Do My Loop Detectors Count Correctly? A Set of Functions for Detector Plausibility Testing

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Abstract: Loop detectors are wide-spread and relatively cheap detecting devices. With today’s traffic communication revolution, high resolution detector data is available on a central traffic management level. High resolution detector data consist of detector slopes, also called pulse data. There is an initial and continuous need for checking the detectors for correct data as all kinds of disturbances may add erroneous information to the data. This paper proposes pulse data checking and interval data checking with optional data replacement in order to guarantee a continuous data flow even if detectors do not deliver the expected data quality: Raw detector data checking analyses rising and falling slopes of detector signals; Cumulative data checking compares interval values to reference curves. Cumulative data checking needs less computational effort, but needs more parameterization effort than raw detector data checking. Both checking principles are applied to different systems in Switzerland since about five years.

Key words: Loop detectors, plausibility, detector count statistics.

1. Introduction

Loop detectors are wide-spread and relatively cheap detecting devices. It is not unusual in Switzerland that each approach to an intersection is equipped with one to three detectors. Even detectors in egresses are common in order to detect outflow problems.

Loop detectors are mainly used for local traffic-actuated intersection control. Raw detector slopes, also called pulse data, are rarely sent until a central traffic computer. Traditionally, detector counts and occupancy durations are accumulated still in the controller to interval values and then sent to a central traffic computer.

In Switzerland, since the 1990s, Zurich and Lucerne only were able to provide raw detector data with a slope resolution of 0.1 s easily and continuously to a central level [1, 2]. With today’s traffic communication revolution in Switzerland, Germany and Austria, driven by the OCIT (Open Communication Interface for Road Traffic Control Systems) standard, city-wide high resolution detector slope data is easily available in more and more cities and everywhere on the city network.

Therefore, raw detector data is increasingly being used for additional observation and control functions, as traffic state calculation, adaptive network control [3] or traffic count data bases [4], the latter Ref. [4] has been used at the co-author’s road authority since over five years. As these detectors were not calibrated originally for exact counting neither exact occupancy time measurement, there is an initial need for checking them for correct data by correct calibration.

Once being used in a central system, the detectors have to be checked periodically for continuous correct functioning.

This paper proposes raw data checking:
• discovery of spontaneous oscillation (erroneous counts);
• discovery of spontaneous long occupancy times (erroneous traffic states).

Furthermore, this paper proposes interval data checking:
• null value statistics;
maximum value statistics;
percentile belt statistics.

Finally, in order to guarantee a continuous data flow, the paper proposes a formalized way for interval data replacement. Plausibility considerations of interval data may lead to a value replacement decision. This is in order to enable long-term statistics with continuous values and confidence indications.

The algorithms described were developed because of operational needs by our customers. Not using them will certainly lead to erroneous decisions of area control systems and to inconsistencies in detector count statistics.

2. Checking of Raw Data

Loop coil detectors are radio emitters. The tuning of the emitted magnetic field is changed by moving or non-moving metal. The tuning amplitude is measured and transformed into a binary signal by a so called evaluation unit where “1” represents an occupied detector and “0” a free detector.

The processing of the electrical signal into a binary output is done by an evaluation unit. Today’s evaluation units are self-calibrating in order to cope with environmental changes such as temperature, pressure, humidity, etc. Unusual behavior can be recognized by themselves, as continuous occupancy or failures.

The detector sensitivity can be set from bicycle detection to heavy truck detection. Some evaluation units are able to adapt to different types of vehicle, i.e. different masses of metal. Nevertheless, unexpected signals may be discovered as spontaneous oscillations and continuous occupancies.

2.1 Spontaneous Oscillation

Detector signals after evaluation unit can oscillate spontaneously. Such erroneous behavior can be triggered by the decision to recalibrate the evaluation unit in a wrong moment. The oscillation is normally stopped by the arrival of the next car.

2.1.1 Raw Data Insight

The detector slope protocol in Fig. 1 shows a spontaneous oscillation. Fig. 1 shows that normally a car platoon is passing the detector every 45 s, but at 07:18:30 the detector continues an oscillation until the next platoon arrives at 07:19.

Analyzing the gross gap distribution shows an accumulation of gross gap times below 1 s. Normal shortest gross gap times are between 1 s and 1.5 s which correspond to a traffic densities of 1 car per second to 1 car per 1.5 seconds. This can be seen in Fig. 2.

![Raw data protocol for Detector 082.D15.201 (28.10.2014)](image)

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Fig. 1  Detector slope protocol with spontaneous oscillation.
Source: Bern (Switzerland) traffic control system.
2.1.2 Problem Solution

To make the counts more reliable, all rising slopes under a minimum gross time gap duration shall be ignored. The example shown in Fig. 3 shows the same detector as shown just before, now in count environment. It can easily be seen that around 07:20 a high traffic volume is counted.

Besides this morning error, also some afternoon errors can be seen around the right red circle in Fig. 3. After application of the minimum gross gap criterion, the extreme count values are gone, and this can be seen in Fig. 4.

