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**QUALITY CONTROL PROCEDURES FOR  
ARCHIVED OPERATIONS TRAFFIC DATA:  
SYNTHESIS OF PRACTICE AND RECOMMENDATIONS  
FINAL REPORT**

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16. Abstract  <p>This report summarizes and provides recommendations for quality control procedures to be used for archived data that have been collected and saved by traffic operations systems. This report summarizes quality control procedures used in numerous archived data management systems (ADMS) implementations. This report provides recommendations for a basic set of quality control procedures that can be adopted, as well as a process to customize quality control procedures for system-specific data quality issues. This report also details the typical steps involved in quality control procedures, including the automation of quality checks, the use of manual visual review, the flagging of failed data records, and the use of metadata to document quality control actions.</p> <p>The intended audience for this report includes developers of ADMS as well as researchers and analysts of archived data. Software developers can adapt some or all of the quality control procedures as deemed necessary. The report could also be used or specified in writing a request for proposals to develop an ADMS. Researchers and data analysts can use the report to perform additional quality control if data quality remains an issue.</p>			
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## EXECUTIVE SUMMARY

### Introduction

The quality of traffic data archived from some traffic operations centers has been identified as a concern. Using quality control procedures to monitor and identify traffic data quality problems is an essential component of improving data quality. This report summarizes quality control procedures suggested in the literature as well as those that are used in numerous archived data management systems (ADMS) implementations. This report provides recommendations for a basic set of quality control procedures that can be adopted, as well as a process to customize quality control procedures for system-specific data quality issues.

### Review of the Literature and Current Practice

The literature review found identified validity criteria that could be classified into the following general categories:

- **Univariate and multivariate range checks** – These criteria typically correspond to the minimum, maximum, or range of expected values for a single variable or combination of variables.
- **Spatial and temporal consistency** – These criteria evaluate the consistency of traffic data as compared to nearby locations (either across lanes, or upstream and downstream monitoring locations) or previous time periods.
- **Detailed diagnostics** – These criteria require detailed diagnostic data from traffic detectors and typically can not be performed with the original source data that is collected and archived by traffic operations centers.

A review of current practice identified the following findings:

- The validity criteria are similar among the nine data archives that were reviewed.
- The validity criteria are less complex than those described in the literature.
- Nearly all of the validity criteria are programmed on a simple pass/fail basis.
- Most of the validity criteria do not have a specified order or sequence.
- In most cases, all criteria are applied even if previous criteria indicate invalid data.

### Recommendations

The following recommendations were provided for quality control procedures as they relate to archived operations data:

- Recognize that validity criteria (i.e., quality control) are only one part of a comprehensive quality assurance process that does more than just discard suspect data that have already been collected.
- Provide metadata to document quality control procedures and results.
- Provide metadata to document historical traffic sensor status and configuration
- Use database flags or codes to indicate failed validity criteria.
- At a minimum, implement basic foundation for data validity criteria (Table ES-1).
- Further develop other spatial and temporal consistency criteria for ADMS.
- When feasible, use visual review to supplement the automated validity criteria.

**Table ES-1. Recommended Validity Criteria for Freeway Traffic Detector Data**

Validity Criteria	Default Parameter
<b>Prescreening Criteria</b>	
Controller error codes (e.g., -1, 255, etc.)	n.a.
Check consistency of elapsed time and poll cycles	n.a.
Check for duplicate records (location ID, date, time identical)	n.a.
If VOL=OCC=SPD=0, then set SPD=missing/null (no vehicles present)	n.a.
<b>Univariate Range Criteria</b>	
Minimum volume	0 vehicles
Maximum volume	3000 vphpl (adjust for appropriate time interval)
Minimum occupancy	0%
Maximum occupancy	100%
Minimum speed	0 mph
Maximum speed	100 mph
<b>Multivariate Logical Consistency</b>	
Maximum consecutive identical volume & occupancy & speed values (including VOL=OCC=SPD=0)	Number of reporting intervals that corresponds to 30 consecutive minutes (max.) with no vehicles detected
If volume>0 & speed=0 then invalid	n.a.
If volume=0 & speed>0 then invalid	n.a.
If volume=speed=0 & occupancy>0 then invalid	n.a.
If occupancy=0 and volume>volume <sub>max</sub> (based on maximum possible volume when occupancy value is truncated to 0)	$VOL_{max} = [(2.932 \times SPEED \times ELAPSED\_TIME) / 600]$

## INTRODUCTION

Many traffic operations centers collect traffic data that is also archived for off-line analytical purposes, such as transportation planning, congestion monitoring, and performance measures. A survey of traffic data programs in all 50 State departments of transportation (DOTs) was conducted in 2005 to assess current practices in using archived operations data for planning purposes.<sup>1</sup> This survey found that unknown or inadequate data quality was one of the most frequently mentioned barriers to integrating archived operations data into traditional statewide traffic databases. Other published reports and workshops have identified similar concerns with the quality of archived operations data.<sup>2,3</sup>

The quality of archived data from traffic operations systems has been influenced by two prevailing issues:

1. The difficulty of maintaining extensive electronic field equipment (traffic sensors and communication) in a public agency focused on large capital expenditures; and,
2. Real-time traffic operations applications that have different data quality requirements than historical/analytical applications of archived operations data.

The result has been that many data archive managers and users have wrestled with data quality problems.

Traffic operations managers use data for different applications than transportation planners, and as such, may have different data quality requirements. Because of these different data uses, many transportation planners are unsure or skeptical of operations data quality, sometimes without the benefit of any actual data comparisons. In other cases, data comparisons and accuracy evaluations have been conducted and have raised concerns about the quality of archived data for historical/analytical applications.

In summary, the quality of traffic data archived from some traffic operations centers has been identified as a concern. Using quality control procedures to monitor and identify traffic data quality problems is an essential component of improving data quality. A 2003 FHWA report, *Traffic Data Quality Workshop: Proceedings and Action Plan*,<sup>2</sup> recommended that quality control procedures be compiled and synthesized in a guidance document. This report is intended to meet this recommendation for a guidance document.

### Quality Control vs. Quality Assurance

This report addresses quality control procedures for archived traffic data. In this report, quality control is defined as the identification, review, and treatment of data that does not meet specified acceptance criteria. Quality control and quality assurance are often used interchangeably to mean

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<sup>1</sup> NCHRP Project 7-16 Interim Report Recommended Revisions to the AASHTO Guidelines for Traffic Data Programs, National Cooperative Highway Research Program (NCHRP), April 2006.

<sup>2</sup> *Traffic Data Quality Workshop: Proceedings and Action Plan*, Publication No. EDL 13839, Federal Highway Administration, Washington, DC, September 25, 2003. For this specific item, see Action Item #2 (Section 4.3.2) in the Action Plan for Improving Traffic Data Quality.

<sup>3</sup> *Traffic Data Quality Measurement: Final Report*, Publication No. EDL 14058, Federal Highway Administration, Washington, DC, September 15, 2004.

the same thing; however, the terms as used in this report have different meanings with important implications.

The term “quality assurance” is used to encompass actions taken throughout the entire traffic monitoring cycle to ensure that traffic data meet or exceed customer expectations. With this definition, quality assurance includes actions taken before data collection as well as after data summarization, such as the following:

- Routine staff training and professional development;
- Effective equipment procurement procedures;
- Bench testing new field equipment;
- Thorough inspection and acceptance testing of new equipment installations;
- Routine equipment testing and calibration;
- Automated quality control to review and detect aberrant data;
- Scheduled maintenance activities; and,
- Data customer feedback through various channels.

The term “quality control” is used to describe the process performed after data collection but prior to data summarization and reporting to ensure that traffic data meet certain acceptance criteria. As used in this report, quality control involves reviewing and manipulating data that have already been collected. Data quality actions that are restricted to simply fixing data that have already been collected (referred to as “scrap-and-rework”) are ineffective in the long-term because they address the symptom but not the root cause of poor data quality.

However, in some cases, users of archived data may have little or no direct control over quality assurance processes other than quality control. For example, planning groups that wish to use archived data may currently have little to no input on procuring and testing operations-based traffic sensors. At the same time, though, users of archived data should recognize that long-term improvements to poor data quality can only be made by moving toward a position that influences how real-time traffic data are collected and archived.

## **Overview of this Report**

With these long-term quality assurance goals in mind, though, this report will focus only on quality control procedures, or the review of archived data that have already been collected and saved by traffic operations systems. This report summarizes quality control procedures used in numerous archived data management systems (ADMS) implementations. This report provides recommendations for a basic set of quality control procedures that can be adopted, as well as a process to customize quality control procedures for system-specific data quality issues. This report also details the typical steps involved in quality control procedures, including the automation of quality checks, the use of manual visual review, the flagging of failed data records, and the use of metadata to document quality control actions.

## **Microscopic vs. Macroscopic Validity Criteria**

Because of its focus on archived operations data, this report focuses on “microscopic” validity criteria for traffic data summarized for relatively short time intervals (typically 5 minutes or

less). Microscopic validity criteria are intended for use on original source data that have been obtained directly from a traffic management system. These microscopic validity criteria are contrasted with macroscopic criteria, which are more commonly associated with the longer time intervals (typically hourly intervals or greater) used in planning-based traffic databases. An example of macroscopic criteria is the following: The volume total in any lane for the entire day must not be 0. In many cases, archived data must be summarized to longer time intervals before macroscopic criteria can be applied. Additionally, a summary of macroscopic validity criteria can be found in other resources.<sup>4,5</sup>

## **Intended Audience**

The intended audience for this report includes developers of ADMS as well as researchers and analysts of archived data. Software developers can adapt some or all of the quality control procedures as deemed necessary. The report could also be used or specified in writing a request for proposals to develop an ADMS. Researchers and data analysts can use the report to perform additional quality control if data quality remains an issue.

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<sup>4</sup> AASHTO *Guidelines for Traffic Data Programs*, American Association of State Highway and Transportation Officials, 1992. These *Guidelines* are currently being updated through NCHRP Project 7-16 and should be available in 2007.

<sup>5</sup> Flinner, M. and H. Horsey. *Traffic Data Editing Procedures: Traffic Data Quality "TDQ" Final Report*, Transportation Pooled-Fund Study SPR-2 (182), no date, summary provided at <http://www.fhwa.dot.gov/policy/ohpi/tdep.htm>.

## REVIEW OF CURRENT PRACTICES

This section summarizes a review of the literature as well as a review of current ADMS practices. A literature search was conducted to identify relevant papers and reports on validity criteria. A survey of current practices was conducted of nine existing data archives.

### Literature Review

The literature review identified validity criteria that could be classified into the following general categories:

- **Univariate and multivariate range checks** – These criteria typically correspond to the minimum, maximum, or range of expected values for a single variable or combination of variables. These criteria are easy to automate in a database environment.
- **Spatial and temporal consistency** – These criteria evaluate the consistency of traffic data as compared to nearby locations (either across lanes, or upstream and downstream monitoring locations) or previous time periods. Automating these criteria in a database may require more effort but could likely yield more extensive reviews of data quality.
- **Detailed diagnostics** – These criteria require detailed diagnostic data from traffic detectors and typically can not be performed with the original source data that is collected and archived by traffic operations centers. Nevertheless, these criteria may be useful in diagnosing the cause(s) for poor data quality at specific detector locations.

