Abstract:

Pneumatic road tube counters are a tool that is commonly used to conduct traffic counts on streets and roads. Many professionals have high confidence in the accuracy of road tube counts, and vendors of pneumatic road tubes often claim accuracy rates in the neighborhood of 99 percent. Several studies have been conducted in Montana intended to test the accuracy of road tube count data. These studies have compared road tube data to hand counts and other traffic-counting technologies, and compared results among multiple road tubes set up in series at a single location. The studies found that though the average error in a daily traffic count might be near zero, the absolute error of a typical 15-minute count averaged closer to ten percent. These results suggest that the level of inaccuracy is being masked by the positive and negative counting errors canceling each other out. Errors in speed and classification were much greater. These results raise questions about the reliability of pneumatic road tube counters in accurately measuring traffic volumes. This report compiles the results of these studies and provides a framework for measuring and reporting error.
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1. INTRODUCTION

Accurately measuring traffic volumes and speeds is important for both research purposes and road design. Data on the speed and volume of traffic can be used, for instance, as a surrogate measure of safety, in level-of-service (LOS) analysis and in transportation planning studies.

- LOS provides a measure of how well a transportation facility is functioning in terms of congestion and delay. The Highway Capacity Manual can be used to determine the LOS of numerous types of facilities such as basic highway and freeway segments, freeway merge areas, signalized intersections or stop-controlled intersections. Although the means of analyzing LOS differs greatly depending on the type of facility, a primary input for any of these analyses is traffic volume data. If the traffic volume data are incorrect the calculated LOS will be incorrect, which can lead to inappropriate investment decisions.

- Long-range transportation plans are made based on current and projected traffic volumes on the major streets and intersections of interest. A base-year traffic measure is used with other data to predict future traffic volumes. The traffic volumes are used to identify problem areas and analyze how the transportation system may be improved to handle these traffic volumes. Traffic impact studies use a similar approach on a smaller scale. For instance, the additional traffic that a new housing development generates can be calculated to determine the magnitude of impacts the new development has on traffic congestion and delay. Inaccurate traffic volume measurements will produce incorrect calculations of future congestion.

- Speeding has been reported as a contributing factor in 30 percent of all fatal crashes in the United States (NHTSA, 1997). Transportation safety improvements such as dynamic warning signs attempt to reduce the speed of traffic in order to reduce the frequency of speed-related crashes. In order to evaluate the effectiveness of these types of improvements, accurate speed data is required.

Inaccurate traffic-flow data can lead to wasteful spending on transportation infrastructure. For instance, in measuring the LOS for a 60-mile-per-hour multi-lane highway, the service flow rate between an LOS rating of D and E (using the Highway Capacity Manual LOS thresholds) is 11 percent. Thus, an 11 percent error in traffic flow measurements could lead to margin of error of one letter grade in the calculated LOS. This, in turn, could lead to unnecessary expenditures to upgrade a facility that does not need it.

Many transportation studies incorporate vehicle speed and volume data. Tools used to collect data on the numbers and speeds of vehicles operating on a road should be accurate, portable and capable of functioning automatically. One of the most common methods for collecting speed and volume data is by using pneumatic road tubes connected to a mechanical counter. This paper describes road tube technology, provides a framework for examining errors common to this collection method, and relates several case studies where road tube data was found to have errors of concerning magnitudes.

Although accuracy of speed data captured by road tube technology is also an issue of concern, this paper focuses on traffic volume data, or count data, acquired over 15-minute intervals, which is a standard that is often used in traffic studies for comparative purposes.

There is little published data on count error for road tubes. In fact, road tubes are often used to measure error for other types of traffic detectors. Vendors will sometimes claim a 99 percent
accuracy rate. This paper will show that these claims may be true for counts performed over a full day or longer, but error rates for individual 15-minute intervals are clearly higher.