For control purposes, a mean value calculation over the last $n$ cycles is preferable (best with $n$ between 3 and 7) as quick changes in counts do not have an effect on control decisions. Cycle mean value calculation in contrast to fixed intervals is suitable for traffic-actuated control as the mean value calculation interval is almost
always different from the cycle length or a multiple of the cycle lengths. When average value calculation interval is not a multiple of the cycle time, the resulting value tends to have ripples.

The two diagrams in Fig. 5 show the counts as mean values over seven cycles.

An additional example of another detector shows a smaller counting error around noon, as one can see in Fig. 6.

The raw signal protocol shows clearly an oscillation of the detector at 11:31:30 as displayed in Fig. 7.

2.1.3 Unreliability Statistics
In order to measure how often such oscillations occur, the minimum gross gap time violations can be categorized as follows:

- Each time a gross gap time of < 1 s is measured, a warning is generated;
- If the gross gap time is < 0.7 s, an alarm is thrown (not show here);
- Warnings and alarms are counted per hour and shown in an evaluation or used for triggering some technical notification.

![Vehicle count on Detector 082.D15.201 (28.10.2014)](image1)

Fig. 4 Corrected counts of a detector with spontaneous oscillations.
Source: Bern (Switzerland) traffic control system.

![Vehicle count on Detector 082.D15.201 (28.10.2014)](image2)

(a)

![Vehicle count on Detector 082.D15.201 (28.10.2014)](image3)

(b)

Fig. 5 Counts of a detector with spontaneous oscillations, mean value over 7 cycles: (a) uncorrected; (b) corrected.
Source: Bern (Switzerland) traffic control system.
Fig. 6 Additional example of a detector with spontaneous oscillations: (a) uncorrected; (b) corrected.
Source: Bern (Switzerland) traffic control system.

Fig. 7 Detector slope protocol of the additional example.
Source: Bern (Switzerland) traffic control system.

All detectors connected to Intersection 082 create the diagram shown in Fig. 8 for end of October 2014; The vertical axis shows the number of warnings per hour.

2.2 Spontaneous Occupancy

Another error is spontaneous long occupancy—the detector misses one or more falling slopes. Detector 092.D6.281 (Fig. 9) is placed in the left lane of the access of a roundabout in Berne, Switzerland. The left lane will turn left at the roundabout (please note that right-hand traffic notation is used). There is a second detector in this left lane named 092.D6.301.
The right lane (Fig. 9), leading to the right turn movement in the roundabout, contains the Detectors 092.D6.291 and 092.D6.311.

2.2.1 Raw Data Insight

Fig. 10 shows the detector protocol. The cars arrive from an upstream traffic light that forms the typical platoons. Cars usually do not change lanes any more when arriving that close to the roundabout. Therefore, the second detectors count as many cars as the first detectors. This can be seen with the blue and red arrows showing the car flows over the two rows of detectors.

At 08:21:18, Detector 092.D6.281 creates a usually long occupancy time (see blue oval in Fig. 10). The long occupancy time contains several cars which can be seen on the next detector (092.D6.301).

When occupancy times are measured that are higher than they should be, a wrong traffic state might be calculated by, e.g. a travel time estimation algorithm which will lead to wrong predictions for car drivers.

2.2.2 Problem Solution

Therefore, the discovery of such erroneously high occupancy times is important: Erroneous long occupancy times can be ignored. For traffic state calculation, a true long occupancy time is always preceded by a shorter occupancy time that is not to be filtered out.
2.2.3 Unreliability Statistics

In order to measure how often such long occupancy times occur, the occupancy times can be categorized as follows:

- Each time an occupancy time of $> 20$ s is measured, a warning is generated;
- If an occupancy time of $> 100$ s is measured, an alarm is thrown (not shown here);
- Warnings and alarms are counted per hour and shown in an evaluation or used for triggering some technical notification.

All detectors connected to Intersection 092 create the diagram shown in Fig. 11 for end of October 2014; The vertical axis shows the number of warnings per hour.

It seems that only Detector 092.D6.281 shows this effect.

3. Checking of Cumulative Data

When raw data is not available, cumulative data can be checked. Cumulative data checking needs less computational effort and less communication bandwidth when done online. It tracks slow changes in detection characteristics. It typically runs every hour. It can also be used for warning in case of unexpected events:

- Cumulative data checking needs reference curves;
- Cumulative data checking can be applied to single detectors or rows of detectors;

Cumulative data checking uses two accumulation interval lengths:

- a 3 minutes count interval, which is called a short interval;
- a 60 minutes count interval, which is called a long interval.

A long interval contains 20 short intervals.

The following criteria can be checked:

- number or maximum number of contiguous zero count value intervals;
- maximum count values;
- percentile belt.

3.1 Reference Curves

All checking is done against reference curves. Three types of confidence results are created:

- implausible: reference values are clearly not met;
- suspicious: single reference value violations;
- otherwise: ok.

Suspicious and implausible values may be corrected or replaced if needed. This enables a full set of count values with corresponding confidence indications.

