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Implementation and Effectiveness of Autonomous Enforcement of OW Trucks in an Urban Infrastructure Environment

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16. Abstract

In this study, the team presented the effort to summarize different WIM standards, develop the calibration procedure for the A-WIM system, and implement the calibration procedure to prove that the A-WIM system is capable of complying with ASTM E1318-09 Type III accuracy.

Three prevailing WIM standards were compiled and compared, ASTM E1318-09, COST 323, and OIML R134-1. At least three trucks are required for an excessive number of calibration/optimization tests to meet the accuracy and compliance level and the Type-Approval test requirement of the ASTM E1318-09. The calibration and optimization tests provided the accuracy and compliance required in ASTM E1318-09 even though the pavement conditions did not meet the ASTM E1318-09 requirement. Based on the preliminary analysis of the change in the number of trucks after the enforcement, direct enforcement would reduce the number of overweight trucks by up to 76.9% for > 10% overweight trucks. More in-depth study would be required to evaluate the efficiency of direct enforcement.

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Implementation and Effectiveness of Autonomous Enforcement of OW Trucks in an Urban Infrastructure Environment

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Executive Summary

While the national roadway infrastructure, including bridges and pavement, has handled substantial daily truck traffic, illegally heavy trucks are one of the primary causes of the deterioration of the aging pavement and bridges. Moreover, overweight trucks threaten public safety, inducing casualties when they are involved in an accident. To regulate these overweight trucks, vehicles on Interstate highways must conform to the Federal Bridge Formula (FBF), designed to protect bridges from truck overloads beyond the legal limits. The enforcement regulation has been executed at the stationary weighing stations across the nation, especially at the borders between states. However, the stationary stations have limited resources for effective enforcement because:

(1) the number of stationary weighing stations is not spatially well distributed across the nation;

(2) the operation hours are limited; and

(3) the number of enforcement officers is insufficient.

When the overweight data from the stationary weighing stations and the main lane WIM systems are compared, the overweight trucks cited at the stationary weighing station were only a tiny fraction (8.6%) of the actual overweight populations recorded by the WIM sensors on the main lanes in New Jersey. In New York City, enforcement officers have been able to cite only 14.7% of the number of overweight trucks on and near Interstate Highway I278 between February and December of 2021. Therefore, direct overweight enforcement would be needed to prolong the structure's service life and provide a safe corridor to the taxpayers. One crucial aspect that needs to be added is how to calibrate the WIM system to provide reliable weight data for enforcement.

In this study, the team presented the effort to summarize different WIM standards, develop the calibration procedure for the A-WIM system, and implement the calibration procedure to prove that the A-WIM system is capable of complying with ASTM E1318-09 Type III accuracy.

Three prevailing WIM standards were compiled and compared, ASTM E1318-09, COST 323, and OIML R134-1. At least three trucks are required for an excessive number of calibration/optimization tests to meet the accuracy and compliance level and the Type-Approval test requirement of the ASTM E1318-09. The calibration and optimization tests provided the accuracy and compliance required in ASTM E1318-09 even though the pavement conditions did not meet the ASTM E1318-09 requirement. Based on the preliminary analysis of the change in the number of trucks after the enforcement, direct enforcement would reduce the number of overweight trucks by up to 76.9% for > 10% overweight trucks. More in-depth study would be required to evaluate the efficiency of direct enforcement.

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Section 1 – Introduction

The national roadway infrastructure, including bridges and pavement, has handled substantial daily truck traffic. While trucks have been integral to the freight movement network infrastructure in distributing goods and services to various communities, many trucks are often overloaded beyond the FHWA legal load limits. Overloading from illegally heavy trucks is one of the primary causes of the deterioration of aging pavement and bridges. In addition, overweight trucks require longer stopping distances and are more likely to roll over during accidents, which would cause several casualties and threaten public safety. Accordingly, the infrastructure suffers from significant deterioration because of the existing environmental conditions exacerbated by the increasing and substantial number of overweight trucks. Vehicles on Interstate highways must conform to the Federal Bridge Formula (FBF), designed to protect bridges from truck overloads beyond the legal limits. The enforcement regulation has been executed at the stationary weighing stations across the nation, especially at the borders between states.

Vehicles on Interstate highways must conform to the Federal Bridge Formula (FBF), designed to protect bridges from truck overloads beyond the legal limits. To date, the enforcement regulations have been executed at stationary weighing stations across the nation, especially at the borders between states. However, the stationary stations have limited resources for effective enforcement because: (1) the number of stationary weighing stations is not spatially well distributed across the nation; (2) the operation hours are limited; and (3) the number of enforcement officers is insufficient. Each state allows vehicles to exceed the FHWA weight limits on Interstate Highways under the grandfather rights. However, the stationary stations have limited resources for effective enforcement because the operation hours are limited, and the number of enforcement officers is insufficient.

Additionally, based on a previous study (Nassif et al. 2016), the number of permit overweight trucks is only 4% of the total overweight trucks observed at NJ WIM stations. In New Jersey, it was also noticed that the overweight trucks cited at the stationary weighing station were only a tiny fraction (8.6%) of the actual overweight populations recorded by the WIM sensors on the main lanes (NJDOT, 2010). In New York City, enforcement officers have been able to cite only 14.7% of the number of overweight trucks on and near Interstate Highway I278 between February and December of 2021. Figure 1 summarizes the percent of overweight trucks relative to the ADTT for each US State based on the LPTT data. The overall overweight rate out of ADTT is 13.2%, based on the data. Therefore, the overweight enforcement practices at the stationary weighing stations and mobile enforcement units are ineffective in reducing the percentage of overweight trucks. Moreover, overweight enforcement in urban areas with congested traffic is even much less effective due to the lack of sufficient shoulder space for enforcement officers to pull over the overweight trucks and to use the portable scale and for the transportation agencies to introduce stationary weighing stations.