#### *Univariate and multivariate range checks*

Nihan et al. (1990)<sup>6</sup> and Jacobson et al. (1990)<sup>7</sup> proposed validity criteria for single loop detectors as follows:

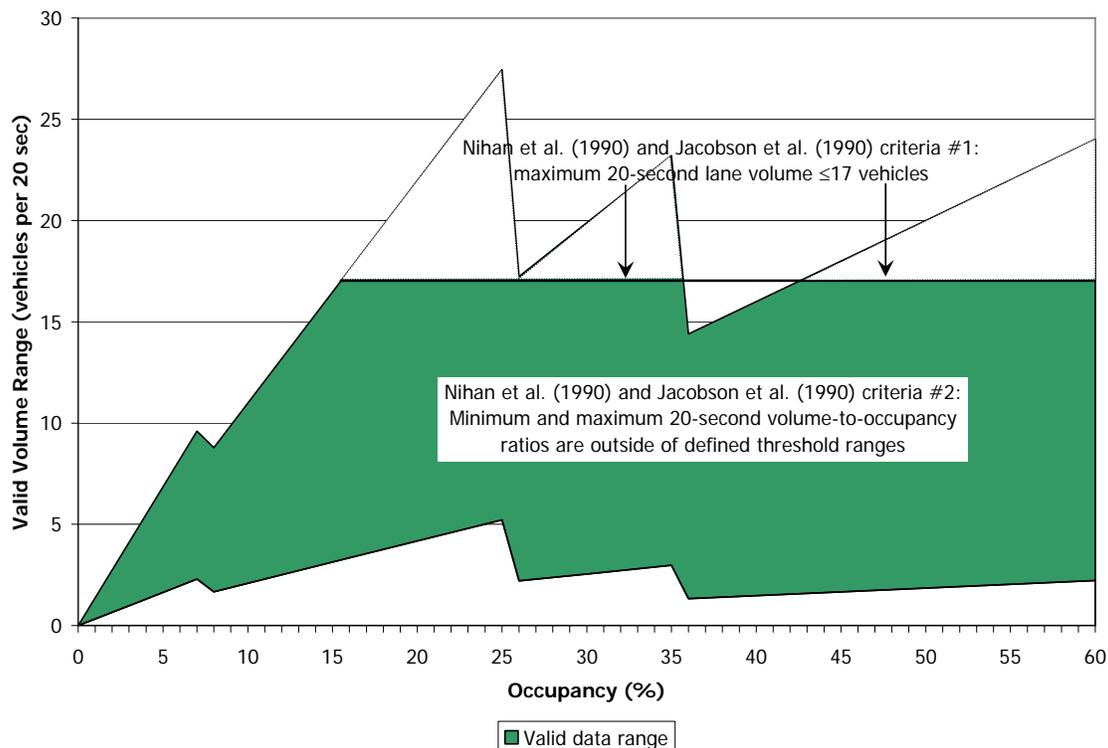
1. Maximum 20-second lane volume of 17 vehicles (3,060 vphpl) (see Figure 1);
2. Minimum and maximum 20-second volume-to-occupancy (v/o) ratios are outside of defined threshold ranges for four occupancy ranges (see Figure 1):
  - a. 0.1 to 7.9 percent occupancy: min v/o ratio=0.327, max v/o ratio=1.372;
  - b. 8.0 to 25.9 percent occupancy: min v/o ratio=0.209, max v/o ratio=1.098;
  - c. 26.0 to 35.9 percent occupancy: min v/o ratio=0.085, max v/o ratio=0.663; and,
  - d. >36.0 percent occupancy: min v/o ratio=0.037, max v/o ratio=0.400.
3. Minimum 20-second lane volume of 1 when 20-second occupancy is between 0 and 0.1 percent; and
4. Maximum 5-minute lane occupancy of 90 percent.

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<sup>6</sup> Nihan, N., L.N. Jacobson, J.D. Bender, and G. Davis. *Detector Data Validity*, Publication WA-RD 208.1, Washington State Department of Transportation, March 1990.

<sup>7</sup> Jacobson, L.N., N.L. Nihan, and J.D. Bender. Detecting Erroneous Loop Detector Data in a Freeway Traffic Management System. In *Transportation Research Record 1287*, Transportation Research Board, 1990, pp. 151-166.

**Figure 1. Illustration of Valid Data Ranges in Nihan et al. (1990) and Jacobson et al. (1990)**



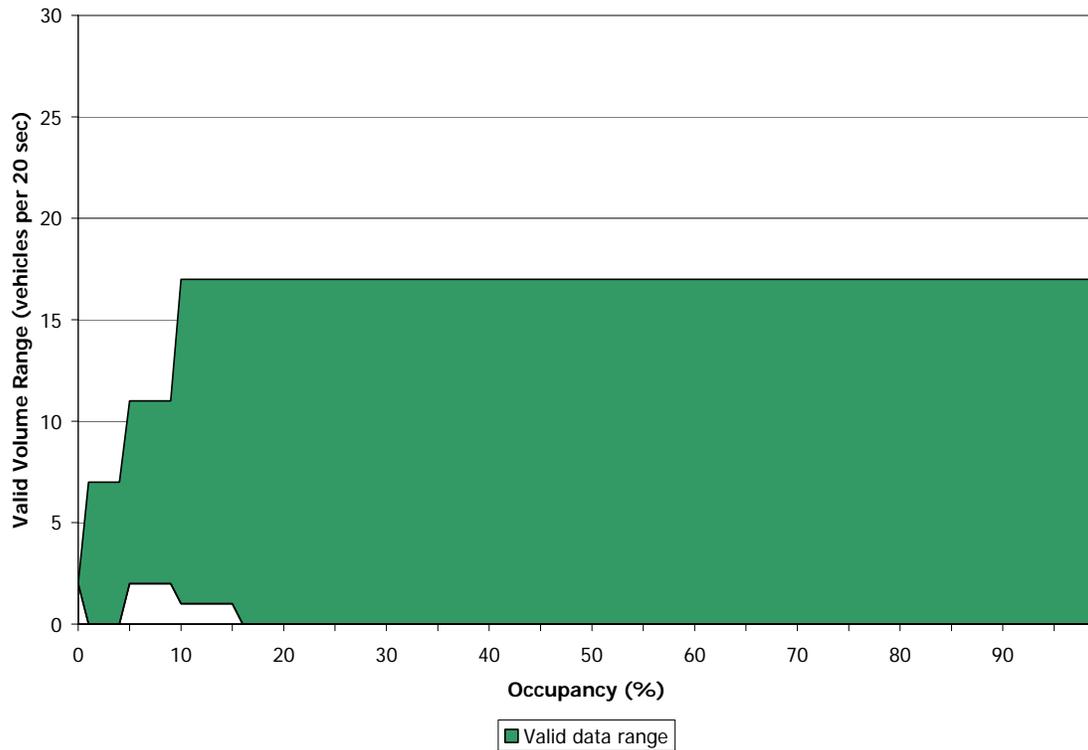
In software documentation for a CD-ROM based data archive (CDR), Ishimaru (1998)<sup>8</sup> describes acceptable volume-occupancy ranges for 20-second data from single loop detectors (Figure 2):

1. If  $OCC = 1\%$ , then  $VOLUME=2$  must occur;
2. If  $1\% < OCC \leq 5\%$ , then  $0 \leq VOLUME \leq 7$ ;
3. If  $5\% \leq OCC \leq 10\%$ , then  $2 \leq VOLUME \leq 11$ ;
4. If  $10\% \leq OCC \leq 16\%$ , then  $1 \leq VOLUME \leq 17$ ; and,
5. If  $OCC > 16\%$ , then  $0 \leq VOLUME \leq 17$ .

The CDR software described by Ishimaru manipulates 5-minute summary data and permits analysts to specify data acceptance thresholds for the maximum permitted number of 20-second records that were considered to be invalid by the above criteria.

<sup>8</sup> Ishimaru, J. M. *CDR User's Guide*, Washington State Transportation Center (TRAC), University of Washington, Seattle, WA, March 1998.

**Figure 2. Illustration of Valid Data Ranges in Ishimaru (1998)**



Turochy and Smith (2000)<sup>9</sup> used five criteria to identify invalid detector data from Hampton Roads, Virginia. Data were considered invalid if:

1. Occupancy > 95 percent;
2. Vehicle volumes > 17 vehicles per lane per 20-second interval (3,060 vphpl);
3. Positive traffic count with zero speed;
4. Vehicle volume is greater than calculated threshold for a reported occupancy of zero (due to occupancy rounding or truncation);
5. Minimum and maximum threshold for average effective vehicle length (AEVL), with values of 9 and 60 feet (2.7 and 18 meters) used as minimum and maximum thresholds for vehicle length. AEVL is calculated as the following:  $AEVL = (10 \times \text{speed [km/hr]} \times \text{occupancy [\%]}) / \text{equivalent hourly flow rate [vehicles per hour per lane, vphpl]}$ .

Hu et al. (2001)<sup>10</sup> and Schmoyer et al. (2001)<sup>11</sup> also used five criteria to identify invalid detector data from Long Island, New York and Orlando, Florida. Data were considered invalid if:

1. Five-minute traffic counts > 300 vehicles (or > 30 vehicles per 30-second period);

<sup>9</sup> Turochy, R.E. and B.L. Smith. A New Procedure for Detector Data Screening in Traffic Management Systems. In *Transportation Research Record 1727*, Transportation Research Board, 2000, pp. 127-131.

<sup>10</sup> Hu, P., R. Goeltz, and R. Schmoyer. *Proof of Concept of ITS as an Alternative Data Resource: A Demonstration Project of Florida and New York Data*, Publication ORNL/TM-2001.247, Federal Highway Administration, September 2001.

<sup>11</sup> Schmoyer, R., P.S. Hu, and R.T. Goeltz. Statistical Data Filtering and Aggregation to Hour Totals of Intelligent Transportation System 30-s and 5-min Vehicle Counts. In *Transportation Research Record 1769*, Transportation Research Board, 2001, pp. 79-86.

2. Traffic count < zero;
3. Number of consecutive identical non-zero traffic count values exceeds maximum threshold (variable based on Poisson probability);
4. Number of consecutive zero count traffic values exceeds maximum threshold (variable depending upon hour of day, ranges from 5 to 15 minute duration);
5. Change in traffic count values exceeds maximum threshold (variable based on Poisson probability), comparing each 30-second count to the 5-minute period before and after.

Chen et al. (2003)<sup>12</sup> describes a daily statistic algorithm that is used to identify erroneous data from single loop detectors in the California PeMS data archive. A daily score is computed for each unique loop detector and compared to a specified threshold that can be customized for different systems:

1. Number of 30-second samples that have OCC=0 (maximum threshold of 1,200 per day);
2. Number of 30-second samples that have OCC>0 and VOLUME=0 (maximum threshold of 50 per day);
3. Number of 30-second samples that have OCC>35% (maximum threshold of 200 per day); and,
4. Entropy of 30-second occupancy samples (minimum threshold of 4), which is defined as:

$$Entropy, E(x) = - \sum_{x, p(x)>0} p(x) \cdot \log(p(x)) \text{ where } p(x) \text{ gives the probability of any } x.^{13}$$

Turner et al. (2004)<sup>14</sup> used the following quality control checks to identify invalid data from nearly 30 cities in the Mobility Monitoring Program:

1. Controller error codes: remove numeric error code values (typically “-1” or “255”);
2. No vehicles present: replace zero speed values with null/missing speed values when VOLUME=OCC=SPEED=0;
3. Check for consistency of elapsed time between data polls;
4. Check for and remove duplicate records (location identifier, date and time stamp are identical);
5. Check for and remove date, time, and location identifier values that are not in the valid domain range;
6. Maximum volume (varies based on time interval, invalid if VOLUME>3000 vphpl as max rate);
7. Maximum occupancy (invalid if OCC>95% for 20-30 second periods, OCC>80% for 1-5 minute periods);
8. Minimum speed (invalid if SPEED<5 mph);

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<sup>12</sup> Chen, C., Kwon, J., Rice, J., Skabardonis, A., and Varaiya, P. Detecting Errors and Imputing Missing Data for Single-Loop Surveillance Systems. In *Transportation Research Record 1855*, Transportation Research Board, 2003, pp. 160-167.