2. PNEUMATIC ROAD TUBES

There are a number of portable, automated tools used for collecting traffic volume and vehicle speed data. A survey conducted of the 50 states found that the pneumatic road tube is the means most commonly employed by state agencies to acquire this type of data (Skszek, 2001):

- pneumatic road tubes: 49 states for counts, 20 states for speed
- passive infrared devices: no state
- active infrared devices: no state
- passive magnetic devices: 4 states for counts, 1 state for speed
- radar: 17 states for counts, 3 states for speed
- ultrasonic devices: no state
- passive acoustic devices: 4 states for counts, 1 for speed
- video image processing systems: 5 states for counts, 1 for speed

Pneumatic road tube technology (Figure 1) uses rubber tubes placed across traffic lanes in a specific configuration. When a pair of wheels (on one axle) hits the tube, air pressure in the compressed tube activates a recording device that notes the time of the event. Based on the pattern of these times (for instance, the length of the interval between the time that two axles of a typical vehicle activate the counter), the device will match each compression event to a particular vehicle according to a vehicle classification scheme. Two tubes attached to the same counter can be placed a set distance apart in order to determine speed by measuring the interval between the time an axle hits the first tube and the time it hits the second tube.

![Figure 1: Road Tubes on Two-Lane Highway](image)
There are several tube configurations that can be used by a counter depending on the number of lanes and the data needs. Some potential sources of error for road tubes are discussed below.

- In some configurations (such as the layout shown in Figure 2) one tube can be used across several lanes of traffic. The detector is able to determine vehicle direction by recording which tube is contacted first. If two vehicles traveling opposite directions cross the tubes at the same time, the quality of the pattern matching degrades.
- The technique used to distinguish a vehicle by matching sequences of axle contacts with the tubes allows for the possibility of error by counting two vehicles as one (with more axles) when they are traveling close together.

![Figure 2: Example Road Tube Layout](image)

### 2.1. Types of Data Outputs

There are a number of ways that road tube data can be compiled and stored for analysis. The raw data provides a list of times each tube was struck by a vehicle. **Raw data**, the time stamps of each axle hit, is not useful without further reducing it to either basic data or interval bins. This raw data must be converted to represent individual vehicles through a vehicle classification scheme based on the number and spacing of axles. A common vehicle classification scheme is shown in Figure 3.
Basic data would include the time of day, speed, class and direction of each vehicle contacting the detector. Some studies utilize data that is averaged over a given time interval—for example, the total number of vehicles that activate the counters during a 15-minute period, and their average speed. Researchers and practitioners will often convert basic data to interval bin data for use in analysis. These bins can be grouped together and envisioned as a three-dimensional table with time intervals on one axis, speed categories on another and vehicle classes on the
third. A single bin might be the number of motorcycles counted between 7:00 a.m. and 7:15 a.m. that were traveling between 30 and 35 miles per hour. For this study, vehicle classification and speed were not investigated so the interval bin data is the total vehicle count for a 15-minute period.

3. WAYS TO QUANTIFY ERROR

When evaluating count data there are several ways to measure the potential for error. A first step is to establish a baseline or basis that represents the actual vehicle count to which the tube count data can be compared. A second consideration is how to properly account for positive errors (road tubes counting more vehicles than are actually present in traffic) and negative errors (road tubes missing vehicles that pass over them) that could cancel each other out and thus reflect a lower than actual average error. Following a discussion of potential means of establishing the basis, this paper provides three methods for calculating error.

3.1. What to Use as Basis

In order to calculate error one needs to compare the actual vehicle count with the road tube counts. The most accurate method to find the actual number is by manually counting the vehicles. Errors can occur when vehicles are counted manually, but such a method should provide a number that is very close to the actual count. Because manual counts require some degree of effort, they typically provide only a small sample size. For this reason the authors have chosen to use several methods for determining the actual count values: manual counting, deployment of a second road tube station, and other technologies such as magnetic and acoustic vehicle detectors.

When using pneumatic road tubes to count vehicles, the sample size is limited only by the length of time the road tube stations are deployed. To acquire a basis count, two road tube stations are set up in close proximity at a single location and one station is arbitrarily chosen as the basis. Errors that affect both road tube stations by the same amount at the same time will not be apparent in this comparison. Also, the difference in counts between the two stations will only signify a relative error rate rather than an absolute rate because error in the basis count will not be known. While a difference between the counts from the two stations will indicate the presence of error, it will provide little information about the magnitude of the error, which can only be determined when compared with a true basis count.