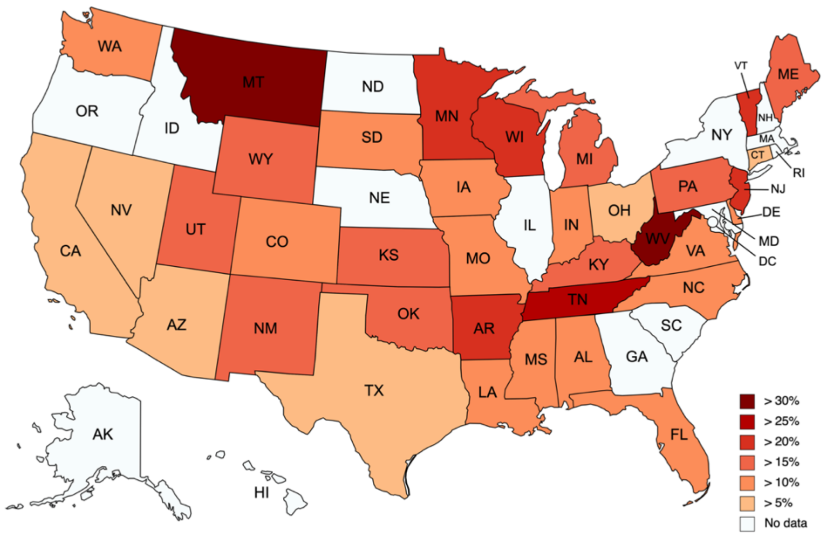


Figure 1 – Overweight percentage per State

The research team has studied the enforcement of overweight trucks under the C2SMART project. Calibration of the WIM system is crucial to enforcing overweight trucks solely by the WIM system. Therefore, in this report, the team reviewed several prevailing WIM standards to develop the entire process to calibrate the WIM system for using overweight enforcement. This includes a selection of calibration trucks, selection of accuracy, calibration procedure, etc. The process developed in this study was applied to the BQE testbed collaborating with NYCDOT. In addition, the team evaluated the number of overweight trucks depending on the permissible error. This study also includes the continuous effort to establish a testbed to evaluate the advanced WIM (A-WIM) system to use an enforcement tool to identify overweight trucks.

Section 2 – Review of Different Calibration Procedures for the A-WIM System

2.1. Calibration Procedure for Automated Enforcement Overweight System

The team reviewed the calibration procedure of three prevailing WIM standards. 1-ASTM E1318-09, 2-OIML R134-1, and 3-COST 323. The team intended to select the governing procedure(s) that would provide the best outcome and results for the calibration based on the available resources. Based on the review and analysis of these prevailing standards and the limited types of trucks available at the NYCDOT yard, the team recommended the following trucks to NYCDOT to calibrate the A-WIM system at the testbed.

1- The team recommended a Class 9 truck applying the ASTM E1318-09 Type III standard for calibration.
2- To fully accommodate the ASTM E1318-09, the team recommended hiring another Class 9 truck with the split axle in the trailer's tandem.
3- To comply with the COST 323 N° 2.2 standard, the team recommended using a dump truck (Class 6 or Class 7).
4- For the OIML R134-1, a Class 5 rigid truck was recommended as a reference truck for calibration.

A procedure is given for on-site calibration of ASTM E1318-09 Type III WIM systems for enforcement purposes. This procedure shall be conducted by the user with the vendor's cooperation or by their authorized representatives as a fundamental part of every Type-Approval Test and is recommended for inclusion in every On-site Acceptance/Verification Test. It requires that two loaded and pre-weighed test vehicles (calibration trucks) will make multiple runs over the WIM sensors in each lane at specified speeds. The calibration procedure shall be applied again when the system and sensors are installed or updated or whenever site conditions or WIM-system components (including software and settings) have changed significantly. Recalibration shall be performed every 6 months. It is necessary to recognize the effects of the site-specific, speed-specific, and vehicle-specific influences on WIM-system performance and attempt to compensate for their adverse effects as much as practicable via on-site calibration.

2.2. Type of Calibration Trucks for Automated Enforcement Overweight System

The team compiled and compared the provisions for the calibration trucks specified in the four specifications: (1) ASTM E1317, (2) OIML R134-1, and (3) COST 323.

1. **ASTM E1318-09** requires two types of FHWA Class 9 trucks – 3S2 and 3S2 Split.
2. **OIML R134-1** requires one FHWA Class 5 truck as a reference for GVW purposes only and 2 or more other trucks among FHWA Class 6/7, FHWA Class 5/6 with a trailer or FHWA Class 8/9/10 for GVW and axle weights.

3. **COST 323** requires at least 3 or 4 trucks among FHWA Class 3 (2-axle Van), FHWA Class 5/6/7, FHWA Class 5/6 with trailer, and FHWA Class 9/10.
4. The classifications in the OIML R134-1 and COST 323 are different from those listed by FHWA because they are the European standards. Thus, the team attempted to compare and match the European classification with the FHWA classification. This comparison is shown in Appendix I.
5. Perhaps borrow the tables submitted before an update showing that the majority are Class 9 and Class 5, which will satisfy all four specifications. However, we suggest using Class 6, which will only meet OIML R134-1 and COST 323, not ASTM E1318.

Table 1 shows a summary of the comparison for the calibration trucks. The most common trucks are Class 5 and Class 9 trucks, followed by Class 6/7 and Class 5/6 with trailers. A minimum of three trucks is required to comply with the three specifications other than ASTM. Thus, the team recommends using two Class 9 trucks ASTM E1318-09 plus an additional Class 5 (per other specifications). The following trucks are listed with their priority.

- Class 9 (Type 3S2, 5-axle, Single Trailer Truck) (i.e., specified by all four specifications)
- Class 9 Split (Type 3S2 Split) (ASTM E1318-09)
- Class 5 (specified by two specifications except for ASTM E1318-09)
- Class 6 or Class 7 (3-axle or 4-axle, Single Unit Truck) (OIML R134-1 and COST 323)
- Class 6 with trailer (3-axle, Single Unit Truck + 2-/3- trailer) (OIML R134-1 and COST 323)

Standard	ASTM E1318-09	OIML R134-1	COST 323
Class 3 (2-Axle Van)	-	-	Class 3
Single Unit Truck (Class 5/6/7)	-	Class 5 (reference*) Class 6 or Class 7	Class 5, Class 6 or Class 7
Single Unit Truck with Trailer (Class 5/6/7)	-	Class 5 or Class 6 + Trailer	Class 5 or Class 6 + Trailer
Semi-Tractor Trailer (Class 8/9/10)	Class 9 (3S2) and Class 9 (3S2 Split)	Class 8, Class 9 or Class 10	Class 9 or Class 10
Minimum number of trucks required for calibration	2 x Class 9	Class 5 (reference*) and 2+ other trucks	3+ trucks

Table 1. Calibration Truck Comparison between ASTM E1318-09, OIML R134-1, and COST 323 (* Class 5 reference truck is required for OIML R134-1 and used only for GVW verification.)

ASTM E1318-09

The test unit for calibration loading shall comprise two loaded, pre-weighed, and measured calibration trucks that each make multiple runs over the WIM sensors in each lane at prescribed speeds. Both shall be FHWA Class 9 (5-axle semi-tractor trailer); one shall be Type 3S2, and the other shall be Type 3S2 Split. The axle spacings for Type 3S2 shall be 14 ft or less between the first (steering) and second axle (front axle of the driver tandem) and 5.0 ft or less between the axles within two tandems (tractor and trailer). The axle spacing for Type 3S2 Split shall be 18 ft or more between the steering and the front of the driver tandem and 9.0 ~ 12 ft between the axles within two tandems. The reference vehicles shall be used for tests in the unloaded and loaded conditions.

OIML R134-1

The type and number of reference vehicles to be used for testing shall represent the range of vehicles at each site. The calibration trucks shall be FHWA Class 5 Single Unit Truck and a minimum of two other reference vehicles listed below. Different axle configurations, tractor/trailer configurations, tractor/trailer linkage systems, and suspension systems shall be used as appropriate.