<sup>13</sup> A low entropy value indicates that data values are not changing much over time (in PeMS, over the period of 24 hours). Originally implemented in PeMS, the entropy criterion has since been replaced with a “consecutive identical values” criterion. The consecutive identical values criterion was easier for traffic practitioners to understand, and it provided comparable results to the entropy criterion.

<sup>14</sup> Turner, S., R. Margiotta, and T. Lomax. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data*. Publication FHWA-HOP-05-018, Federal Highway Administration, December 2004. Available at <http://mobility.tamu.edu/mmp/FHWA-HOP-05-018/>. Accessed July 21, 2006.

9. Maximum speed (invalid if SPEED>100 mph for 20-30 second periods, SPEED>80 mph for 1-5 minute periods;
10. Multivariate consistency (invalid if SPEED=0 and VOLUME>0 [and OCC>0]);
11. Multivariate consistency (invalid if VOLUME=0 and SPEED>0);
12. Multivariate consistency (invalid if OCC>0 and SPEED=0 and VOLUME=0);
13. Truncated occupancy values of zero (invalid if OCC=0 and  $VOLUME > [(2.932 \times SPEED \times ELAPSED\_TIME) / 600]$ );
14. Maximum estimated density (invalid if density > 220 where  $density = [VOLUME \times (3600 / ELAPSED\_TIME) / SPEED]$ );
15. Consecutive identical volume, occupancy and speed values (invalid if more than 8 consecutive volume AND occupancy AND speed values are identical, including zero values).

Weijermars and Van Berkum (2006)<sup>15</sup> presented criteria that could be used to check traffic counts from loop detectors on signalized arterial streets. The criteria are based on maximum expected traffic flow, minimum expected traffic flow, and the principle of flow conservation.

### *Spatial consistency*

Chen and May (1987)<sup>16</sup> recommended comparing the average detector on-time against the average on-time for all lanes at that location/station. The recommended time sampling interval was five minutes and the allowable deviation for a particular lane from the station average was  $\pm 15$  percent.

Cleghorn et al. (1991)<sup>17</sup> presented several validity criteria for detector data on freeways:

1. An upper boundary line for volume and occupancy as indicated by the following equation:  $Volume = (occupancy \times maximum\ expected\ speed \times time\ interval) / (minimum\ expected\ vehicle\ length + detector\ length)$ .
2. Maximum difference in traffic counts between paired loop detectors should be two vehicles or less.
3. The maximum acceptable deviation from historical averages (varies based on number of standard deviations selected as acceptable).

Cleghorn et al. also indicated that several unusual combinations of volume, occupancy, and speed values may be possible due to the manner in which data are collected in small time intervals:

1. Records with small positive occupancy and zero volume could be caused by a vehicle signal that “bridges” across two different time polling intervals;

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<sup>15</sup> Weijermars, W.A.M. and E.C. van Berkum. Detection of Invalid Loop Detector Data in Urban Areas. Presented at the 85<sup>th</sup> Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.

<sup>16</sup> Chen, L. and A.D. May. Traffic Detector Errors and Diagnostics. In *Transportation Research Record 1132*, Transportation Research Board, 1987, pp. 82-93.

<sup>17</sup> Cleghorn, D., F. Hall, and D. Garbuion. Improved Data Screening Techniques for Freeway Traffic Management Systems, In *Transportation Research Record 1320*, Transportation Research Board, 1991, pp. 17-23.

2. Records with a zero occupancy and small positive volume could be caused if the occupancy values are reported as integer and the computer system truncates or rounds decimal places;
3. Records with valid volume and occupancy values but no speed values could be caused if the computer controller is unable to sort out vehicle arrivals between the two loops

Dailey (1993)<sup>18</sup> suggests and demonstrates three different methods to identify detector errors:

1. The correlation between volume and occupancy;
2. The correlation between data from adjoining lanes; and,
3. The correlation between time series from detectors along the path of traffic flow.

Nihan (1997)<sup>19</sup> recommends the use of storage rates between downstream and upstream detectors to identify data errors. The sum of the storage rate over several time intervals is calculated by taking the difference in vehicle volumes between upstream and downstream locations. A steadily increasing or decreasing storage rate indicates that one location is consistently over or under counting vehicles. The maximum storage rate for consecutive detectors can not exceed the number of vehicles at jam density.

Wall and Daily (2003)<sup>20</sup> describe a similar process of comparing traffic counts from reference stations to a target station to identify poorly calibrated detectors. The process relies on accurately identifying valid reference stations, and then determining the proper time lag by which to compare upstream and downstream locations. The authors also suggest the use of a correction factor based on the difference in traffic counts.

Kwon et al. (2004)<sup>21</sup> recommended automatic and semiautomatic statistical methods to detect spatial configuration errors in traffic detectors. The methods are based on the strong correlation between measurements made by spatially close detectors. The proposed automatic method uses a scoring scheme that computes the probability of detector mislabeling, whereas the semiautomatic method uses a multidimensional scaling (MDS) map of detectors, which visually displays the similarity between detector measurements.

Vanajakshi and Rilett (2004)<sup>22</sup> also recommended the principle of vehicle conservation be used to compare the vehicle counts from consecutive detector locations. Their paper suggested two criteria:

1. The difference between the cumulative volume at a downstream and an upstream detector should equal the number of vehicles between the downstream and upstream detectors; and,

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<sup>18</sup> Dailey, D.J. *Improved Error Detection for Inductive Loop Sensors*. Publication WA-RD 300.1, Washington State Department of Transportation, May 1993.

<sup>19</sup> Nihan, N. Aid to Determining Freeway Metering Rates and Detecting Loop Errors. In *Journal of Transportation Engineering*, November/December 1997, pp. 454-458.

<sup>20</sup> Wall, Z.R. and D.J. Daily. Algorithm for Detecting and Correcting Errors in Archived Traffic Data. In *Transportation Research Record 1855*, Transportation Research Board, 2003, pp. 183-190.

<sup>21</sup> Kwon, J., C. Chen, and P. Varaiya. Statistical Methods for Detecting Spatial Configuration Errors in Traffic Surveillance Sensors. In *Transportation Research Record 1870*, Transportation Research Board, 2004, pp. 124-132.

<sup>22</sup> Vanajakshi, L. and L.R. Rilett. Loop Detector Data Diagnostics Based on Conservation-of-Vehicles Principle. In *Transportation Research Record 1870*, Transportation Research Board, 2004, pp. 162-169.

2. The maximum difference between the downstream and upstream detector cumulative flows can not exceed the maximum number of vehicles that can be accommodated on the length of road between these two detectors at jam density.

Achillides and Bullock (2004)<sup>23</sup> describe a process used to evaluate the performance of microloop and radar-based traffic detectors. Most of their evaluation process relied on comparing the consistency of volume, lane occupancy, and speed measurements between closely spaced microloops and radar detectors. The authors also estimated AEVL as defined by Turochy and Smith (2000) using volume, occupancy, and speed data. AEVL values of 9 and 60 feet were used as minimum and maximum permissible ranges for vehicle length.

#### *Detailed diagnostic data*

There is several validity criteria in the literature that rely on detailed sensor output that are not typically available in archived traffic data. These criteria would be limited to specific locations where detailed sensor output can be obtained from the field controllers. For example, Coifman (1999)<sup>24</sup> recommended an off-line test that compares the matched individual vehicle on-time between the upstream and downstream loops in a loop detector pair, and suggested a possible on-line implementation as well. In later work, Coifman and Dhoorjaty (2004)<sup>25</sup> suggested eight off-line tests that rely on individual vehicle data. Five of the eight tests can be applied at single loop detectors, whereas all eight tests can be applied at loop detector pairs. The eight tests are as follows:

1. Individual vehicle velocity versus moving median velocity
2. Headway versus on-time
3. Feasible range of vehicle lengths
4. Feasible range of headway and on-time
5. Length differences and ratios at dual-loop detectors
6. Cumulative distribution of vehicle lengths
7. Loss of loop in dual-loop detector
8. Counting number of consecutive congested samples

Ameth et al. (2001)<sup>26</sup> suggested measuring individual vehicle lengths using detector on-time from both loop detectors in a detector pair, and then comparing the average measured effective vehicle length to a an acceptable range for average vehicle length.

#### *Miscellaneous*

In a dissertation, Buchheit (2002)<sup>27</sup> presents the following taxonomy for data errors and includes examples for weigh-in-motion data:

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<sup>23</sup> Achillides, C.D. and D.M. Bullock. *Performance Metrics for Freeway Sensors*, Final Report. Publication FHWA/IN/JTRP-2004/37, Federal Highway Administration, December 2004.

<sup>24</sup> Coifman, B. Using Dual Loop Speed Traps to Identify Detector Errors. In *Transportation Research Record 1683*, Transportation Research Board, 1999, pp. 47-58.

<sup>25</sup> Coifman, B. and S. Dhoorjaty. Event Data-Based Traffic Detector Validation Tests. In *Journal of Transportation Engineering*, May/June 2004, pp.313-321.

<sup>26</sup> Ametha, J., S. Turner, and S. Darbha. Formulation of a New Methodology to Identify Erroneous Paired Loop Detectors. *IEEE Intelligent Transportation Systems Proceedings*, 2001, pp. 591-596.

1. Systematic errors
  - a. Calibration
  - b. Threshold
  - c. Missing data
  - d. Extra data
2. Individual record errors
  - a. Missing records
  - b. Garbling errors
  - c. Duplications
  - d. Combinations

Aside from this taxonomy, no specific validity criteria were presented in this dissertation. Other errors that were not discussed in this dissertation but can exist include:

- Latency of data transmission;
- Communication line breaks/distortion; and,
- Lack/loss of synchronization with a system clock.

## Review of Current Practice

This section summarizes the use of validity criteria at nine data archives (Table 1) as of July 2006. Table 2 summarizes the validity criteria used in these archives' quality control processes, and the next several pages contain descriptions for each archive. The findings from the review of current practice are as follows.

- **The validity criteria are similar among the nine different data archives.** Six of the criteria in common are simple range checks (minimum and maximum values) for the most common freeway detector data collected (volume, occupancy, and speed). Other criteria that are common across many archives are those that relate to logical multivariate consistency. The similarities should not be too surprising considering the open sharing of validity criteria among data archive developers.
- **The validity criteria are less sophisticated and complex than those described in the literature.** These differences may be due to the need for easily-programmable criteria that requires limited computer processing time. Another factor may be that the criteria used in the literature were for "special studies" whereas the criteria in the nine data archives are used on a production basis.
- **Nearly all of the validity criteria are programmed on a simple pass/fail basis.** For example, if a data record fails a criterion, the data archive administrator typically does not manually or visually review the failed data in the context of other good data. This is most likely due to the large amount of data being processed and loaded into these data archives on a daily basis. Manual or visual review may be performed by users of the archived data when special studies are conducted using selected times and locations from the data archive.

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<sup>27</sup> Buchheit, R.B. *Vacuum: Automated Procedures for Assessing and Cleansing Civil Infrastructure Data*. Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA, May 2002.