Other types of automated detectors can also be used to measure deviance from the basis, though they might also introduce errors that could be greater or less than the road tube error. These errors could mask or exaggerate the absolute error of the road tube. Also, because these alternative technologies utilize a fundamentally different method for detecting vehicles, problems that cause error specific to road tubes may not cause error in the counts made by alternative technologies.

The two alternative technologies used as a basis in this research were the NC-97 magnetic detector and the SAS-I passive acoustical detector. High Star model NC-97 developed by Nu-Metrics, shown in Figure 4, detects vehicles by measuring the change in the earth’s magnetic field as the vehicles pass over the detector. The sensor collects vehicle lengths, vehicle speeds,
temperature, and pavement “wet/dry” condition. The self-contained unit is placed in the center of the travel lane.

Figure 4: NuMetrics NC-97 Detector

The SAS-1 passive acoustical detector developed by Smartech is installed on a pole and pointed down toward the lane of traffic. It detects vehicles by the sound created as the vehicle passes. The detector can collect counts and speeds for one or more travel lanes.

3.2. How to Calculate Error

Error is the difference between the road tube count and the basis. Readers should keep in mind that there are several ways to calculate the error. Consider the hypothetical data shown in Table 1. Five vehicles pass over the counter in a 45-minute period from 8:00 to 8:45. If one is concerned with the accuracy of a count for the 15-minute intervals the actual count is two in the first 15 minutes, one in the second 15 minutes, and two in the last 15 minutes. The counter did not count the vehicle that passed at 8:37, but counted the vehicle that passed at 8:22 twice.
Table 1: Example of Basic Data

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Time</th>
<th>Actual Number (Basis)</th>
<th>Number Counted</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00-8:15</td>
<td>8:03</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8:11</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8:15-8:30</td>
<td>8:22</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8:30-8:45</td>
<td>8:37</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8:40</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

In this example, the counter experienced one overcount and one undercount, errors that cancelled each other out and resulted in an apparently accurate total count. For this paper we will consider the count errors for the entire study period as well as for individual 15-minute intervals.

How the error rate is calculated can affect its magnitude. There are two main issues. First, positive and negative errors will cancel each other out. Two of the three intervals in Table 1 have errors, but the average error is zero.

The second issue is that a single missed vehicle can have a great impact on the percent error if the count for that interval is small. Some of the datasets used for this paper cover periods of more than 24 hours and contain many intervals (late night/early morning, for instance) during which only one or two vehicles passed by. For example in the third time interval of the hypothetical data in Table 1, the counter only missed a single vehicle, but the error is negative 50 percent. If an interval had a count of 20 and the counter missed only one vehicle, the error would be negative 5 percent.

The first issue will be dealt with by calculating the average absolute error for intervals. To deal with the second issue, the data will be cleaned by throwing out intervals with counts less than four. Additionally, a weighted error will be used so that intervals with lower counts will have a smaller impact on the error rate calculated. The three error rates calculated are discussed below.

The total percent error is the difference between the road tube count and the basis count for the entire study period, divided by the basis count (Equation 1). For comparison with other equations the total count and total basis count are shown as the sum of all interval counts. The total percent error gives an indication if the counter is consistently biased in one direction (either positive or negative).

\[
(1) \text{Total Error} = \frac{\sum_{\text{Int}} \text{Count} - \sum_{\text{Int}} \text{Basis}}{\sum_{\text{Int}} \text{Basis}} \times 100\%
\]

Notice that for the hypothetical data in Table 1 total error is zero. A counter could show numerous errors within individual intervals, but as positive errors and negative errors cancel each other out, the total error will appear smaller than its true size. To capture the error within a given interval, the absolute interval error will be used (Equation 2).

\[
(2) \text{Absolute Interval Error} = \frac{\sum_{\text{Int}} \left| \frac{\text{Count} - \text{Basis}}{\text{Basis}} \right|}{\text{Total Number of Intervals}} \times 100\%
\]
The absolute interval error is the combination of positive and negative errors within each interval that would cancel each other out when calculating the total error. For the hypothetical data in Table 1 it would be the sum of 0, 100 and 50 percent divided by three intervals, or 50 percent (Equation 3).