- FHWA Class 6 or 7 Single Unit Truck,
- FHWA Class 5 or 6 Single Unit Truck with a 2/3-Axle Draw-Bar Trailer, or
- FHWA Class 8, 9, or 10 Semi-Tractor Trailer Truck.

The two-axle rigid vehicle shall be used as the reference vehicle for determining the actual conventional value of static reference single-axle loads and as one of the reference vehicles for in-motion tests. The other reference vehicles shall be selected to cover, as far as practicable, the weighing range for which the instrument is approved.

COST 323

Proper initial calibration requires to be done with two test vehicles according to the traffic to be weighed:

- FHWA Class 5/6/7 Single Unit Truck (2-4-axle rigid lorry) loaded at 22-56 kips
- FHWA Class 8/9/10 Semi-Tractor Trailer Truck (a tractor with a semi-trailer) loaded at 67+ kips

Each calibration truck shall be loaded to at least 90 % of its registered gross vehicle weight (GVW). The load shall be a non-shifting, solid, and approximately symmetric load (side-to-side) in excellent mechanical condition. Any load that may be fluctuated during acceleration and deacceleration, such as but not limited to liquid, sand, fine aggregate, etc., shall not be used. Special care shall be exercised to ensure that the tires on the test vehicles are in excellent condition (preferably dynamically balanced) and inflated to recommended pressures.

Both calibration trucks shall be loaded and weighed at the static scale within 24 hours of the starting calibration test to measure the reference-value loads and weights. All For reference-value loads and weights against which to compare WIM-system estimates, use the calculated arithmetic mean value (rounded to the nearest 100 lb (50 kg)) for the respective wheel load, axle-load, tandem-axle-load, and GVW values that resulted from successfully weighing each test vehicle three or more times. Record these mean values for future reference.

Measure the distance between adjacent axles on each test vehicle and record these data to the nearest 0.1 ft (0.03 m) as axle-spacing reference values. Also, measure the distance between the front-most and the rear-most axles on each test vehicle and record these data to the nearest 0.1 ft (0.03 m) as wheelbase reference values.

These test vehicles shall have air-type suspension on all dual-tired axles; however, another suspension type deemed by the user conducting the test to be representative of most vehicles of their type operating at the site may be approved by the user. The suspension type of every test vehicle used for calibration loading shall be carefully documented in the test report (preferably including video images).

Most Frequent Trucks at BQE2

Truck counts and percentages for both directions (QB and SIB) at BQE2 were determined. Table 2 and Table 3 summarize the most frequent trucks – Class 5 (2-axle single unit truck), Class 9 (5-axle semi-tractor trailer truck), and Class 6 (3-axle single unit truck). Three FHWA class trucks are the dominant truck types constituting 75% of the total trucks.

Rank	Class	Truck Counts	%
1	5	76657	33.1%
2	9	53027	22.9%
3	6	41938	18.1%
4	8	21243	9.2%
5	4	16175	7.0%
6	7	11474	5.0%
7	10	5475	2.4%
8	11	3350	1.4%
9	13	1003	0.4%
10	12	965	0.4%
Total		**231307**	**100%**

Table 2. Most Frequent Trucks at BQE2 for Staten Island Bound

Rank	Class	Truck Counts	%
1	5	79260	34.0%
2	9	73665	31.6%
3	6	36217	15.5%
4	8	17531	7.5%
5	4	14349	6.2%
6	10	5065	2.2%
7	7	4223	1.8%
8	11	2598	1.1%
9	13	307	0.1%
10	12	82	0.0%
Total		**233297**	**100%**

