounted site being measured by only the variability introduced by the annual growth factor employed. The result can be, as in Petroff's and Bodle's work, that the calculated precision of an estimated summary statistic reflects less variability than the inherent variation in traffic at the site.

Ritchie's paper (*25*) was based on Washington State Department of Transportation data. The Washington traffic data procedures were detailed during the same time period in a Washington State study by Ritchie and Hallenbeck (*26*). Their study did not address the issue of permanent traffic recorder mechanical failure and data imputation. Washington state traffic summary statistics included imputed data to complete a 365-day data set at permanent counter sites (*27*). Neither Ritchie's paper (*25*) nor Ritchie and Hallenbeck's study (*26*) addressed inherent site variability and the variability introduced by data imputation. Their findings, as those of Caltrans in 1979, reflect data variability under the condition of the imputation techniques employed in the traffic data base.

In 1985 FHWA (*14*) published the *Traffic Monitoring Guide*. This document presented an efficient procedure for states to use in providing system-level traffic information for federal reporting purposes. The document addressed neither the question of inherent temporal variability nor the question of base data integrity. It did, however, provide an overview of the state-of-the-art in traffic monitoring. It was this document that first provided the incentive and direction for the refinement of traffic monitoring procedures.

In 1988 the first statewide standards for traffic monitoring practice were implemented (*28*). The standards specified data integrity and prohibited data imputation. After the first 2 years of standard data, the underlying distribution of traffic volume characteristics was examined.

In 1990 two events took place that have the potential of positively changing the history of traffic monitoring practice. In June 1990, ASTM initiated the first draft of traffic monitoring standards. The intention of the ASTM standards was to provide a common traffic monitoring specification for public agencies and private firms. Then in December 1990 the AASHTO Standing Committee on Planning established a Traffic Monitoring Task Force. The task force was charged with the responsibility of preparing a guidance for state transportation agencies. The purpose of the guidance was to provide a common traffic monitoring practice, and it was to be developed in concert with ASTM standards.

From the outset, both the ASTM and AASHTO activities were based on clearly defined traffic monitoring principles. Among the initially proposed principles was assurance of base data integrity. If endorsed and implemented, base data integrity will permit analysis of the underlying distribution of the data. This analysis will, in turn, refine the understanding of traffic volume summary statistics. The unfolding ASTM standards and AASHTO guidance have the potential to return traffic monitoring to the careful attention to and regard for data as expressed by Shelton in the 1930s.

SUMMARY: ATTEMPTING TO LEARN FROM THE PAST

It seems remarkable that as common and important a statistic as annual traffic volume would be so subject to modification and estimation. The benefit of tracing the errors in traffic volume summary statistics is more than reforming current practice under standards. This task alone will be a challenge to develop and implement, but it is not enough. There is a broader sense in which future practice is structured to avoid similar problems.

When standards of and guidance for traffic monitoring practice are completed, they will be subject to the same limitation as the mid-twentieth century work of Petroff and Bodle. The errors will be different, but there will be errors. They will not be intentional; rather, they will be the result of persons attempting to use available tools in a responsible manner.

If the profession is to learn from the past, what must change is the growing distance of the analyst from the measurements being analyzed. The profession could retain the illusion that traffic volume summary statistics were equivalent and comparable only because examination of base measurements was rare. Simple questions were unasked, such as, On what measurements are these summary statistics based? Although such questions were unasked, vast traffic data sets were computer processed, analyzed, and reported erroneously with ever-increasing speed.

By learning from the past, the ability to master quantity and speed of data has been demonstrated. Through deliberate concern with relatively simple questions about base data, the challenge is to demonstrate the ability to master quality.