(3) Absolute Interval Error \(= \frac{|2-2| + |2-1| + |1-2|}{3} \times 100\% = \frac{0+100+50}{3}\%\)

Notice that the second interval with a smaller basis count had twice the impact on the total error as the third interval, even though both were off by only one vehicle. A third error calculation is used that essentially weights the intervals by their basis counts. The weighted absolute interval error is calculated by Equation 4.

(4) Weighted Absolute Interval Error \(= \frac{\sum_{int} |\text{Count-Basis}|}{\sum_{int} \text{Basis}} \times 100\%\)

The weighted absolute interval error for the hypothetical data in Table 1 would be the sum of the actual errors (0, 1 and 1) divided by the total basis count of five, or 40 percent (Equation 5).

(5) Weighted Absolute Interval Error \(= \frac{|2-2| + |2-1| + |1-2|}{5} \times 100\% = \frac{0+1+1}{5} \times 100\%\)

4. CASE STUDIES

The idea for this paper originated when the two authors were discussing the accuracy of road tube data. Independent of each other both had collected and used road tube data for various studies, plans and designs over the last 15 years. Each had become suspicious of the accuracy of the data and had at various times collected data in order to test the accuracy. This chapter contains four case studies that shed light on the accuracy of road tube data. These case studies were opportunistic and used data collected for various projects. They were not specifically designed to measure the accuracy of road tube data, but allowed for error estimation.

4.1. Case Study 1: Rouse Street in Bozeman, MT

For this case study, data from a road tube device (the TRAX I Traffic Counter/Classifier from Jamar Technologies, Inc.) was compared to the NC-97 magnetic detector. Data was collected on Rouse Street/State Highway 86 just north of Bozeman, Montana, over a two-day period from 7:00 p.m. October 14 to 5:15 p.m. October 16, 2002. One TRAX device was used in the configuration shown in Figure 2. Two NC-97 units were used (one for each lane).

Table 2 shows results separately for the eastbound and westbound lanes using the NC-97 as the basis. A positive total error implies the TRAX road tube had a higher count than the NC-97. Absolute interval errors will always be positive.
Table 2: Case Study 1 Results

<table>
<thead>
<tr>
<th></th>
<th>WB Rouse</th>
<th>EB Rouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of 15-Minute Intervals</td>
<td>111</td>
<td>123</td>
</tr>
<tr>
<td>Total Error</td>
<td>0.0%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Absolute Interval Error</td>
<td>28.5%</td>
<td>28.5%</td>
</tr>
<tr>
<td>Weighted Absolute Interval Error</td>
<td>27.2%</td>
<td>27.6%</td>
</tr>
<tr>
<td>Maximum Absolute Count Error</td>
<td>31</td>
<td>20</td>
</tr>
</tbody>
</table>

The total vehicle count in the westbound lane was 2,500 for both devices. The eastbound count was 2,437 for the NC-97 and 2,448 for the TRAX. The average difference between counters for individual time intervals is about six vehicles, and as high as 31 vehicles. However, the positive and negative errors cancel each other out resulting in a low total error. By considering the absolute interval error, the potential disparity can be seen.

4.2. Case Study 2: 19th Street in Bozeman, MT

This study was conducted on June 27, 2003, on 19th Street in Bozeman, Montana. Although within the city boundary, the average speeds were over 50 miles per hour. Data was collected from 11:00 a.m. to 3:30 p.m. using three automated counters: the NC-97, the SAS-1, and the Trax road tubes. A manual count was taken from 11:15 a.m. to 12:15 p.m. and from 1:45 p.m. to 3:00 p.m. The NC-97 was not active for the entire first time interval so this interval count was not used in the analysis. The error results are shown in Table 3.

Table 3: Case Study 2 Results

<table>
<thead>
<tr>
<th></th>
<th>Basis Count Used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SAS-1</td>
</tr>
<tr>
<td>Number of 15-Minute Intervals</td>
<td>18</td>
</tr>
<tr>
<td>Total Error</td>
<td>1.9%</td>
</tr>
<tr>
<td>Absolute Interval Error</td>
<td>12.5%</td>
</tr>
<tr>
<td>Weighted Absolute Interval Error</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

The total vehicle count from the road tubes was 872. The SAS-1 acoustical detector counted 856, resulting in a total error of 1.9 percent when using it as the basis. Considering the total error, road tubes were less than one percent off when using the manual count as the basis. However, when considering individual intervals, the road tubes are off by as many as eight vehicles with an average difference of five.
4.3. Case Study 3: King Ave. and Shiloh Ave. in Billings, MT

This study was conducted in Billings, Montana, on May 3, 2011, from 4:30 p.m. to 5:30 p.m. on the approaches to a roundabout intersection at King Avenue and Shiloh Avenue. Two road tubes were placed next to each other on each approach as shown in Figure 5. Manual counts were taken during this same time period.