- **Most of the validity criteria do not have a specified order or sequence.** The exceptions to this occur in two situations: 1) prescreening procedures are used to replace numeric error codes (e.g., 0, -1, 255) with null or missing values before validity criteria are applied; and 2) validity criteria are applied to disaggregate data first, then to aggregate data second.
- **It appears that all validity criteria are applied even if previous criteria indicate invalid data.** The documentation reviewed for this report did not indicate that the validity criteria checking were stopped once a criterion fails a particular data value. Instead, the data archives seem to apply all validity criteria regardless of previous criterion failures. One viewpoint suggests that further review is not necessary if a data value has already failed a validity criterion (as a technique to save computer processing time). However, the consistent application of all validity criteria may be important for identifying multiple data quality issues that are caused by separate and distinct problems.

**Table 1. Listing of Data Archives Surveyed**

<b>Data Archive</b>	<b>Maintaining Agency</b>	<b>Sponsoring Agency and Data Source(s)</b>
ADMS Virginia	University of Virginia	Virginia DOT
California PeMS (Performance Measurement System)	University of California-Berkeley/Berkeley Transportation Systems	Caltrans
CATT (Center for Advanced Transportation Technology) Lab	University of Maryland	Maryland State Highway Administration
Central Florida Data Warehouse	University of Central Florida	Florida DOT
FHWA Mobility Monitoring Program	Texas Transportation Institute and Cambridge Systematics, Inc.	Federal Highway Administration
Kentucky ADMS	University of Kentucky	Kentucky Transportation Cabinet
Phoenix RADS (Regional Archived Data Server)	Maricopa County DOT	Maricopa County DOT
PORTAL (Portland Oregon Regional Transportation Archive Listing)	Portland State University	Oregon DOT
WisTransPortal V-SPOC (Volume-Speed-Occupancy Suite)	University of Wisconsin	Wisconsin DOT



**Table 2. Summary of Validity Criteria in Nine Data Archives (Continued)**

Validity Criteria	ADMS VA	CA PeMS	MD CATT	Central FL	FHWA MMP	KY ADMS	Phoenix RADS	PORTAL (OR)	V-SPOC (WI)
If OCC=0 or OCC=1, then FLOW<580 vphpl									✓
If 1<OCC≤15, then 1<FLOW<1400									✓
If 15<OCC<25, then 180<FLOW<2000									✓
If OCC>25, then FLOW>500									✓
If OCC>25, then 0<SPD<80									✓
Minimum required daily data samples <sup>4</sup>		>60%							
Daily data samples where OCC > X% (default X=70%) <sup>4</sup>		>20%							
Daily data samples where VOL > X in 30-sec (default X=20veh) <sup>4</sup>		>20%							
Daily data samples with OCC=0 <sup>4</sup>		>59%							
Daily data samples with VOL=0 <sup>4</sup>		>95%							
Daily data samples with VOL=0 and OCC > X (default X=0%) <sup>4</sup>		>2%							
Daily data samples with consec. identical OCC values <sup>4</sup>		>50%							
Minimum entropy value <sup>5</sup>				<1					
Monthly detector samples where OCC <sub>max</sub> =0 <sup>6</sup>									✓
Monthly detector samples where OCC <sub>avg</sub> <4% <sup>6</sup>									✓

Abbreviations: VOL=volume, OCC= occupancy, SPD=speed, AEVL=average effective vehicle length, FLOW= hourly vehicle flow rate, in vehicle per hour per lane (vphpl)

Notes: <sup>1</sup> VOL<sub>max</sub> = [(2.932×SPEED×ELAPSED\_TIME)/600 – based on maximum possible volume when occupancy value is truncated to 0.

<sup>2</sup> AEVL = 10 × SPD (km/hr) × OCC (%) / hourly equivalent flow rate (vphpl).

<sup>3</sup> Density = [VOL ×(3600/ELAPSED\_TIME)/SPEED].

<sup>4</sup> These validity criteria identify a detector as invalid for the entire day.

<sup>5</sup> Entropy,  $E(x) = - \sum_{x, p(x)>0} p(x) \bullet \log(p(x))$  where  $p(x)$  gives the probability of any  $x$ .

<sup>6</sup> These validity criteria are used to generate monthly detector quality reports.

<sup>7</sup> If VOL=0 and SPD>0 and not equal to the previous speed value reported, then speed is invalid. If the speed value equals the previous speed value, then the value is kept but marked as “DoNotUseForCalculations.”

<sup>8</sup> If VOL=0 and OCC ≠ 0, then mark invalid. If VOL>[(OCC×3)+4], then the value is kept but marked “SuspectRecord”.

<sup>9</sup> Criteria applied only to mainline freeway stations.

<sup>10</sup> Criteria are applied only to data measured from 5 am to 10 pm.

<sup>11</sup> Criteria applied to data at 30-second time intervals.

<sup>12</sup> Criteria applied to data at 5-minute time intervals.

<sup>13</sup> Criteria applied to 20-second and 30-second data.

<sup>14</sup> Criteria applied to 1-minute, 5-minute, and 15-minute data.

Prior to 2006, the University of Virginia’s Smart Travel Laboratory used validity criteria in ADMS Virginia that were based mostly on work described in Turochy and Smith (2000). Empirical data analyses conducted since then have resulted in refined criteria as described below and in separate documentation.<sup>28</sup>

**Table 3. Real-Time Screening Tests Recommended For Northern Virginia (NOVA) Smart Traffic Center (STC) Detector Data**

Test Name	Reason and details
A note on error code	<ul style="list-style-type: none"> <li>• If either of volume or speed or occupancy is 255, the record is a suspect and is failed. It should be noted that this error code is much above the acceptable upper limit values for all the three traffic variables, and would automatically be failed in the individual thresholds.</li> <li>• This is not a test. Only a note.</li> <li>• Reference: Turner et al. (2004); and discussion with the NOVA STC staff</li> </ul>
A note on VOS=000	<ul style="list-style-type: none"> <li>• Volume,Occupancy,Speed(VOS)=0,0,0 is legitimately possible data. So, we recommend passing such records, when evaluated in real-time. Since it is never failed in real-time, this is not a test.</li> <li>• This is not a test. Only a note.</li> <li>• Reference: Discussion with the NOVA STC staff</li> </ul>
No input data available	<ul style="list-style-type: none"> <li>• When studying data for long periods of time, only two cases of detector data have been found:               <ul style="list-style-type: none"> <li>○ The detector data are present in the input data stream. In this case, values for all three traffic quantities (volume, occupancy, speed) are present as numbers. In this case, the record shall be subjected further to the screening tests described below.</li> <li>○ The detector data are completely absent from the input data stream. This is interpreted and inserted in the database archive as V=NULL and O=NULL and S=NULL. There are two possible reasons for missing detector data: there is no data for that particular time interval or that particular detector is missing from the data stream. In this case, if V=NULL and O=NULL and S=NULL, the record shall be failed directly and shall not be subjected to any more screening tests.</li> </ul> </li> </ul>
<b>Test 1</b> Volume Thresholds <b>Position 0</b>	<ul style="list-style-type: none"> <li>• If the volume &gt; 52, then the record shall be failed. A 1-minute detector volume of 52 is equivalent to 52*60=3120 vehicles per hour per lane, which is suspiciously high in almost all the cases.</li> <li>• If the volume is negative (i.e. &lt; 0), the record shall be failed.</li> <li>• Reference: Turner et al. (2004) and Turochy and Smith (2000).</li> </ul>
<b>Test 2</b> Occupancy Thresholds <b>Position 1</b>	<ul style="list-style-type: none"> <li>• If the lane is not reversible high-occupancy vehicle (RHOV) and not entrance or exist ramp, and occupancy &gt; 100, the record shall be failed.</li> <li>• If the lane is on an entrance or exit ramp and occupancy &gt;100, the record shall be failed.</li> <li>• If the lane is RHOV and the occupancy is between 100 and 127 (i.e. &gt; 100 and &lt;= 127), the record shall be failed. If occupancy &gt; 228, the record shall be failed. If the occupancy is between 128 and 228 (&gt;= 128 and &lt;= 228), then a value of 128 shall be subtracted from the occupancy, and the record shall be passed. If a value of 128 is subtracted from the occupancy this situation will be marked with a “RhovOccChanged” code and the record shall not be failed. This operation is performed to account for an artifact observed with the data stream over a long time.</li> </ul>

<sup>28</sup> Validity criteria and other documentation for ADMS Virginia are available at [http://cts.virginia.edu/nv\\_staflo.htm](http://cts.virginia.edu/nv_staflo.htm) for Northern VA data and [http://cts.virginia.edu/hr\\_stflw.htm](http://cts.virginia.edu/hr_stflw.htm) for Hampton Roads data.

Test Name	Reason and details
	<ul style="list-style-type: none"> <li>If the occupancy is negative (i.e. &lt; 0), the record shall be failed (this lower threshold is irrespective of the lane type).</li> <li>Reference: Turner et al. (2004) and discussion with the NOVA STC staff</li> </ul>
<b>Test 3</b> Speed Thresholds <b>Position 2</b>	<ul style="list-style-type: none"> <li>If the speed &gt; upper threshold (120 mph), the record shall be failed.</li> <li>If the speed is negative (i.e. &lt; 0), the record shall be failed.</li> <li>Reference: Turner et al. (2004) and Turochy and Smith (2000).</li> <li>Note: From Turner et al’s reference, speeds between 0-5 mph were tested for failing. A number of records were found with reasonable volume patterns in this speed range. Further, some accidents with corresponding changes in occupancy were also found in this speed range. For this reason, this test is eliminated.</li> </ul>
<b>Test 4</b> (VS relation) Positive speed with zero volume (V=0, S>0) OR Positive volume with zero/no speed (V>0, and S=0) <b>Position 3</b>	<ul style="list-style-type: none"> <li>If the volume is zero and the speed is positive, then: <ul style="list-style-type: none"> <li>If the speed is equal to the speed from the most recent record for which volume was positive and speed was positive and equal to the speeds from all the records between this one and the most recent record with a positive volume and positive speed, then this record shall also be passed. In this case, the record shall be marked with a distinct code of “DoNotUseForCalculations”, but shall not be failed. This is irrespective of whether the record with the most recent positive volume and positive speed was failed because of other reasons (like for ex. by the VO test).</li> <li>If the speed is not equal to the previous record, this record shall be failed.</li> </ul> </li> <li>This is an artifact of many NOVA controllers. If V=0, the controller outputs the S from the previous record. Although this case is construed as S=0, the field data shall not be modified.</li> <li>If volume is positive and speed is zero, the record shall be passed, irrespective of the detector type (single loop, double loop, RTMS, acoustic).</li> <li>Reference: Turner et al. (2004) and discussion with the NOVA STC staff</li> </ul>
<b>Test 5</b> (VO relation) <b>Position 4</b>	<ul style="list-style-type: none"> <li>If the Volume = 0, and Occupancy is not 0, then the record shall be failed.</li> <li>If <math>V &gt; O * 3 + 4</math>, record shall be marked with a “SuspectRecord” code, but shall not be failed.</li> <li>Reference: Adapted from Jacobson et al. (2000) and empirical data analyses.</li> <li>Note: A test (If the Volume &gt; 5, and Occupancy = 0, then the record shall be failed) was originally designed, and then tested. A number of detector records were found having reasonable volume patterns, but with occupancy=0. So, this test has been eliminated.</li> </ul>
<b>Test 6</b> (VOS relation) AEVL (Average Effective Vehicle Length) <b>Position 5</b>	<ul style="list-style-type: none"> <li>If volume, occupancy and speed are all positive numbers, then consider</li> <li>AEVL = <math>10 * S * O / V</math> where <ul style="list-style-type: none"> <li>AEVL = Average Effective Vehicle Length (meters)</li> <li>S = speed (km/h)</li> <li>O = occupancy (%)</li> <li>V = hourly equivalent volume (vehicles/lane/hour)</li> </ul> </li> <li>The record shall be marked with a “SuspectRecord” code if <math>AEVL &lt; 2.2</math> or <math>AEVL &gt; 18</math> and shall not be failed. If <math>2.2 \leq AEVL \leq 18</math>, the record shall be passed.</li> <li>If any of volume, occupancy, speed is zero, then this test is not applicable and the situation shall be marked by “AEVLNotApplicable” code and shall not be failed.</li> <li>Reference: Turochy and Smith ( 2000)</li> </ul>
<b>Not a test</b> Data estimation <b>Position 6</b>	<p>There is no temporal aggregation for NOVA detector data. The detector data are not estimated before being inserted in the archive. This is reserved for traffic data from other regions where there is temporal aggregation for detector data. All NOVA detector data records shall be marked with a “DataNotInflated” code in this position and shall not be failed.</p>