REFERENCES

1. Desai et al. *Traffic Forecasting for Pavement Design.* Report FHWA-TS-86-225. FHWA, U.S. Department of Transportation, March 1988, p. 121.
2. J. A. Deacon, J. G. Pigman, and J. G. Mayes. *Estimation of Equivalent Axleloads.* Kentucky Transportation Research Program, University of Kentucky, Lexington, Dec. 1985, pp. 15–16.
3. *Fatal Accident Reporting System, 1988.* NHTSA, U.S. Department of Transportation, 1988.
4. The Clean Air Act of 1990, Title II, Part A Section 202 (C.3.C). In *Environmental Statutes*, 1990 ed., Government Institutes, Inc., Maryland.
5. A. N. Johnson. Highway Traffic Capacity. *Public Roads*, Vol. 13, No. 3, May 1932.
6. J. Kinzer. Application of the Theory of Probability to Problems of Highway Traffic. *Proc., 5th Annual Meeting of the Institute of Traffic Engineers,* ITE, New York, N.Y., 1934.
7. W. F. Adams. Road Traffic Considered as a Random Series. *Journal of the Institution of Civil Engineers,* London, 1936.
8. W. A. Shelton. Dispersion of Highway Traffic by Time Periods: Medium and Small Stations in Farm Area. *HRB Proc.,* 1938.
9. W. A. Shelton. Dispersion of Highway Traffic Volume by Time Periods. *HRB Proc.*, 1939, pp. 347–348.
10. J. Darrell, R. Dale, and W. Hayne. Minnesota Experience in Counting Traffic on Low-Volume Roads. *HRB Proc.*, 1958.
11. B. Petroff and R. Blensly. Improving Traffic-Count Procedures by Application of Statistical Method. *HRB Proc.*, 1954.
12. B. B. Petroff. Experience in Application of Statistical Method to Traffic Counting. *Public Roads*, Vol. 29, No. 5, Dec. 1956.
13. F. Burggraf, E. Ward, and H. Orland. Minnesota Experience in Counting Traffic on Low-Volume Roads. *HRB Proc.*, 1958, pp. 396–397.
14. *Traffic Monitoring Guide.* FHWA, U.S. Department of Transportation, 1985.
15. B. Petroff. Discussion of "Estimating Traffic Volumes by Systematic Sampling." In *Traffic Volume and Speed Studies. Bulletin 281*, HRB, National Research Council, Washington, D.C., 1961.
16. D. Albright. The Development of ASTM Highway Traffic Monitoring Standards. *Standardization News*, Vol. 19, No. 2, Feb. 1991.
17. E. Parrish, E. Peterson, and R. Threlkeld. Georgia's Program for Automated Acquisition and Analysis of Traffic-Count Data. In *Highway Research Record 199*, HRB, National Research Council, Washington, D.C., 1967.
18. *Guide for Traffic Volume Counting Manual.* Bureau of Public Roads, U.S. Department of Commerce, May 1963.
19. R. R. Bodle. *Evaluation of Rural Coverage Count Duration for Estimating Annual Average Daily Traffic.* Highway Planning Technical Report 5. Bureau of Public Roads, U.S. Department of Commerce, Oct. 1966, pp. 2–3.
20. Technical Council Committee 6U. Data Collection Guidelines and Analysis Techniques, Part I. In *Traffic Engineering,* ITE, New York, May 1975.
21. *Guide for Traffic Volume Counting Manual,* 2nd ed. Bureau of Public Roads, U.S. Department of Commerce, Feb. 1965.
22. D. Hartgen and J. Lemmerman. Streamlining Collection and Processing of Traffic Count Statistics. In *Transportation Research Record 928*, TRB, National Research Council, Washington, D.C., 1983.
23. *1988 Traffic Volumes on California State Highways.* Division of Traffic Engineering, California Department of Transportation, Sacramento, 1989.
24. E. Stoker. Interview in *New Mexico Traffic Monitoring System Requirements Definition*, Vol. III, New Mexico State Highway and Transportation Department, Santa Fe, 1988.
25. S. Ritchie. A Statistical Approach to Statewide Traffic Counting. In *Transportation Research Record 1090*, TRB, National Research Council, Washington, D.C., 1986.
26. S. Ritchie and M. Hallenbeck. *Statewide Highway Data Rationalization Study.* Washington State Department of Transportation, Olympia, 1986.
27. C. Smith. Interview in *New Mexico Traffic Monitoring System Requirements Definition*, Vol. III, New Mexico State Highway and Transportation Department, Santa Fe, 1988.
28. D. Albright, R. Goldstine, and C. Blewett. Statewide Traffic Monitoring Standards: Implementing the Traffic Monitoring Guide in New Mexico. In *Transportation Research Record 1236*, TRB, National Research Council, Washington, D.C., 1989.

Publication of this paper sponsored by Committee on Transportation Data and Information Systems.