

Dear Reviewer,

Thank you for carefully reading our article and for all valuable comments. Below are our answers. We hope that these answers, as well as changes made to the text of the article are satisfactory.

Reviewer's note: Abstract: Poorly written. Does not convey purpose of the work and doesn't provide sufficient detail about the "estimators" to appreciate the methodology presented in the paper. Overly vague.

Answer:

Sentence added - line 12-16: The term estimator is understood as an algorithm according to which the dynamic axle load measurement results are processed in order to determine the static load. The result obtained is called static load estimate. As a measure of measurement uncertainty, we adopted the standard deviation of the static load estimate.

Reviewer's note: -Methodology: Method minimizes the relative standard deviation of sensor measurements. Can the authors explain how their work addresses the issue that standard deviation can be minimized (high precision) but the measurements could be incorrect (low accuracy)? Consider a scenario where the sensor array was mis-calibrated at installation. It is not clear how the static weights of the test vehicles in the experiment were used in the assessment. There should be a table showing weighing errors for each test run given the two averaging methods. Perhaps this is what the authors have embedded in the relative standard deviation, but it is not clear. Thus a formulation for calculating relative standard deviation in this context would be helpful in understanding the averaging and MLE methods and the ordering of sensor measurements within those averages.

Answer:

The subject of the analysis is only one component of the measurement error, i.e. uncertainty (precision). We assumed that the second component, i.e. systematic error (bias) is minimized as a result of the WIM system calibration. The inspiration to undertake such research was to observe the difference between the standard deviation of the weighing results obtained from individual load sensors in the multi-sensor WIM system. It is also known that random variability of measurement results cannot be removed during the calibration process.

Sentence added – line 56-61: The accuracy of vehicle weighing is determined by two components: systematic error (bias) and random variability of results (uncertainty). Bias is minimized as a result of WIM system calibration. In the paper, we present the results of a comparison of two algorithms for measurement results fusion. These measurement results

are obtained from load sensors installed in the WIM system. As the comparison criterion, we adopted the uncertainty of the final result, i.e. the gross vehicle weight and the static load of each axle.

Reviewer's note: The paper lacks a sensitivity analysis to speed and weight of the test trucks and the degree of mis-calibration of the sensor array and individual sensors. Without a sensitivity analysis, one cannot truly judge the performance of the two estimators.

Answer:

Manufacturers of load sensors installed in WIM systems ensure their linear characteristics over the entire range of allowable load. However, the influence of speed on the weighing result is observed. It depends on the technology of the sensor. The authors studied this issue. The results were published, e.g. in [J. Gajda, P. Burnos, and R. Sroka, "Weigh-in-Motion systems for direct enforcement In Poland" In ICWIM7: 7 International Conference on Weigh-in-Motion & PIARC workshop, 2016, pp. 302-311]. During the experiments carried out, the reference vehicles passed through the WIM site 10 times at a speed equal (40, 50, 60, 70, 80) km/h, respectively. This range corresponds to traffic speed where WIM is installed. The obtained measurement data therefore take into account the speed spread observed in the conditions of normal traffic.

In the analysis, we adopted, in accordance with the principles, that systematic error is removed in the calibration process. However, uncertainty of measurement results due to random factors and calibration uncertainty remains. This component of the measurement error is minimized as a result of using a specific data fusion algorithm.

The sensitivity analysis of both estimators was not the subject of our research. However, we agree that such an analysis should be carried out in the future

Specific issues:

1. Reviewer's note: Define WIM and GVW as acronyms around line 40

Sentence added – line 43: (gross vehicle weight)

Sentence added – line 45: (Weigh-in-Motion)

2. Reviewer's note: What is the meaning of 1-2% GVW on line 42?

Answer:

(1÷2% for GVW) means that the gross vehicle mass is measured with a relative error in the range of 1% - 2%.

3. **Reviewer's note:** Applications of WIM need to be mentioned near line 40 to appreciate the context of the problem. e.g., enforcement of truck loading to protect pavement and bridge infrastructure. This is later mentioned but would have value mentioning sooner in the paper.

Answer:

Sentence added – line 46-48: Such accuracy ensures the effective use of WIM systems in mass enforcement systems to protect the traffic infrastructure

4. **Reviewer's note:** The phrase "disturbing" factors on line 44 can be better phrased as "Factors that produce inconsistent weight measurements"

Answer:

Sentence changed – line 50: factors that produce inconsistent weight measurements

5. **Reviewer's note:** The paper needs light grammar editing. e.g., Line 94, "The ML consists of..."