**Table 4. Batch Screening Tests Recommended For Northern VA Detector Data**

Test Name	Reason and details
VOS=000 Or VS=0? Or VOS=NULL  <b>Position 7</b>	VOS=000 could be legitimate traffic data, or could be due to errors in the detection system (such as power, communication, hardware or software failure). The potential error can be identified only with the context of the surrounding time periods. The following are the various cases for treating VOS=000 data: <ul style="list-style-type: none"> <li>• Ramps may often have low flow conditions and should never be failed under this test.</li> <li>• It has been noted that more than 2 hours can pass without a single vehicle on a detector. When this happens, the controller locks up, and needs to be reset by the maintenance personnel. This scenario occurs mainly during nights i.e. very low flow conditions. Between 10:00 PM and 5:00 AM, the general purpose Norm and HOV Norm lane detectors shall be tested thus: If records for 120 or more consecutive minutes have VOS=000, then the records beyond the first 120 minutes shall be failed. The records for the first 120 minutes shall be passed as reasonable.</li> <li>• Between 5:00 AM and 10:00 PM, for general purpose Norm and HOV lane detectors, if records for 10 or more consecutive minutes display a pattern of VOS=000 or VOS=00&lt;constant&gt;, then all of them shall be failed. For this test, all the patterns shall be treated on par. i.e., if 3 records are VOS=00&lt;constant&gt; and 7 exhibit VOS=000, then all the records for all 10 minutes shall be failed.</li> <li>• For RHOV and other restricted lanes, VOS=000 is the expected pattern during the periods when vehicles are not legally allowed to use those lanes and those records shall be passed. Between 5:00 AM and 10:00 PM, AND during the periods when vehicles are legally allowed to use these lanes, if records for 10 or more consecutive minutes display the pattern of VOS=000 or VOS=00&lt;constant&gt;, then all of them shall be failed.</li> </ul> Reference: Adapted from Chen et al. (2003), discussion with the NOVA STC staff, and empirical data analyses.
Stuck detector  <b>Position 8</b>	<ul style="list-style-type: none"> <li>• If records for 8 or more consecutive minutes have the same values for VOS (other than 000 or 00&lt;constant&gt;), all of them shall be failed.</li> <li>• Reference: Turner et al. (2004), discussion with the NOVA STC staff, and empirical data analyses.</li> </ul>
Speed threshold  <b>Position 9</b>	<ul style="list-style-type: none"> <li>• Between 5:00 AM and 10:00 PM, if 5 or more consecutive records have speeds &gt; higher threshold (say, 85 mph), and non-zero volumes, all the records shall be failed.</li> <li>• Reference: Turner et al. (2004), discussion with the NOVA STC staff, and empirical data analyses.</li> </ul>

Note: In this table, “Position X” refers to the position of the explanatory metadata code in a character string that is stored to document quality control results.

Some detectors are known not to give data or to give unreasonable data for legitimate reasons (like under construction or milled out). This is stored separately and can be combined with the results of the screening tests to completely assess the quality of the data from a particular detector or the overall data quality for a larger geographical area. All detectors are considered in the screening above, irrespective of their “active” or “not active” status.

**Spatial aggregation from detectors to station.** Station data are obtained by aggregating the detector data for each time stamp. Only stations for which all constituent detectors are “active” are considered in the aggregation. If a station has at least one “not active” detector, then no data are generated for that station. The detector volumes are added to get the station volume, the station speed is the volume-weighted average of the detector speeds, and the station occupancy is the simple average of the detector occupancy. The station volume is extrapolated if only few of the constituent detectors return data. If the VOS for all the constituent detectors are suspect or

missing, then the station data record for that time stamp shall be left as NULL. Only the reasonable, non-failed detector data records are considered in calculating the station data.

If all the constituent detectors of a station have VOS=000, and they pass the screening tests, then the station record shall be stored as VO=00 and S=NULL.

If all the constituent detectors of a station have V=0 and S>0, and they pass the screening tests, then the station record shall be stored as V=0 and S=NULL.

**Real-time screening tests recommended for Northern Virginia station data.** The station records are obtained by linear combination of the reasonable detector records. The station records are therefore not prone to the threshold errors as the raw detector data, and therefore need not be subjected to those tests. However, the AEVL value is not a linear combination of volume, occupancy or speed and thus not guaranteed to pass at the station level even if it passed at the detector level. The AEVL test shall therefore be performed again at the station level.

**Table 5. Batch Screening Tests Recommended For Northern VA Station Data**

Test Name	Reason and details
<b>Test 1</b>  No input data available  <b>Position 0</b>	If V=NULL and O=NULL and S=NULL, the record shall be failed.
<b>Test 2</b>  (VOS relation) AEVL (Average Effective Vehicle Length)  <b>Position 1</b>	<ul style="list-style-type: none"> <li>• If volume, occupancy and speed are all positive numbers, then consider</li> <li>• <math>AEVL = 10 * u * h / q</math> where                  AEVL = Average Effective Vehicle Length (meters)                  u = speed (km/h)                  h = occupancy (%)                  q = hourly equivalent volume (vehicles/lane/hour)</li> <li>• The record shall be marked with a “SuspectRecord” code if <math>AEVL &lt; 2.2</math> or <math>AEVL &gt; 18</math> and shall not be failed. If <math>2.2 \leq AEVL \leq 18</math>, the record shall be passed.</li> <li>• If any of volume, occupancy, speed is zero, then this test is not applicable and the situation shall be marked by “AEVLNotApplicable” code and shall not be failed.</li> <li>• Reference: Turochy and Smith (2000)</li> </ul>
<b>Not a test</b>  Data estimation  <b>Position 2</b>	<ul style="list-style-type: none"> <li>• If not all the data from the constituent detectors pass the detector screening tests, the station shall be marked with a code of “DataInflated” and shall not be failed.</li> <li>• If all the detector of the constituent detector return data that passes the detector screening tests, the station shall be marked with a code of “DataNotInflated” and shall not be failed.</li> </ul>

**Batch screening tests recommended for NOVA station data.** Further, the detector records may be failed in batch mode, even though they are passed in real-time. Therefore, the station data shall be calculated again, after the batch screening of detector data, and the station level Data Estimation code shall be recomputed and AEVL test at the station level shall be performed again.

**Table 6. Codes Used To Explain Screening Tests**

<b>Code</b>	<b>Value</b>
Reasonable/feasible data (test passed)	1
Unreasonable/unfeasible data (test failed)	0
SuspectRecord	8
DoNotUseForCalculations	9
AEVLNotApplicable	2
DataInflated	2
DataNotInflated	3
RhovOccChanged	2

*California PeMS (Performance Measurement System)*

The California PeMS statewide data warehouse includes data from nine different Caltrans districts and is the most extensive data archive surveyed for this report. The PeMS quality control procedures are unique, in that the diagnostic tests include both microscopic and macroscopic data validity rules. The microscopic validity rules are similar to those used in other data archives:

1. Vehicle flow: valid if  $0 \leq \text{flow} \leq 260$  vehicles/5-minutes
2. Occupancy: valid if  $0 \leq \text{flow} \leq 100\%$
3. Speed: valid if  $0 \leq \text{flow} \leq 100$  mph

The macroscopic rules used in PeMS are focused on identifying detectors that are likely to have been malfunctioning for most of the day. These diagnostic tests are unique because they focus on identifying malfunctioning detectors rather than identifying erroneous data samples. The underlying principle for this approach is that each detector is fundamentally either working or broken. Each night PeMS examines the individual raw data samples over a configurable hour range throughout the day (the default hour range is 5:00am through 10:00pm). Table 7 lists the statistics gathered for mainlane (ML) and ramp (RM, flow data only) detectors.

**Table 7. PeMS Macroscopic Diagnostic Statistics**

<b>Statistic</b>	<b>Detector Types</b>	<b>Description</b>
diag_samples	ML, RM	Total number of samples received.
high_occ	ML	Total number of samples with occupancy greater than a user-defined threshold (default=70%).
high_flow	RM	Total number of samples with flow greater than a user-defined threshold (default=20veh/30-sec).
zero_occ	ML	Total number of samples with occupancy equal to 0.
zero_flow	RM	Total number of samples with flow equal to 0.
flow_occ_mismatch	ML	Total number of samples with occupancy greater than a user-defined threshold (default=0%) and zero flow.
repeat_occ	ML	The number of contiguous five-minute points with the same occupancy. This is the only test that operates on processed five-minute data. Imputed points are excluded from this test.

The sample counts are then compared against user-defined thresholds to determine if the detector is functioning correctly. Table 8 summarizes the thresholds and their default values, which are based on heavy traffic in urban areas. These default threshold values have been modified when PeMS has been used to warehouse rural traffic data.

**Table 8. PeMS Default Threshold Values for Macroscopic Diagnostic Tests**

<b>Threshold</b>	<b>Detector Types</b>	<b>Default Setting</b>	<b>Description</b>
sample_pct	ML, RM	60	Minimum amount of data needed for data quality tests.
high_occ_pct	ML	20	Percentage of samples with occupancy higher than sig_occ for the high_occ test.
high_flow_pct	RM	20	Percentage of samples with flow higher than sig_flow for the high_flow test.
zero_occ_pct	ML	59	Percentage of samples with zero occupancy for zero_occ test.
zero_flow_pct	RM	95	Percentage of samples with zero flow for the zero_flow test.
flow_occ_pct	RM	2	Percentage of samples with flow/occ mismatch for the flow_occ_mismatch tests.
repeat_occ	ML	50	Percentage of five-minute points for repeat_occ test.

Thresholds expressed as a percentage in Table 8 are normalized using the following equation.

$$\text{Normalized Threshold} = (\% \text{ threshold} / 100) \times \max(\text{samples received})$$

The thresholds are normalized so that if the data feed fails for an hour during the day, the PeMS diagnostics will not penalize all of the other detectors. After normalizing the thresholds, PeMS applies the tests in Table 9 in the order listed. If a detector's statistics meet the test condition, PeMS marks the detector as bad and records the suspected error condition. If all tests succeed, the detector is marked as good.

**Table 9. PeMS Macroscopic Diagnostic Tests**

Test	Detector Types	Suspected Error
Diag_samples=0	ML, RM	Communication down
Diag_samples < sample_pct	ML, RM	Insufficient data
High_occ > high_occ_pct	ML	High values
High_flow > high_flow_pct	RM	High values
Zero_occ > zero_occ_pct	ML	Card off
Zero_flow > zero_flow_pct	RM	Card off
Flow_occ_mismatch > flow_occ_pct	ML	Intermittent
Repeat_occ > repeat_occ (threshold)	ML	Constant

*CATT (Center for Advanced Transportation Technology) Lab*

The CATT Lab is in the process of developing a comprehensive transportation data archive for the Washington DC metropolitan area and the state of Maryland. This expanded archive will include enhancements to data validation tools and criteria.