In comparing the upstream road tube counts (counter numbers 13, 14, 16 and 17 in Figure 5) with the hand counts, the total vehicles counted for each method was 1,372, resulting in a total error of zero (Table 4). Compiling all the data leads to a sample size of 32 intervals (four 15-minute periods by four directions by two lanes). The downstream counters (69, 18, 15 and 67 in Figure 5) had a combined count of 1,362 resulting in a total error of -0.7 percent. Similar to the other case studies, the total error may be small because the positive and negative errors for individual 15-minute intervals cancel each other out. For individual intervals, the road tubes were off by as many as 11 vehicles within a single 15-minute interval. The average absolute difference between the road tubes and the manual counts was three vehicles.
Table 4: Case Study 3 Results

<table>
<thead>
<tr>
<th></th>
<th>Upstream Counters</th>
<th>Downstream Counters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of 15-Minute Intervals</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Total Error</td>
<td>0.0%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Absolute Interval Error</td>
<td>7.9%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Weighted Absolute Interval Error</td>
<td>6.9%</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

4.4. Case Study 4: Grand Ave. and Shiloh Ave. in Billings, MT

Similar to case study 3, this data was collected on approaches to a roundabout intersection in Billings Montana, but at the intersection of Shiloh Avenue and Grand Avenue. A similar configuration was installed with two count stations on each approach. The data was collected on April 27, 2011, from 10:00 a.m. to 6:00 p.m. Hand counts were completed from 10:15 a.m. to 11:15 a.m. and 4:30 p.m. to 5:30 p.m. Combining the two hours of hand counts resulted in 64 intervals (eight 15-minute intervals by two lanes by four directions). The data from the four upstream count stations were combined and compared to the hand counts resulting in 2.6 percent total error and 11.7 percent weighted absolute interval error (Table 5). Comparing one counter to another allowed a higher sample size. Using the upstream counter as a basis, the error of the downstream counter was negative 3.1 percent, with a weighted absolute interval error of 9.5 percent. The sample size was 256 (32 intervals by two lanes, by four directions).

Table 5: Case Study 4 Results

<table>
<thead>
<tr>
<th></th>
<th>Hand Count as Basis</th>
<th>Upstream Counter as Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upstream Counter</td>
<td>Downstream Counter</td>
</tr>
<tr>
<td>Number of 15-Minute Intervals</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Total Error</td>
<td>2.6%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>Absolute Interval Error</td>
<td>14.7%</td>
<td>14.2%</td>
</tr>
<tr>
<td>Weighted Absolute Interval Error</td>
<td>11.7%</td>
<td>11.3%</td>
</tr>
</tbody>
</table>

*One counter produced an error code and did not provide a count during one of the 15-minute intervals so that interval was not included in the analysis.

Similar to the other case studies, the total counts were very close. For the two hours when hand counts were collected the counts were 3,252, 3,335 and 3,206 for the hand count, the upstream counters and the downstream counters, respectively. Compared to the hand count, a single interval count for a single lane was off by as much as 26 vehicles. On average an individual interval count was off by six vehicles.
5. CONCLUSIONS

For the case studies, regardless of the basis used, the total error of the road tube counts was less than 4 percent. These results indicate that for daily counts, the road tubes have small error rates consistent with those reported by the vendors. When considering individual intervals the error is much higher. The weighted absolute interval error rate ranged from 7 to 12 percent when using a hand count as a basis. Individual interval counts were off by five to eight vehicles on average when compared to the hand count. One interval was off by 26 vehicles. Considering that many design inputs are based on 15-minute interval counts, the magnitude of this error is concerning and worthy of further study. Recalling the example in the introduction, an 11 percent error could result in a different calculated LOS and thus an inappropriate design/policy decision.
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7. REFERENCES