Answer:

Sentence changed – line 105-108: The ML method allows for determination of the coefficients of a model describing the identified object. The determined coefficients maximize the probability of a certain event. This event involves the occurrence of such values of measurement results that were actually obtained during an experiment carried out on this object.

6. **Reviewer's note:** The authors point out that measurement errors are a result of installation and degradation (line 143). They should also note that discrepancies are the result of vehicle dynamics over the sensor. This is a concern especially for large trucks with liquid bulk content that shifts position and thus axle weight over the sensor.

Answer:

We agree with this remark. This impact is particularly evident on roads with inferior pavement. However, WIM systems with the highest accuracy should not be installed on such roads.

7. **Reviewer's note:** The authors mention polymer sensor accuracy (line 149). I think a more specific weight measurement accuracy profile by sensor type would benefit the relevance

of the work. More specific details on measurement error ranges is needed in general, e.g., line 149, two or three fold is too vague.

Answer:

The text of the paper has been supplemented with the following information:

Sentence added – line 167-169: The metrological properties of various load sensors (capacitive, piezoelectric, fibre optic, strain gauges, quartz, etc.) used in WIM systems are presented in detail in the papers [28-32].

- 8. Reviewer's note:** I am unclear of what the graphs in Figures 1 and 2 represent. If the horizontal axis is meant to show the "number of sensors" then I follow the logic in the statements beginning on line 158. If it is "sensor number" in reference to the position of the sensor in the array, then I do not understand what the Figures convey or how they were determined. For the case where sensors are averaged in order of increasing uncertainty, I am unclear if the horizontal axis in the figure means the number of sensors or the order of sensors. In this case does the order change for each alternative (1), (2), etc.? In figure 2, I am unsure what the black line labeled as (2) represents in (a), e.g., is it the same order of sensors but using the averaging estimator?

Answer:

In both estimators, in order to determine the static load estimate, the dynamic load measurement results from individual sensors are averaged. However, not all dynamic load measurement results need to be used. The parameter of estimators is the number of averaged results. The characteristics presented in Figures 1 and 2 show that in the case of the estimator (1) it is expedient to omit the results with greater uncertainty. Horizontal axis shows the number of average dynamic measurement results (number of sensors). However, two different orders of averaging these results are considered: starting with the result with the least uncertainty and in the order of installation of sensors at the WIM site.

- 9. Reviewer's note:** A schematic to accompany the photos of the sensor array would be helpful to understand if the sensors are an array in the direction of travel or in a direction perpendicular to the direction of travel.

Answer:

The sensors are made in the form of a strip 4 m long. They are installed perpendicular to the direction of vehicle movement.

10. Reviewer's note: Figure 3a and b and e and f are not necessary.

Answer:

The photos presented in Figure 3 show the subsequent stages of preparation of reference vehicles and their use in the testing process of the WIM system. We've found that this information may be of interest to those less familiar with the problem of WIM systems, that have never carried out the calibration process.

11. Reviewer's note: Explanation of the correction procedures is needed (line 217).

Answer:

The text of the paper has been supplemented with the following information:

Sentence added – line 244-245: The correction consisted in removing the trend from the measurement results obtained in subsequent passings of reference vehicles.

12. Reviewer's note: The rationale for the selection of vehicle weights and speeds is needed. Were they randomly selected or was there an underlying hypothesis about how the ML and averaging estimators may perform given varied weight and speed profiles of test trucks?

Answer:

The gross weight of reference vehicles was selected to cover the interval in which the weight of heavy goods vehicles belonging to the class 2-axle tractor with 3-axle semi-trailer is included. In Poland, these are the most common trucks with the largest mass. They also contribute the most to the degradation of infrastructure.

As mentioned earlier, during the tests, the reference vehicles passed the WIM station 10 times at each speed of (40, 50, 60, 70, 80) km/h, respectively. This range includes traffic speed in the place where the WIM test system is installed.

13. Reviewer's note: Referencing the first and fifth axles is beneficial for a sensitivity analysis. However, the statement on line 244 about the axle group is unclear. Do the authors mean to say that the fifth axle supports the load and therefore has more variability?

Answer:

The characteristics presented in Figures 7 and 8 relate to axle 1 and axle 5. We have presented them as an example of both compared estimators, when the purpose of the measurement is

the static load of a single axle. We decided that a presentation of characteristics of all axles is not necessary from a cognitive point of view.

The fifth axle is part of the so-called axle group. The dynamic behavior of such axles is different from that of the single axle. In practice, this can result in increased weighing uncertainty. We wanted to draw the reader's attention to this.

Literature has also been supplemented.

The text was checked by a native speaker