Reference curves depend on weekdays. Dependence on seasons turned out not being necessary. Nevertheless, it is necessary to adapt the reference curves periodically. Reference curves are parameterized by using past data from normal and typical days.
3.2 Zero Count Value Plausibility Check

It is checked if null values (no traffic for three minutes) are allowed:

- One checks the counts of the number of null intervals (N1);
- The other checks the maximum number of contiguous null values (N2).

The reference curve parameters are shown below:

- N2: time-varying maximum number of contiguous null intervals;
- N1: time-varying maximum number of null intervals per hour;
- limit between suspicious and implausible.

The results calculated are shown below:

- suspicious when measured number exceeds a given threshold;
- implausible when number exceeds the threshold by a given percentage > 100 %.

3.2.1 Reference Curve Examples

The curves in Fig. 12a show N1 reference values for Monday to Friday, Saturday and Sunday for a given detector. The curves in Fig. 12b show N2 reference values.

The reference curves can also be documented in predefined forms, as seen in Fig. 13.

3.3 Maximum Count Value Plausibility Check

Short intervals cannot count more cars than it is physically possible. This maximum value is around 1,800 cars/h to 2,400 cars/h per lane. This is a short-term maximum count check (M1).

Long-term maximum count check (M2) considers traffic flows with capacities corresponding to the surrounding intersection capacities, e.g., 1,200 cars/h per lane for main axes.

Fig. 12  Reference curve examples for: (a) N1; (b) N2 test.
Source: Solothurn (Switzerland) traffic control system.
The reference curve parameters are shown below:

- M2: time-varying maximum number of cars per short interval;
- M1: constant physical limit;
- limit between suspicious and implausible.

The results calculated are shown below:

- suspicious when measured number exceeds a given threshold;
- implausible when number exceeds the threshold by a given percentage > 100%.

The curves shown in Fig. 14 show the M2 reference curve for a given detector.

### 3.4 Percentile Belt Plausibility for Hourly Counts

Percentile values express the distribution of short interval values while creating a long interval value. When calculating an hourly count value, the percentiles can be calculated as well and compared to the expected percentile values. Experience shows that such pattern comparison is not necessary and that a simple criterion like “the final value should lie within a certain percentile belt” (e.g., within the 10th and the 90th percentile) is sufficient.

The form in Fig. 15 shows the percentile belt values of a unidirectional row of detectors:
Fig. 14  Reference curve examples for M2 test.
Source: Solothurn (Switzerland) traffic control system.

Fig. 15  Reference curve form examples for plausibility belt test.
• 0% is the 0th percentile which is the minimum count value;
• 100% is the 100th percentile which is the maximum count value;
• 10% and 90% are the limitation curves for the plausibility percentile belt.

The reference curve parameters are shown below:
• usually 10th and 90th percentile, defining the “percentile belt”;
• limit between suspicious and implausible.

The results calculated are shown below:
• suspicious when hourly count is outside the percentile belt;
• implausible when number exceeds the threshold by a given percentage > 100% for 90th percentile and < 100% for 10th percentile.

4. Cumulative Data Replacement Strategies
When calculating replacement values, the goal is to always obtain 60-minute interval values even when the original value is suspicious or implausible. This enables easy long-term statistics for weekly, monthly or even yearly statistics. All 60-minute values can be used, and a trustworthy number is added to the result. Three different replacement value generations are used following criteria that base on the judgments “suspicious” and “implausible”.

In the case of isolated suspicious values, no replacement of values shall be done. Fig. 16a shows an example of two isolated suspicious values. Suspicious values are colored yellow. And Fig. 16b shows value replacement. Values are replaced when implausible or when too many suspicious values follow each other. The replacement values are calculated on the base of a reference count curve. The reference count curve gives the shape of the replacement curve by being adjusted to the last plausible edge values (see the green ovals in Fig. 16b).

![Fig. 16 Replacement rules: (a) no replacement; (b) calculated.](image-url)
In case of too many suspicious or implausible values in a row, it might be necessary to simply use the reference curve values instead of doing any adaptation to the measured values (i.e., hourly values). This is shown in Fig. 17.

4.1 Mapping and Reference Curves

In order to give a trustworthy number, the discrete states “suspicious” and “implausible” are mapped to numeric values as percentage values between 100% (very trustworthy) and 0% (entirely constructed) (Fig. 18a). Mapping is necessary for higher interval value calculation, as day values, week values or month values.

The reference curves have to be calculated and adjusted periodically. The form in Fig. 18b shows a set of reference curves for two unirows.

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**Fig. 17** Replacement rules: replacement by reference curve.

**Fig. 18a** Replacement rules: replacement by reference curve.

**Fig. 18b** Replacement rules: replacement by reference curve.
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5. Conclusions

“Big data” enables easier data communication, but data sources are not always as reliable as they should be. Algorithms like the presented ones enable data checking and data completion and lead to verified data quality:

- online usage (observation, control);
- offline usage (statistics).

Not using them will certainly lead to erroneous decisions of area network control systems and to inconsistencies in detector count statistics.
References