In the current data archive that includes detector data from CHART, the quality control process has two stages:

1. With each data packet, the CHART detectors also report status with the following possible messages:
  - a. Operating Correctly
  - b. Communications Failure
  - c. Unknown Problem
  - d. Offline
  - e. Hardware Failure
2. For those detectors that are “Operating Correctly,” the subsequent data are compared to the 15 validity criteria used in the FHWA’s Mobility Monitoring Program (see Turner et al. (2004) in the literature review).

*Central Florida Data Warehouse*

The University of Central Florida developed validity criteria to be used at several different temporal levels in the Central Florida Data Warehouse:

30-second criteria

1. Data invalid if zero flow and non-zero speed
2. Data invalid if non-zero flow and zero speed
3. Data invalid if zero flow and speed, non-zero occupancy
4. Data invalid if speeds greater than 100 mph
5. Data invalid if occupancies greater than 100%
6. Data invalid if flows greater than 25 vehicles (3,000 vphpl)

5-minute criteria

1. Data invalid if average vehicle length is less than 10 feet or greater than 60 feet

### 24-hour criteria

1. Data invalid if entropy of variables is less than 1 (where entropy is defined below)

$$\text{Entropy, } E(x) = - \sum_{x, p(x)>0} p(x) \bullet \log(p(x)) \text{ where } p(x) \text{ gives the probability of any } x.$$

### *FHWA Mobility Monitoring Program*

Turner et al. (2004)<sup>14</sup> documented the 15 validity criteria used for FHWA's Mobility Monitoring Program, in which the Texas Transportation Institute and Cambridge Systematics currently compile and analyze archived traffic data from freeway detectors for congestion reporting purposes. The Program has gathered archived data from more than 30 cities. These validity criteria were presented in the literature review.

When performing more detailed data analyses in specific cities, TTI researchers also manually review various summary charts for data consistency (in addition to the automated criteria described earlier). These summary charts typically include:

- Daily total traffic counts by lane/location;
- Average 15-minute or 60-minute traffic count or speed profiles by time of day and lane/location (sometimes on the same chart);
- Speed-flow relationship for all data points, by lane/location.

Manual or visual reviews of archived data are sometimes considered impractical when processing archived data for multiple cities in a "production" environment. Manual or visual reviews of average trends by location are more feasible when doing special studies for a limited number of cities and shorter time periods. These manual or visual reviews may identify calibration or other data quality issues that may not be detected by automated validity criteria.

### *Kentucky ADMS*

The University of Kentucky is developing the Kentucky ADMS as a statewide data warehouse similar to PeMS and ADMS Virginia. This data warehouse is under development, but is planning to include freeway detector data from the ARTIMIS center in Cincinnati/Northern Kentucky and the TRIMARC center in Louisville/Southern Indiana. Preliminary design documents for the Kentucky ADMS indicate that their validity criteria will be adapted from the criteria used in the Mobility Monitoring Program (see page 7), with the exception that the maximum estimated density rule will not be used.

### *Phoenix RADS (Regional Archived Data Server)*

The Maricopa County DOT is developing the RADS to be a regional data clearinghouse for the Phoenix metropolitan area. This regional data archive is under development, but is planning to use validity criteria that have been adapted from the criteria used in the Mobility Monitoring Program (see page 7), with the following two additions:

- Volume counts invalid if greater than a configured minimum; and,
- Occupancy values invalid if greater than a configured minimum.

*PORTAL (Portland Oregon Regional Transportation Archive Listing)*

The PORTAL system has adapted several of the validity criteria used in the Mobility Monitoring Program; however, the system developers have created conditions and thresholds for the purposes of identifying the worst malfunctioning detectors. The PORTAL system uses the criteria (consisting of conditions and thresholds) shown in Table 10 for 20-second original source data. Data quality reports are currently sent to the Oregon DOT on a monthly basis. These reports indicate the detectors which have failed the “High” threshold over the past month.

**Table 10. Detector Configuration Tests in PORTAL Data Archive**

Condition	Threshold		
	Low	Medium	High
Count > 17	0.2% of samples	0.3% of samples	1% of samples
Occupancy > 95%	0.25% of samples	0.5% of samples	5% of samples
Speed > 100 mph	0.5% of samples	1% of samples	5% of samples
Speed < 5 mph	5% of samples	10% of samples	30% of samples
Low max occupancy	Max occ < 25	Max occ < 20	Max occ = 0
Low average occupancy peaks	Avg occ < 6%	Avg occ < 5%	Avg occ < 4%

*WisTransPortal*

The Wisconsin Traffic Operations and Safety (TOPS) Laboratory *WisTransPortal Data Hub* contains a complete archive of 5-minute traffic detector data from the Wisconsin DOT (WisDOT) Advanced Traffic Management System (ATMS). The WisTransPortal, located at the University of Wisconsin-Madison, is being developed in coordination with WisDOT Bureau of Highway Operations to support a variety of traffic operations and safety data clearinghouse and analysis applications.

The V-SPOC (Volume, Speed, and Occupancy) Application Suite was developed as a component of the WisTransPortal to provide online tools to retrieve and analyze traffic detector data from the ATMS data archive. The V-SPOC application provides access to traffic data from nearly 4,000 freeway detectors in the Milwaukee, Madison, and Wausau metropolitan regions.

The V-SPOC application provides a “Quality Assurance Report” which includes a “pre-screen test” that is used to identify invalid data based on range checking and a “data quality” report which flags missing or repeating values. The pre-screen test applies the following validity criteria to identify invalid 5-minute data:

1. Invalid if volume, occupancy or speed is negative.
2. Invalid if volume > 3100 or occupancy > 100
3. Invalid if (occupancy = 0 or occupancy = 1) and volume > 580
4. Invalid if  $1 < \text{occupancy} \leq 15$  and (volume = 0 or volume > 1,400)
5. Invalid if  $15 < \text{occupancy} < 25$  and (volume < 180 or volume > 2000)
6. Invalid if occupancy > 25 and volume < 500
7. Invalid if occupancy > 25 and speed > 80 mph

The data quality report includes the following columns:

- Detector ID
- Time Interval
- Average Volume (VPH)
- Average Speed (MPH)
- Average Occupancy (%)
- Maximum Volume (VPH)
- Maximum Speed (MPH)
- Maximum Occupancy (%)
- Percentage of null values for Volume
- Percentage of null values for Speed
- Percentage of null values for Occupancy
- Percentage of zero values for Volume
- Percentage of zero values for Speed
- Percentage of zero values for Occupancy
- Percentage of repeating values for Volume
- Percentage of repeating values for Speed
- Percentage of repeating values for Occupancy
- Percentage of simultaneous null values for Volume, Speed, Occupancy
- Percentage of simultaneous zero values for Volume, Speed, Occupancy
- Percentage of simultaneous repeating values for Volume, Speed, Occupancy

For the “percentage of repeating values” criteria, the reports are based on 5-minute detector values that have been repeating for at least four consecutive periods (20 minutes). In contrast, the “percentage of null values” and “percentage of zero values” are based on a simple count of all occurrences. The Quality Assurance Report is not fixed to any particular set of detectors or time interval. Rather, it is applied to a given user selection of detectors and time intervals and reports on the individual detectors and time intervals as well as aggregate results taken over the set of detectors and time intervals.

In 2006, TOPS Lab began sending an automatic daily email to the State Traffic Operations Center and others that summarizes the status of the detector data archive from the previous day. This daily status report categorizes data quality into one of three categories, in which the sum of these always equal 100 percent:

1. percent data missing (null);
2. percent data repeating, and,
3. percent data available.

The daily email is part of a longer-term development to enhance V-SPOC with automated reporting tools that will help identify and rank data quality issues in the detector database. In addition to basic range checking, it is expected that the new tools will make use of detector status and other ATMS logging information that is stored in the WisTransPortal but is not currently available through V-SPOC.

## RECOMMENDATIONS FOR QUALITY CONTROL PROCEDURES

This section provides the following recommendations for quality control procedures as they relate to archived operations data:

- Recognize that validity criteria (i.e., quality control) are only one part of a comprehensive quality assurance process that does more than just discard suspect data that have already been collected.
- Provide metadata to document quality control procedures and results.
- Provide metadata to document historical traffic sensor status and configuration
- Use database flags or codes to indicate failed validity criteria.
- At a minimum, implement basic foundation for data validity criteria.
- Further develop other spatial and temporal consistency criteria for ADMS.
- When feasible, use visual review to supplement the automated validity criteria.

### **Recognize that quality control is one part of quality assurance**

“Quality control” and “quality assurance” are often used interchangeably to mean the same thing. The term “quality control” has been used in this report to describe the process of reviewing and manipulating data that have already been collected. However, one should recognize that data quality actions restricted to removing suspect data that have already been collected (referred to as “scrap-and-rework”) are ineffective in the long-term because they address the symptom but not the root cause of poor data quality.

This distinction in terms is highlighted here because some data archives may be focused primarily on quality control, such as reviewing and editing traffic data that have already been collected. However, total quality management principles indicate that process efficiency and customer satisfaction are most cost-effectively met when quality is considered in all steps of a product cycle. This means that if data archives are to meet customer’s needs, data quality must be considered in all steps of the traffic monitoring system. Quality assurance refers to these various quality considerations that are made throughout the traffic data collection and archiving cycle. In several cities, for example, transportation planners have worked with the traffic operations personnel to designate selected detector locations for priority maintenance. Other examples of quality assurance actions are discussed in AASHTO’s *Guidelines for Traffic Data Programs* update in 2007.

In some cases, users or managers of archived data may have little or no direct control over quality assurance processes other than quality control. For example, planning groups that wish to use archived data may currently have little to no input on procuring and testing operations-based traffic sensors. At the same time, though, users of archived data should recognize that long-term improvements to poor data quality can only be made by moving toward a position that influences how real-time traffic data are collected and archived.

## Provide metadata to document quality control procedures and results

This report recommends that ADMS provide adequate metadata to document quality control procedures and results. Metadata are “data about data” and typically describes the content, quality, lineage, organization, availability, and other characteristics of the data. Metadata are typically used to:

1. Determine the availability of certain data (for example, through searches of a data catalog or clearinghouse);
2. Determine the fitness of data for an intended use;
3. Determine the means of accessing data; and,
4. Enhance data analysis and interpretation by better understanding the data collection and processing procedures.

An ADMS metadata standard, ASTM E2468-05<sup>29</sup> was published in 2005 for the purpose of providing a standard framework for ADMS documentation, including quality control procedures. The framework standardized in ASTM E2468-05 includes qualitative and quantitative data that are associated with an information system or information object for the purposes of description, administration, legal requirements, technical functionality, use and usage, and preservation. As such, this type of metadata can be differentiated from other metadata in that it describes and provides an interpretation of an organized collection of data, not a single data element. For example, ASTM E2468-05 includes a section titled “Data Quality Information,” within which there are the following subsections:

- 2.1 **Attribute Accuracy** – An assessment of the accuracy of attributes within a data archive (contains several subsections);
- 2.2 **Logical Consistency** – An explanation of the fidelity of relationships in the data set and tests used.
- 2.3 **Completeness Report** – Information about omissions, selection criteria, generalization, definitions used, and other rules used to derive the data set.
- 2.4 **Positional Accuracy** – An assessment of the accuracy of the positions of spatial objects (contains several subsections, may not be applicable).
- 2.5 **Lineage** – Information about the events, parameters, and source data which constructed the data set, and information about the responsible parties (contains several subsections).
- 2.6 **Cloud Cover** – Area of a data set obstructed by clouds, expressed as a percentage of the spatial extent (may not be applicable).