Table 3. Most Frequent Trucks at BQE2 for Queens Bound

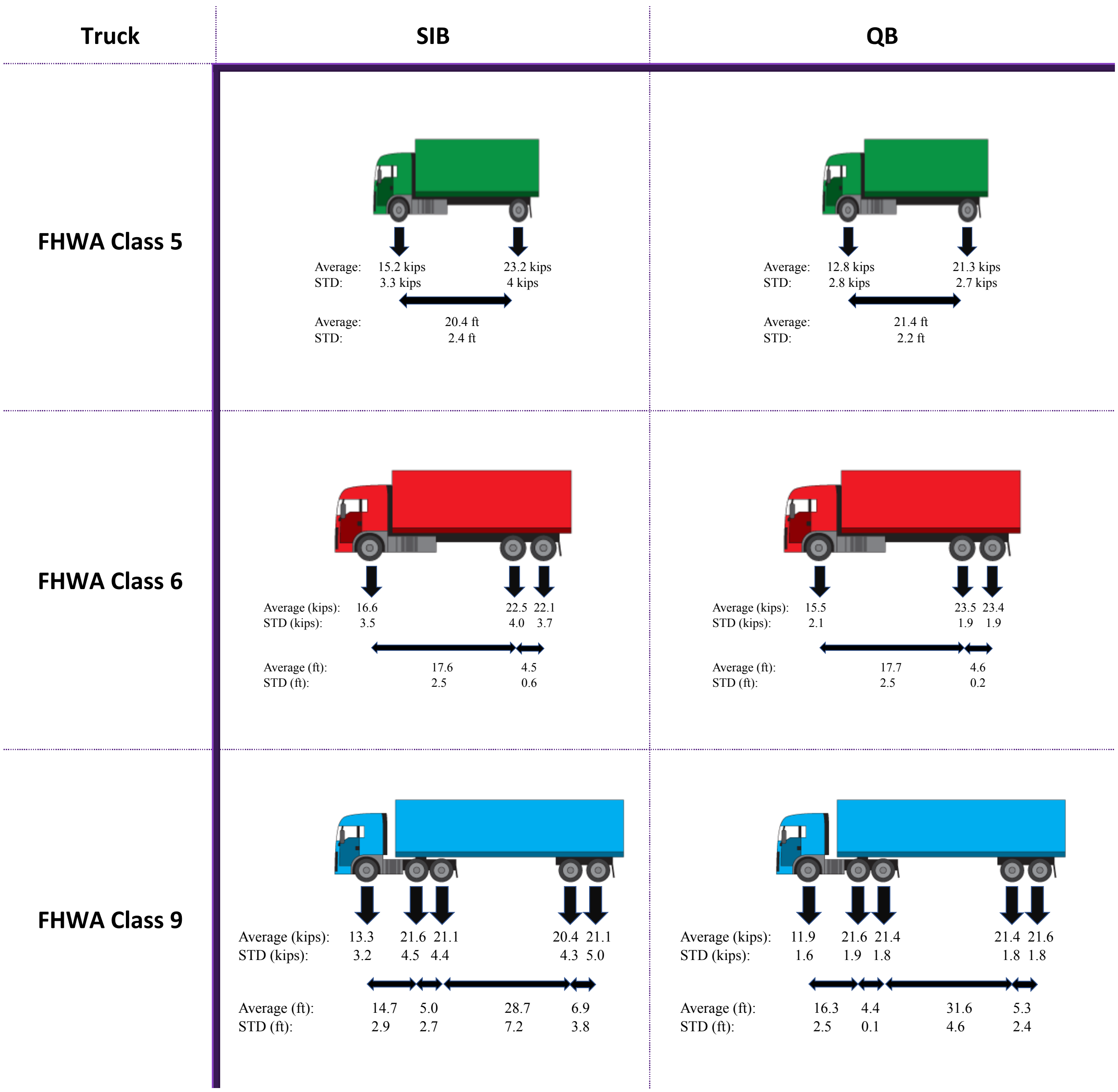


Table 4. Most Frequent Trucks at BQE Testbed

Weighing Static Vehicles

All axle-load scales and multi-platform vehicle scales used for weighing static vehicles shall be certified as meeting the applicable maintenance tolerance specified in NIST Handbook 44 within 30 days prior to use. The tire-pavement contact surfaces of all tires on the vehicle being weighed shall be within 0.25 in. (6 mm) of a plane passing through the load-receiving surface(s) of the multi-platform vehicle scale or axle-load scales whenever any tire-load measurement is made. The maximum slope of this plane from horizontal shall be 2 %. Suitable blocking or mats may be utilized, or the weighing device(s) may be recessed into the pavement surface to provide the required vertical orientation of the tire-pavement contact surfaces. Axle-load shall be determined by positioning each axle to be weighed either simultaneously or successively on an axle-load scale(s) or a multi-platform vehicle scale. Axle-group load shall be determined either by positioning all axles in the group simultaneously on the required number of weighing devices (preferred) or by successively positioning each axle in the group on an axle-load weighing device. The number of movements of the vehicle to accomplish the successive tire-load measurements shall be minimized. A tire-load measurement shall be made only when the brakes of the vehicle being weighed are fully released and all tires are correctly positioned on the load-receiving surface(s) of the weighing device(s). Suitable means (for example, chocks) shall be used to keep the tires adequately positioned while the brakes are released. Gross vehicle weight (GVW) shall be the sum of all axle loads for the vehicle if axle-load scales are used. If the multi-platform vehicle scale is used, the GVW shall be measured by positioning the entire vehicle on the scale.

2.3. Selection of Accuracy Level and Calibration Runs for the A-WIM System

ASTM E1318-09

After agreement by both the user and the vendor, using traffic control procedures approved by the appropriate public authority and other reasonable safety precautions, have each test vehicle make five or more runs over the sensors in each lane at an attempted speed of approximately 5 mph (8 km/h) less than the maximum speed, and then five or more additional runs at an attempted speed about 5 mph (8 km/h) greater than the minimum speed. At each speed, one or more runs shall be made with the test vehicle tires near the left-hand lane edge and one or more runs with the test vehicle tires near the right-hand lane edge. The other runs shall be made with the test vehicle approximately centered in the lane. Make the calculations for the 20 or more runs (five or more runs at two speeds by two vehicles) of the test vehicles as summarized in Table 5. Then, compare all the results with the functional performance requirement for the Type III WIM system to check whether the WIM system provides accuracy at the tolerance for 95% compliance, as summarized in Table 6. If the results do not comply with the functional performance requirement, repeat the test until they comply with the requirement:

Test Vehicle	Speed	Load	Number of Runs
Class 9, 3S2 & Class 9, 3S2 Split	v_high = max speed - 5 mph	85-95% of GVW	5 runs per truck (3 runs on center, 1 run on right lane edge, and 1 run on left lane edge))
Class 9, 3S2 & Class 9, 3S2 Split	v_low = min speed + 5 mph	85-95% of GVW	5 runs per truck
			20 runs in total

Table 5. ASTM E1318-09 Calibration Truck Requirement

Function	Wheel Load	Axle Load	Axle-Group Load	Gross-Vehicle Weight	Speed	Axle-Spacing and Wheelbase
Type I	±25%[A]	±20%	±15%	±10%	±1 mph (2 km/h)	±0.5 ft (0.15 m)
Type II	N/A	±30%	±20%	±15%	±1 mph (2 km/h)	±0.5 ft (0.15 m)
Type III	±20%	±15%	±10%	±6%	±1 mph (2 km/h)	±0.5 ft (0.15 m)
Type IV Value ≥lb[B] ± lb	5,000 300	12,000 500	25,000 1,200	60,000 2,500	±1 mph (2 km/h)	±0.5 ft (0.15 m)
Remarks	A. Tolerance for 95% Complaince. 95% of the respective data iems produced by the WIM system must be within the tolerance. B. Lower values are not usually a concern in enforcement					

Table 6. ASTM E1318-09 Accuracy Requirements

OIML R134-1

Prior to any test, adjust the instrument under test in-situ and in accordance with the manufacturer's specifications. All weighing operations shall be started with the reference vehicle positioned in advance of the approach apron at a distance sufficient for the vehicle to be traveling at a steady speed before arriving at the apron. Table 7 summarizes the testing runs. Test runs shall be conducted using the two-axle rigid reference vehicle (FHWA Class 5) plus a minimum of two other reference vehicles (Class 5/6 with a draw-bar trailer, Class 6/7 or Class 8/9/10) with each vehicle unloaded and loaded. The speed of the vehicle shall be kept as constant as feasible during each in-motion test run. A minimum of 90 runs shall be performed. For each vehicle and loading condition, at least five test runs shall be performed, with three test runs made over the center of the load receptor, one test run made to the left side of the load receptor, and one test run made to the right side of the load receptor. The five test runs shall be conducted at the following speeds that are within the range of speeds for which the instrument is to be evaluated:

- near maximum operating speed, v_max
- near minimum operating speed, vmin
- near the center of the range of operating speeds

Record the vehicle masses as they are displayed or printed by the instrument under test, and calculate the errors according to the vehicle reference weights. No error shall exceed the applicable maximum permissible error for the specified accuracy class as below in Table 8.