This metadata standard was adapted from a geographic information system (GIS) metadata standard developed by the Federal Geographic Data Committee (FGDC); thus, some of the sections (e.g., cloud cover) may be not applicable to archived traffic data.

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<sup>29</sup> ASTM E2468-05, *Standard Practice for Metadata to Support Archived Data Management Systems*, available from ASTM International at <http://www.astm.org>.

Another ASTM standard under development (work item WK7604) for ADMS will include metadata for specific traffic monitoring data elements. For example, this standard will provide data definitions for quality control flags within ADMS. This standard will also likely provide data definitions for the number of data samples within summary statistics. For example, traffic operations data are often collected in short time intervals (e.g., 20 seconds to 1 minute) and aggregated to longer time intervals (e.g., 5 to 15 minutes) when loaded into an ADMS. There may be occasional interruptions in the operations data feed, which results in missing data samples. Therefore, it is important to document the number of data samples that have been used to calculate summary statistics. If any adjustments have been made to summary statistics based on missing data samples (i.e., factoring up traffic counts to account for missing data samples), this should be clearly documented or represented in the ADMS.

### **Provide metadata to document historical traffic sensor status and configuration**

In many real-time traffic monitoring systems, the configuration of point-based traffic sensors is relatively dynamic. That is, traffic sensors fail, are damaged, are replaced, are relocated, etc. on a routine basis. Real-time traffic data applications mostly care about where the data is coming from at the current time, not where or how data has been collected in the past five years. However, the historical configuration of the traffic sensor system has critical importance for the analytical uses of archived traffic data.

Data archives should provide metadata to document the historical status and configuration of a traffic sensor system. The most basic metadata would be an inventory of traffic sensors, with a date and time field representing when the shown sensor configuration (e.g., information about sensor location, type, characteristics, etc.) was activated and when (or if) the shown sensor configuration has been deactivated. Depending upon the archived data applications, data managers may find it helpful to add additional metadata to track temporary sensor configurations that may only be used during maintenance or reconstruction activities.

### **Use database flags or codes to indicate failed validity criteria**

This report recommends that database flags or markers be used when traffic detector data does not meet one or more of the established validity criteria. The specific implementation design of database flags or codes is not specified here. However, the implementation design should include the ability to distinguish between the failures of different criteria. That is, a unique database flag or marker should be associated with each validity criterion, so that it is possible to determine how many data records have failed each individual validity criterion.

In most planning-based traffic data systems, flagged or marked data are then manually reviewed by a traffic data analyst who makes an accept/reject decision based on supporting information (e.g., local knowledge, comparative traffic data from other time periods or locations, or other anecdotal information from field data collection notes or logs) or professional judgment. If manual review is used, a second flag could be used to indicate whether data values have passed or failed manual review. Due to the sheer volume of incoming data in many data archives, it may not be feasible to manually review all flagged or marked data from traffic operations systems.

However, periodic monitoring of the extent of flagged data is highly recommended, and any deviations or extreme fluctuations should be further investigated.

If the flagged data in question is accepted by the analyst after manual review, it is then typically included in data summarization and reporting procedures. Some traffic data systems provide the flexibility to exclude data that have failed a validity criterion but was subsequently accepted. Other traffic data systems may simply flag all data that fails the validity criteria without discarding the flagged data. Users that query the database then have the ability to exclude flagged data on a criterion-by-criterion basis.

In many data archives, the validity criteria and the resulting flags are applied to original source data before it is aggregated and loaded into the data warehouse. Therefore, nearly all data archives that offer summary statistics have made the decision to exclude data that have failed validity criteria. For example, validity criteria are applied to 30-second data, and the invalid values (i.e., those with “failed” flags) are not included in the calculation of 5-minute data stored and offered through the data archive.

The quality control process may assign a severity level to each validity criterion. In practice, however, most data archives assign a simple pass/fail to each criterion. The severity level is used to indicate the seriousness of the criterion failure as well as the necessity of manually reviewing the failed data. The following severity levels should be considered when flagging or marking data that have not met validation criteria:

- **Error** – An “error” is a condition that is highly likely to be caused by equipment malfunction. An example would be 24 consecutive hours of zeros in a single lane of a four-lane highway. But even here, it is possible that one lane is closed, so it could be marked as “actual.” The default action for data marked as containing an error is not to use the data for further processing.
- **Caution or Warning** – A “caution” or “warning” indicates that data are outside the acceptable ranges, but not significantly so. These data should be investigated to determine whether to accept or reject them. The default action for a caution or warning condition is to use the data in downstream processing.
- **Informational** – “Informational” messages indicate data toward the boundaries, but not outside them. Depending on conditions, these data might need to be investigated further. These data will be used in downstream processing unless the operator specifically changes their status.

**At a minimum, implement basic foundation for data validity criteria**

From the state-of-the-practice review, there are several univariate range criteria and multivariate logical consistency criteria that are used in most of the data archives surveyed. These criteria that are widely accepted form the basis of recommended validity criteria in this report. Table 11 summarizes the validity criteria that are recommended for implementation in data archives. The table also contains suggested default parameters for these criteria. These default parameters can be adjusted or customized for local or regional differences in traffic data collection systems.

**Table 11. Recommended Validity Criteria for Freeway Traffic Detector Data**

Validity Criteria	Default Parameter
<b>Prescreening Criteria</b>	
Controller error codes (e.g., -1, 255, etc.)	n.a.
Check consistency of elapsed time and poll cycles	n.a.
Check for duplicate records (location ID, date, time identical)	n.a.
If VOL=OCC=SPD=0, then set SPD=missing/null (no vehicles present)	n.a.
<b>Univariate Range Criteria</b>	
Minimum volume	0 vehicles
Maximum volume	3000 vphpl (adjust for appropriate time interval)
Minimum occupancy	0%
Maximum occupancy	100%
Minimum speed	0 mph
Maximum speed	100 mph
<b>Multivariate Logical Consistency</b>	
Maximum consecutive identical volume & occupancy & speed values (including VOL=OCC=SPD=0)	Number of reporting intervals that corresponds to 30 consecutive minutes (max.) with no vehicles detected
If volume>0 & speed=0 then invalid	n.a.
If volume=0 & speed>0 then invalid	n.a.
If volume=speed=0 & occupancy>0 then invalid	n.a.
If occupancy=0 and volume>volume <sub>max</sub> (based on maximum possible volume when occupancy value is truncated to 0)	$VOL_{max} = [(2.932 \times SPEED \times ELAPSED\_TIME) / 600]$

Nearly all of the validity criteria should have parameters that can be customized for individual detectors or groups of detectors. Certain criteria may use parameters that do not vary regardless of the detector location or traffic characteristics. For example, data values less than zero will be used for all detectors regardless of location or functional type. Other criteria, such as the maximum vehicle count, may utilize different parameters for freeway mainlanes than for ramps or arterial streets.

## Further develop other validity criteria for ADMS

The validity criteria in Table 11 are basic criteria that build a solid foundation for archived data quality control. However, subtle errors or biases could potentially go undetected with these basic criteria. The available literature contains numerous examples of more sophisticated validity criteria. The traditional (i.e., planning-based) traffic monitoring industry uses validity criteria that compare current values in temporal and spatial context. That is, data values are checked for consistency by comparing to historical data at the same location, or to other current data values at nearby locations.

Researchers and data archive managers should investigate and further develop validity criteria that evaluate current data values for temporal and spatial consistency. These criteria could identify suspect or invalid data in which there are:

- Rapid fluctuations in values across successive time periods;
- Detectors in adjacent lanes at the same location reporting significantly different values or trends;
- Detectors in adjacent upstream or downstream locations reporting significantly different values or trends;
- Detectors from multiple locations reporting the same values (indicative of a system problem);
- Reported values that are significantly different from the location's history for similar days of the calendar.

In developing these and other additional criteria, they should be tested with local data to verify expected results before implementation. The testing of new or different validity criteria is often a trial-and-error process that involves exploratory data analysis. The following is a suggested approach to testing validity criteria for implementation:

- **Identify data records that do not meet the candidate criterion** – Use database queries or filters to identify several dates, times, and locations at which the data do not meet the candidate criterion.
- **Look at the suspect data values in their temporal context** – Use time-of-day charts to visualize the data trends before and after the failed data value. Does the failed data value represent an abrupt (suspect) or gradual (not as suspect) change? Does the suspect data value seem possible or reasonable given the daily trends for that day, or for other days in that week or weekdays in that month?
- **Look at the suspect data values in their spatial context** – Graph the data values from all lanes at that location as separate lines on a time-of-day chart. Are the trends throughout the day consistent and reasonable? Does the suspect data value represent abrupt or gradual change?
- **Would the suspect data values also be flagged by other existing validity criteria?** When considering a new validity criterion, it should identify suspect data that is not

otherwise identified by existing criteria. Otherwise, this additional criterion will be redundant and may slow data processing and data warehouse loading.

- **Consider how the inclusion or exclusion of data failing this criterion may impact your data applications** – A candidate criterion may identify data that in some cases seems reasonable, but in other cases does not seem reasonable. In determining whether to implement this candidate criterion, one should consider the likely impact on the data. Will implementation of the criterion have a large impact, in terms of excluding a significant portion of the data from further analyses? Consideration should also be given to how conservative or aggressive the quality control should be. In other words, would including invalid data be a bigger problem than excluding valid data?

In developing validity criteria, data managers should also pay attention to the data source and whether data values are measured directly or estimated/calculated. For example, many freeway mainline detectors rely on two consecutive loops to collect speed data. In some cases, however, speed is an estimated value derived as a function of occupancy. For such detectors, it may not be obvious when data errors are the result of equipment failure or poor calibration.

#### **Use visual review when feasible**

Validity criteria often identify only the upper and lower bounds for valid data. As such, it may be difficult to identify subtle data quality issues (such as slight undercounting of vehicles) using automated validity criteria. When feasible, visual review of summary data should be used to supplement automated validity criteria. There are certain traffic patterns and trends that may be more suitable for manual visual checks. These checks may be difficult to automate, or data analysts may intrinsically value the ability to visualize the data to be used in the performance monitoring analysis. In these cases, a “human-in-the-loop” can be used to visually review a standard chart, graphic, or table to determine whether the represented data portrays a reasonable pattern or trend. These visual checks will require more staff time, but are valuable in building confidence in the quality of the analysis database.

For example, Figure 3 shows the flow rate and speed profiles by time of day for a group of adjacent lane detectors west of downtown Phoenix. At this location, one would expect to see a strong morning peak to coincide with peak traffic driving east to Phoenix. Showing flow rates in conjunction with speed values helps to determine the typical times of congestion, as well as the reduced volumes during congestion.