For the two-axle rigid reference vehicle, the maximum difference between the indicated single-axle load for in-motion tests and the true conventional value of the static reference single-axle load shall not exceed one of the following values, whichever is the greater (100% compliance):

For all reference vehicle types except the two-axle rigid reference vehicle, the maximum difference between any indicated single-axle load or, if required, any axle-group load recorded during in-motion tests and the corrected mean single-axle load or the corrected mean axle-group load, respectively, shall be one of the following values, whichever is the greater (100% compliance):

Test Vehicle	Speed	Load	Number of Runs
One Class 5 & Two Other Trucks	v_max (max operating speed) & v_min (min operating speed(& v_mean (mean of max and min)	100% GVW & 50+% GVW (unloaded)	5 runs per speed, load, and truck (30 runs per truck)
			90 runs in total

Table 7. OIML R134-1 Calibration Truck Requirement

Accuracy Class for single axle and axle group load	Two-axle rigid reference vehicle (FHWA Class 5 Single Unit Truck)		Other reference vehicles (FHWA Class 5/6 with a draw-bar trailer, FHWA Class 6/7, or FHWA Class 8/9/10), n = number of axle per group, n = 1 for single axle	
	Calibration	**In-Service**	**Calibration**	**In-Service**
A	± 0.25%	± 0.5%	± 0.5% x n	± 1.0% x n
B	± 0.50%	± 1.0%	± 1.0% x n	± 2.0% x n
C	± 0.75%	± 1.5%	± 1.5% x n	± 3.0% x n
D	± 1.00%	± 2.0%	± 2.0% x n	± 4.0% x n
E	± 2.00%	± 4.0%	± 4.0% x n	± 8.5% x n
F	± 4.00%	± 8.0%	± 8.0% x n	± 16.0% x n

Table 8. OIML R134-1 Accuracy Requirements

COST 323

The assessment of the accuracy of a WIM system requires a test. The more extensive the test plan, the higher the confidence of the occlusions. This means that the client risk decreases as the test becomes more extensive while the test cost increases. The client risk is governed by the probability of an individual error concerning the static load or weight lying outside of the specified confidence interval. An upper bound of this risk is fixed at 5% and a confidence level of 95%. The accuracy classes are summarized in Table 8.

Three main test plans are proposed as summarized in Table 10, two of these being divided into two sub-plans to comply with the client's requirement and resources depending on the test period length. According to the number of test vehicles, and load and speed cases, the test may be carried out in the following 4 categories. For the enforcement calibration, (R1) limited reproducibility category shall be applied. After the initial calibration as (R1) category, the enforcement system may be calibrated using the (r2) extended repeatability category.

- (r1) full repeatability – Recommended for periodical checks by carrying out several times per year.
- (r2) extended repeatability – Recommended for a yearly check of a WIM system.
- (R1) limited reproducibility – Recommended for a newly installed WIM system or after repair or modification of the system.
- (R2) full reproducibility

Criteria	Domain of Use	A(5)	B+(7)	B(10)	C(15)	D+(20)	D(25)	E
Gross Weight	> 3.5 t	5	7	10	15	20	25	> 25
Axle Load	> 1 t							
Group of Axles		7	10	13	18	23	28	> 28
Single		8	11	15	20	25	30	> 30
Axle of a Group		10	14	20	25	30	35	> 35
Speed	> 30 km/h	2	2	4	6	8	10	> 10
Inter-axle distance		2	3	4	6	8	10	> 10
Total flow		1	1	1	3	4	5	> 5

Table 9. COST 323 Accuracy Requirements (Confidence Interval Width δ (%))

N°1.1. – This test shall be performed in a single day for periodical checks.

N°1.2. – This test shall be performed in a single day for a yearly check after initial calibration. This shall not be applied if a modification to the roadway, sensors, and system is made.

N°2.2. – This test shall be performed in 1-3 consecutive days for a newly installed WIM system or after repair or modification of the system and pavement.

Truck	Speed	NO 1.1. (r1) Half Load	NO 1.2. (r2) Half Load	NO 2.2. (R1) Half Load	NO 2.2. (R1) Full Load
2/3/4-Axle Rigid Body (Class 5/6/7) & 4/5/6-Axle Semi-Trailer (Class 8/9/10)	1.2 Vm	2 (0)*	3 (0)	8 (0)	5 (0)
2/3/4-Axle Rigid Body (Class 5/6/7) & 4/5/6-Axle Semi-Trailer (Class 8/9/10)	Vm	6 (7)	9 (10)	14 (20)	10 (13)
2/3/4-Axle Rigid Body (Class 5/6/7) & 4/5/6-Axle Semi-Trailer (Class 8/9/10)	0.8 Vm	2 (3)	3 (5)	8 (10)	5 (7)
Total Runs		20 (20)	30 (30)	60 (60)	40 (40)

Table 10. COST 323 Calibration Truck Requirement (* Runs in the parentheses is applied if 1.2Vm exceeds the speed limit.)

2.4. Selection of the Accuracy Level Needed for Automated Enforcement

Based on the previous communication with NYCDOT, the team reviewed various specifications and different levels of accuracy in the following summary.

ASTM E1318-09

- Accuracy: ASTM Type III (GVW 6%, Axle 15%, and Tandem 10% at 95% compliance)
- Calibration Truck: Two Class 9 Trucks
  - Class 9, 3S2: The first axle spacing < 14 ft & tandem of trailer spacing < 5 ft
  - Class 9, 3S2 Split: The first axle spacing > 18 ft & tandem of trailer spacing = 9 ~ 12 ft
  - Air-type suspension on all dual-tire axle is recommended.
  - GVW >= 90% of its registered GVW

OIML R134-1

- Accuracy: Class F10 (GVW 5% for verification and 10% in service; axle weight 8% for verification and 16% in service at 100% compliance)
  - This level of accuracy is adopted by the Czech Republic, Hungary, Russia, and China
  - Similar to ASTM E1318-09 Type III.
- Calibration Truck: Reference vehicle (Class 5) and 2+ other vehicles (Class 6/7 or Class 8/9/10)
- The description in the parentheses next to FHWA Classification is the exact wording in OIML R134-1.
  - Class 5 (2-axle rigid vehicle): Reference vehicle
  - Class 6/7 (3-/4-axle rigid truck)
  - Class 8/9/10 (4+ axle articulated truck)
  - Class 5/6 with a draw-bar trailer (2-/3-axle rigid vehicle and one 2-/3-axle draw-bar trailer)
    - At least two of three other vehicles
  - GVW = 100% and 50+% of registered GVW

COST 323

- Accuracy: ASTM E1318-09 Type III equivalent accuracy will be between Class A(5) and Class B+(7).
  - Class A(5) (GVW 5%, Single 8%, and Tandem 7% at 95% compliance)
    - Legal purposes such as the enforcement of legal weight limits and other particular needs
  - Class B+(7) (GVW 7%, Single 11%, and Tandem 10% at 95% compliance)
    - Enforcement of legal weight limits in particular cases if Class A(5) requirements may not be satisfied.
- Calibration Truck: At least 3 or 4 test vehicles among Class 3, Class 5 ~ Class 10 below
- The description in the parentheses next to FHWA Classification is the exact wording in COST 323.
  - Class 3 Van (2-axle rigid van) with GVW around 7.7 kips
  - Class 5/6/7 (2-/3-/4-axle rigid lorry truck) with GVW = 22 ~ 55 kips
  - Class 9/10 (a tractor with a semi-trailer supported by tandem or tridem axle) with GVW > 66 kips
  - Class 5/6 with a trailer (a lorry with a trailer (2+2, 3+2, 2+3, 3+3 axles) with fully loaded

Based on the above review of accuracy from all specifications, the team recommends using 5% on GVW and 8% on a single axle weight for the initial calibration. Also, 10% on GVW and 16% on single axle weight in-service (operation) are recommended. This recommendation is slightly better than ASTM Type III and equivalent to OIML F10.

2.5. Summary of Different Standards

The following observations are a summary of the review of each standard concerning the following metrics: 1 – Accuracy Tolerance, 2 – Calibration truck, 3 – Calibration test, 4 – Other:

Accuracy and Tolerance: COST 323 Class A(5) is almost equivalent to the ASTM Type III. All three standards require 95% compliance, while the OIML R134-1 requires 100% compliance.

Calibration Truck: ASTM E1318-09 Type III requires two Class 9 calibration trucks - one 3S2 and the other 3S2-Split with at least 90% of the registered GVW (in general 72 kips). The OIML R134-1 requires a minimum of 3 trucks (Class 5, Class 6~7, Class 8 ~10, and 4+axle articulated truck) loaded and unloaded. The COST 323 requires a minimum of 3-4 trucks selected according to the European Truck Classifications.

Number of Test Runs for the Calibration Truck: ASTM E1318-09 requires a minimum of 20 runs in total or 10 runs per truck. This includes 5 runs each at low and high speeds per truck, and it requires at least 1 run on each edge of the road at each speed (low and high) regardless of the truck. OIML R134-1 mandates a minimum of 90 runs in total or 30 runs per truck. This includes 5 runs at 3 speeds and loaded/unloaded conditions. COST 323 requires a minimum of 110 runs in total. This includes 2-3 speed levels and loaded/unloaded conditions.

Required Speed for the Calibration Truck during Test: ASTM E1318-09 shall be performed 5 mph below the maximum speed and 5 mph above the minimum posted speed. The OIML R134-1 requires 3 speeds the minimum operation speed, the maximum operation speed, and the mid-speed between the minimum and the maximum speeds. The COST 323 recommends 3 speeds at the mean speed, 80% of the mean speed, and 120% of the mean speed of the site.

Additional Requirements for Accuracy: The ASTM E1318 -09requires Type-Approval Test Loading for 51 vehicles (randomly selected Class 5 ~ Class 13 from the regular truck traffic, other than using the calibration trucks) for any type of approval (Type I, II, III, and IV), while OIML R134-1 have no such requirement.

Pavement Surface Preparation: ASTM E1318-09 recommends preparing the pavement surface 200 ft before and 100 ft after WIM sensors. The OIML 134-1 mandates making the concrete or rigid apron 53 ft before the WIM sensors. The COST 323 defines the Site Class I~III depending on the rutting and IRI.

Section 3 – Development and Implementation of Calibration Procedure for the A-WIM System

3.1. Calibration Test Requirements

The calibration test requires three or four (3~4) test trucks followed by a verification test. Table 11 summarizes the calibration trucks per WIM standards.

FHWA Class	NYCDOT Fleet	ASTM	OIML	COST
Class 9	Available but axle spacing not complying with ASTM	Mandated	Required	Required
Class 9 Split	Not available	Mandated	Required	Required
Class 5	Not available	Not required	Mandated	Required
Class 6/7	Available	Not required	Required	Required
Class 5/6 with trailer	Not available	Not required	Required	Required
Minimum number of trucks required		2 x Class 9	1 x Class 5 + two out of Class 6/7, Class 8/9/10, and Class 5/6 with trailer)	3~4 out of Class 5/6/7, Class 8/9/10, and Class 5/6/7 with trailer)

Table 11. Compliance of Calibration Trucks for WIM Standards

Calibration Trucks Requirements

- Class 9 Truck (Standard 3S2): ASTM, OIML, COST
  - 3-axle tractor + 2-axle trailer (5-axle FHWA Class 9 Truck)
  - ASTM E1318-09 Requirement
    - First axle spacing < 14 ft or > 18 ft.
    - Tandem spacing < 4 ft.
    - Air-type suspension on all dual-tire axles
    - Load = > 90% of GVWR
      - OIML R134-1: 100% and 50% of GVWR
      - COST 323: 66+ kips

    - The combination of tractor 890TT and asphalt trailer 16FB would be configured as a Class 9; however, it would not comply with the axle spacing requirement (the steering and the front axle of the tandem shall be < 14 ft or > 18 ft).
    - Air-type suspension is highly recommended to improve test accuracy as it helps get back to a stable state quicker.
    - The load should be a minimum of 72 kips (90% of the FHWA GVW limit of 80 kips)
- <u>Class 9 Truck with split tandem (3S2 Split): ASTM, OIML, COST</u>
    - 3-axle tractor + 2-axle trailer (5-axle FHWA Class 9 Truck)
    - ASTM E1318-09 Requirement
        - First axle spacing < 14 ft or > 18 ft.
        - Tandem spacing = 9 ~ 12 ft.
        - Air-type suspension on all dual-tire axles
        - Load = > 90% of GVWR
            - OIML R134-1: 100% and 50% of GVWR
            - COST 323: 66+ kips
    - No fleets would comply with the Class 9 Split configuration. Therefore, a Class 9 truck with a split tandem should be employed.
    - Air-type suspension is highly recommended to improve test accuracy as it helps get back to a stable state quicker.
    - The load should be a minimum of 72 kips (90% of the FHWA GVW limit of 80 kips)
- <u>Class 5 Truck: OIML, COST</u>
    - 2-axle single unit truck (2-axle FHWA Class 5 Truck)
    - ASTM E1318-09 Requirement
        - Load (no requirement)
            - OIML R134-1: 100% and 50% of GVWR
            - COST: 22 ~ 55 kips (close to max GVWR)
    - The Dually Pickup 1286B would *not* be appropriate for this calibration as it is Class 3 (axle spacing less than 15 ft).
    - There is no Class 5 truck, and it should be employed.
    - The truck shall be loaded with at least 90% of each registered GVW (minimum 22 kips).
- <u>Class 6 Truck: OIML, COST</u>
    - 3-axle single unit truck (3-axle FHWA Class 6 Truck)
    - ASTM E1318-09 Requirement
        - Load (no requirement)
            - OIML R134-1: 100% and 50% of GVWR
            - COST 323: 22 ~ 55 kips (close to max GVWR)
    - FE Dump truck would be OK.
    - The load should be a minimum of 72 kips (90% of the FHWA GVW limit of 80 kips).

- This truck could be used as this is one of the predominant truck types on BQE.

Table 12 summarizes the NYCDOT fleet and its compliance with standards.