**Figure 3. Flow Rate and Speed Profiles Used to Check Data Quality in Phoenix, Arizona**

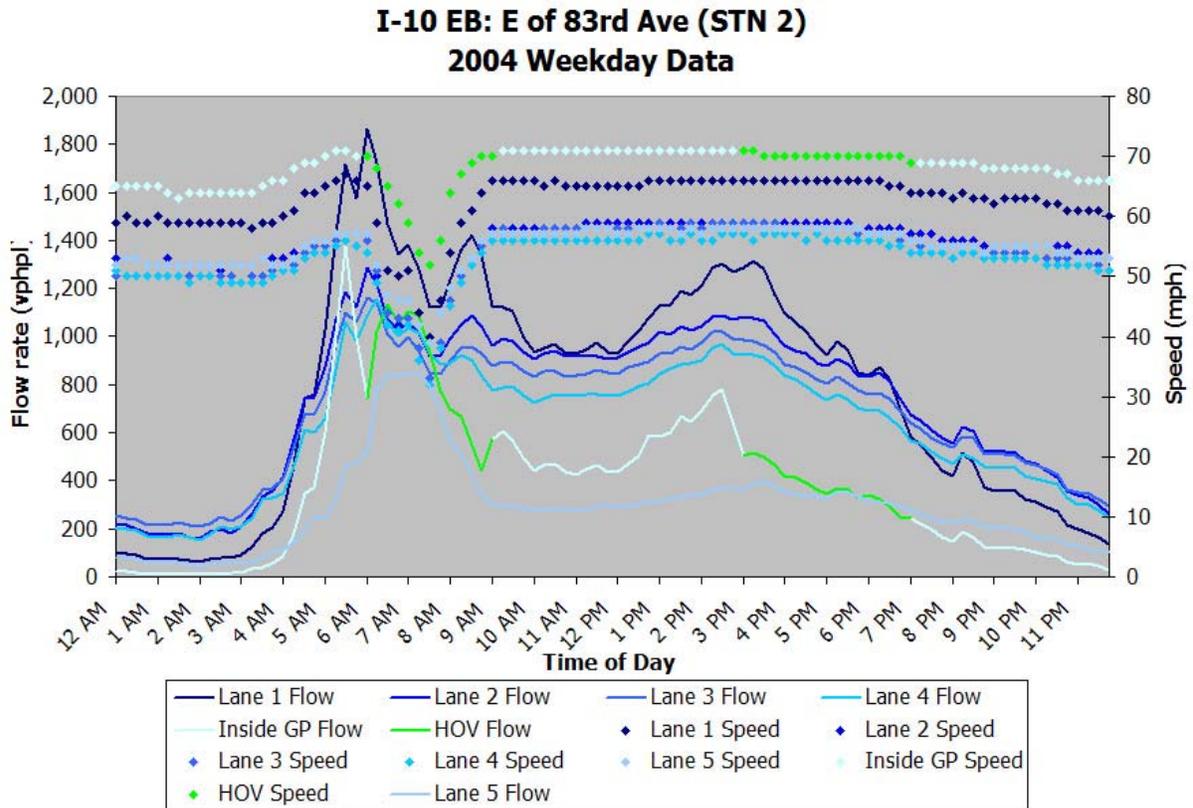
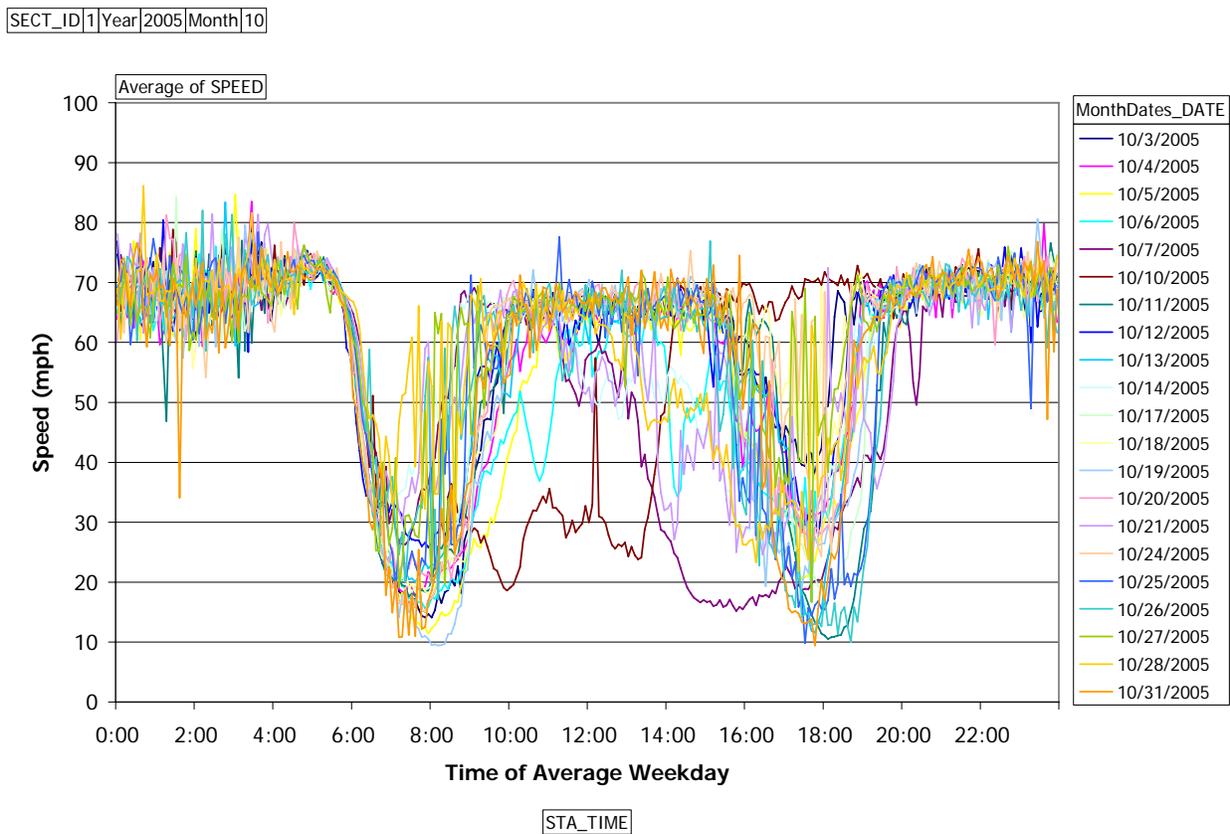


Figure 4 shows another example of a chart that is used to visually review large amounts of speed and travel time data in the FHWA’s Urban Congestion Reporting Program. In this chart, average weekday speeds for an entire month are displayed together as a way to identify odd or suspect days. Depending upon the extent of the suspect data, further “drill down” analyses may be conducted for that day to determine if the speed data are plausible.

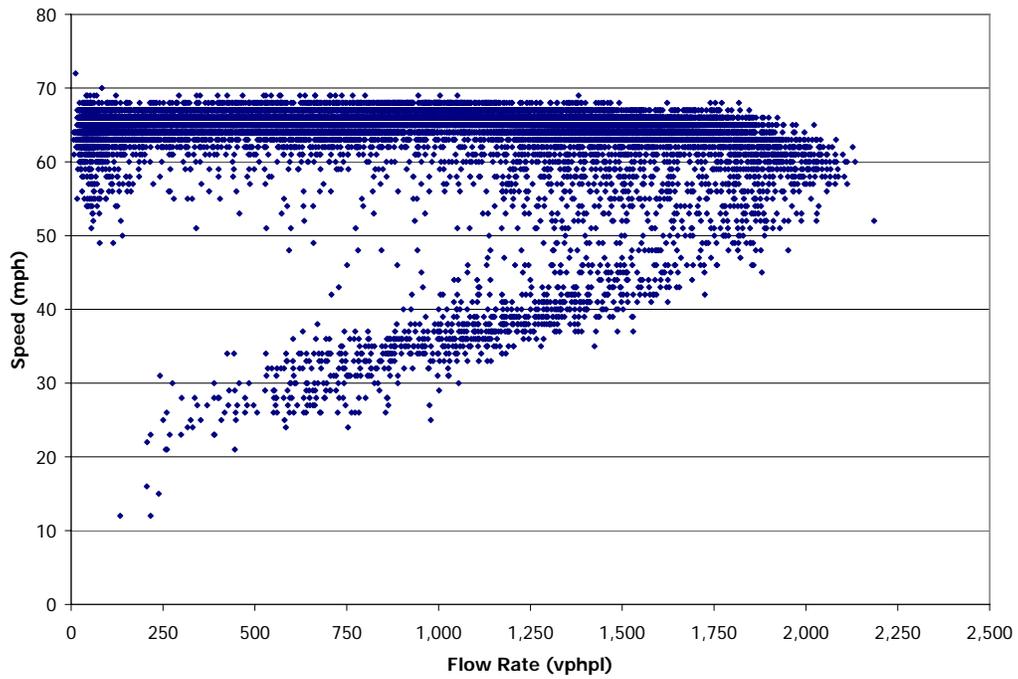
**Figure 4. Average Weekday Speed Profiles Used to Identify Suspect Data in the FHWA’s Urban Congestion Reporting Program**



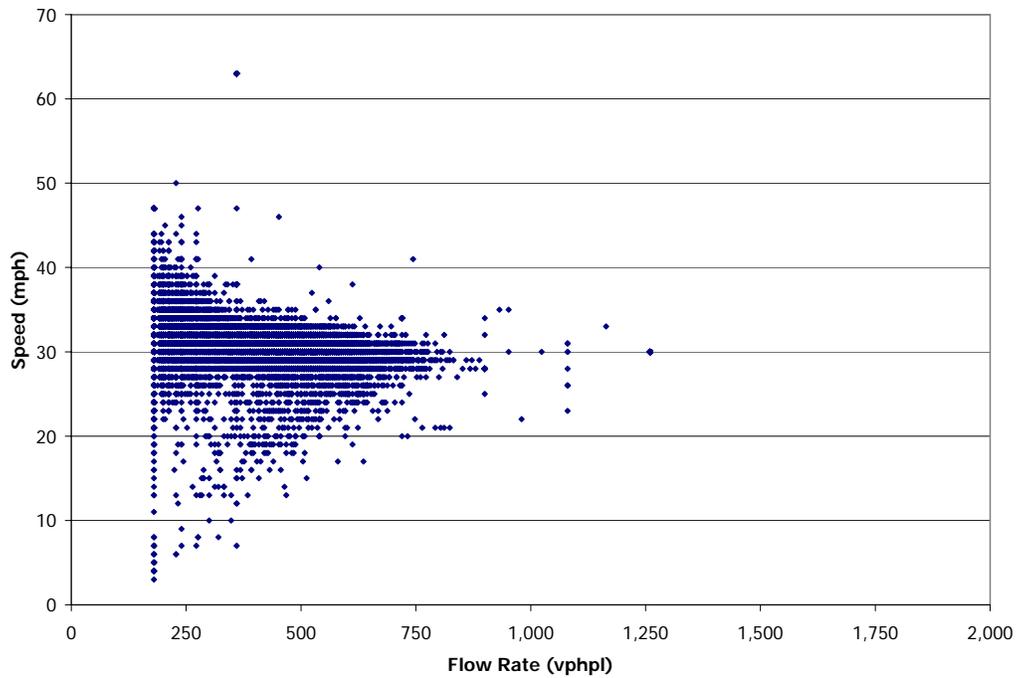
Another visual review approach uses highway capacity theory to identify suspect data.<sup>30</sup> Figure 5 shows a chart that plots traffic flow rates versus speeds (a full year of data are shown). This chart enables the data analyst to compare the shape of the field data points to the expected parabolic shape, as indicated in highway capacity theory. Figure 5 shows an example of loop detector data that embodies typical characteristics of a speed-flow curve: a near-parabolic shape with a flattened top that peaks at traffic capacities near 2,000 vehicles per hour per lane. Figure 6 provides an example of data that does not appear to conform to traffic flow theory. In this case, the data at this location should be further examined to determine its validity.

<sup>30</sup> Eureka, E., *Improving Planning-Level Speed Estimation Models*, Undergraduate Fellows Program, Texas A&M University, August 2004.

**Figure 5. Example of Speed-Flow Curve Identifying Valid Archived Data**



**Figure 6. Example of Speed-Flow Curve Identifying Suspect Archived Data**



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