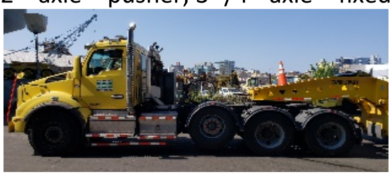
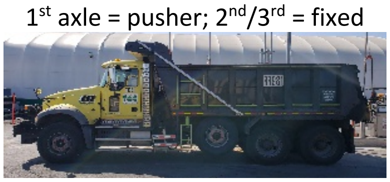
Model & Picture	GVWR	Axle Spc (ft)	Note
Truck Tractor 890TT with a tridem. 2nd axle = pusher; 3rd/4th axle = fixed 	74k (92k with a pusher)	S12 = 11.7 S23 = 4.3 (S13 = 15.9) S34 = 4.4	The axle spacing between the steering and the front of the tandem is approx. 16 ft, which does not comply with ASTM E1318-09 (<14 ft or >18 ft.)
Lowerboy Trailer 172T with a tridem 	75k	Kingpin ~ 1st axle = 41.2 ft S12 = 4.6 S23 = 4.6	Tractor truck to haul this trailer would not comply with ASTM E1318-09 requirement. Also, this is too long for the calibration test.
Asphalt Trailer 16FB with a tridem 1st axle = pusher; 2nd/3rd = fixed 	46k (66k with a pusher)	Kingpin ~ 1st axle = 15.5 ft S12 = 4.6 S23 = 4.6	Tractor truck to haul this trailer would not comply with ASTM E1318-09 requirement.
Dump Trailer with a tridem 1st axle = pusher; 2nd/3rd = fixed 	N/A	N/A	Tractor truck to haul this trailer would not comply with ASTM E1318-09 requirement.
FF Dump Truck with a tridem 1st axle = pusher; 2nd/3rd = fixed 	74k (92k with a pusher)	S12 = 12.8 S23 = 4.2 (S13 = 17.0) S34 = 4.6	This is good for calibration if NYCDOT agrees to use this truck as one of the test trucks.

Table 12. Selection of Calibration Trucks from NYCDOT Fleets

Calibration Speeds Requirements

- S1 = 40 mph (Max posted speed – 5 mph)
- S2 = 10 mph (Min posted speed + 5 mph): Not applicable for IRD system
- S3 = 25 mph (intermediate speed)
- Speed may vary depending on the traffic condition
- The difference between S1 and S2 should be more than 20 mph
- Truck shall maintain a speed 50 ft before and after WIM sensors.

Calibration Runs Requirements

- 2 runs per each speed and truck on the right lane (= 6 runs per truck = 18 runs in total)
- Trucks shall run at least 100 ft of headway to minimize any dynamic effect between trucks on the WIM sensors.
- Trucks shall be running in the center of each lane.

3.2. Verification Procedure

Verification Speed Requirements

- S1 = 40 mph (Max posted speed – 5 mph)
- S2 = 10 mph (Min posted speed + 5 mph)
- S3 = 25 mph (intermediate speed) – Only for IRD system
- Speed may vary depending on the traffic condition
- The difference between S1 and S2 should be more than 20 mph
- The truck shall maintain a speed 50 ft before and after WIM sensors.

Verification Runs Requirements

- 5 runs per each speed and truck (= 10 runs per truck = 30 runs in total)
- Trucks shall run at least 100 ft of headway to minimize any dynamic effect between trucks on the WIM sensors.
- Trucks shall be running in the center of each lane otherwise specified.

3.3. Selection of Calibration Testing Trucks

The team visited the Harper Street Yard in Corona, NY, on 10/15/2020 to check the calibration trucks and to make records of axle configurations and axle weights. Four portable scales were used to measure the wheel weight and GVW (see Figure 2(a)). The GVW was measured again using a static scale (see Figure 2(b)). In some cases, the GVW measured by the static scale was different from that measured by the portable scale. Then, the wheel weights and axle weights were adjusted proportionally to the static scale GVW. The load was the Jersey barrier for Class 9 with a split axle (see Figure 3(a)), and the recycled asphalt for all other trucks except Class 5 of 1197B truck which had no load (see Figure 3(b)). The team measured the axle spacing (between the center of each axle) and the track width (between the center of each wheel). Figure 4 shows some examples of this measurement.

(a) Portable Scale

(b) Static Scale

Figure 2 – Weight Measurement using Portable Scale and Static Scale

(a) Jersey Barrier

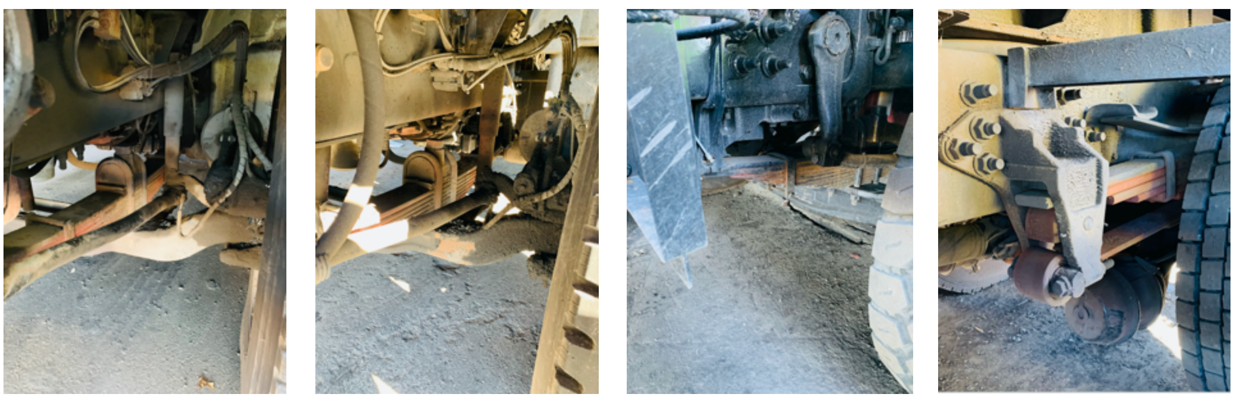
(b) Recycled Asphalt Pile

Figure 3 – Load Type used for Calibration Trucks

(a) Wheel Width (b) Axle Spacing

Figure 4 – Axle Spacing Measurements

All trucks were equipped with multi-leaf suspension except the Class 5 1197B Truck. The suspension pictures are summarized in Figure 5.



(a) R1 (b) R2 (c) R3 (d) R4

Figure 5 – Truck Suspensions

A total of 5 trucks were employed for this calibration test, as listed below. These trucks were carefully selected to comply with various standards (ASTM, OIML, and COST). Figure 6 through Figure 10 show the truck configuration (axle weight, wheel weight, axle spacing, and track width). The adjusted weights (wheel, axle, and gross) and the measured axle spacing information are summarized in Appendix I. The weight tickets of the static scale are shown in Appendix II.

Truck R1: Class 9 Truck (Standard 3S2)

- Standards: ASTM, OIML, and COST
- Configuration: tractor 882T + dump trailer
- GVW = approx. 79 kips with recycled asphalt
- Length (wheelbase) = 479” or 39’-11’
- Suspension = multi-leaf suspension

Truck R2: Class 9 Truck (Standard 3S2 with a split tandem)

- Standards: ASTM, OIML, and COST
- Configuration: tractor 883T + lowboy trailer 172T
- GVW = approx. 79 kips with recycled asphalt
- Length (wheelbase) = 790” or 65’-10’
- Suspension = multi-leaf suspension

Truck R3: Class 6 Truck

- Standards: OIML and COST
- Configuration: dump truck 242FF
- GVW = approx. 71 kips with recycled asphalt
- Length (wheelbase) = 264” or 22’
- Suspension = multi-leaf suspension

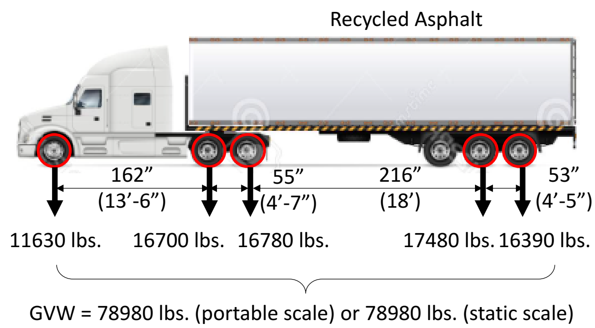
Truck R4: Class 5 Truck (Big)

- Standards: OIML and COST
- Configuration: dump truck 109E
- GVW = approx. 32 kips with recycled asphalt
- Length (wheelbase) = 230” or 19’-2’
- Suspension = multi-leaf suspension

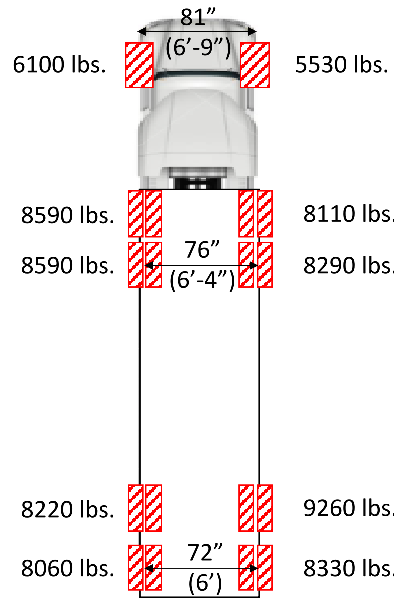
Truck R5: Class 5 Truck (Small)

- Standards: OIML and COST
- Configuration: pickup truck with dual rear tire 1197B
- GVW = approx. 10 kips with recycled asphalt
- Length (wheelbase) = 159” or 13’-3”
- Suspension = air-suspension

(a) Test Truck R1



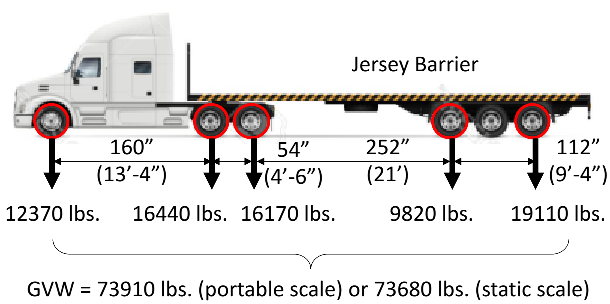
(b) Axle Weights and Spacings



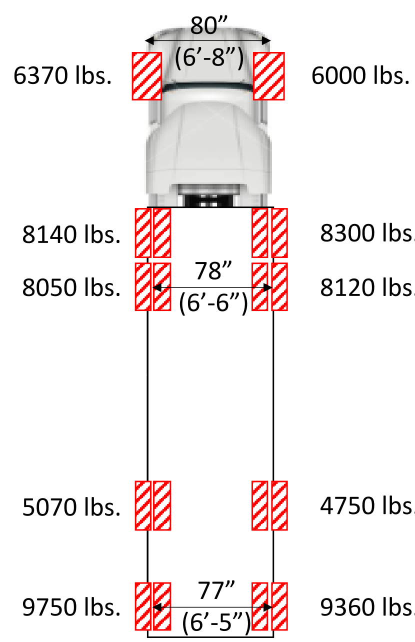
(c) Wheel Weights and Wheel Widths

Figure 6 – Truck R1, FHWA Class 9 (3S2), 5-axle Tractor Truck with Dump Trailer

(a) Test Truck R2



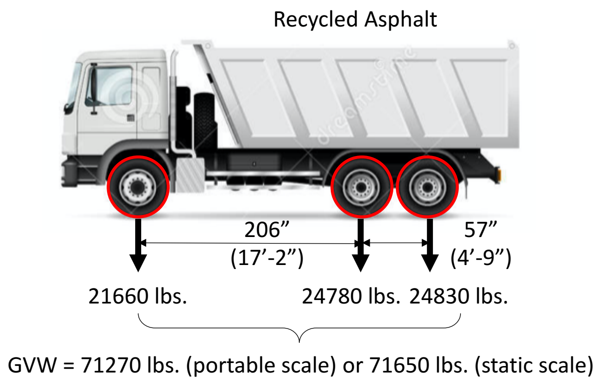
(b) Axle Weights and Spacings



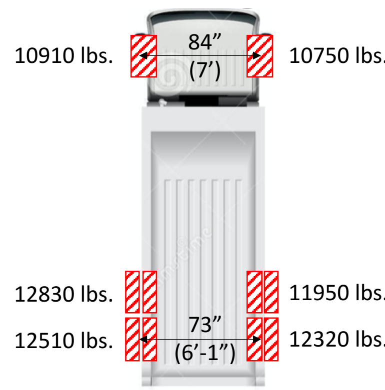
(c) Wheel Weights and Wheel Widths

Figure 7 – Truck R2, FHWA Class 9 with a split tandem (3S2 Split), 5-axle Tractor Truck with Lowboy Trailer

(a) Test Truck R3



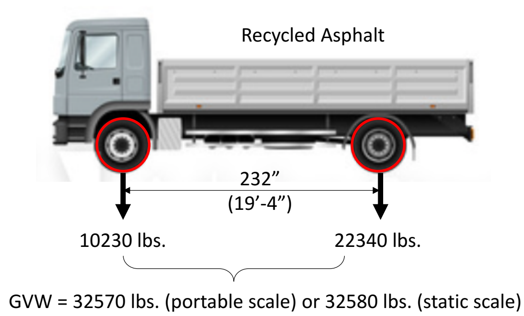
(b) (b) Axle Weights and Spacings



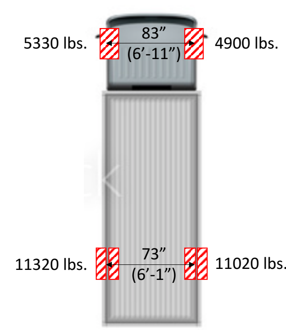
(c) Wheel Weights and Wheel Widths

Figure 8 – Truck R3, FHWA Class 5, 3-axle Dump Truck

(a) Test Truck R4



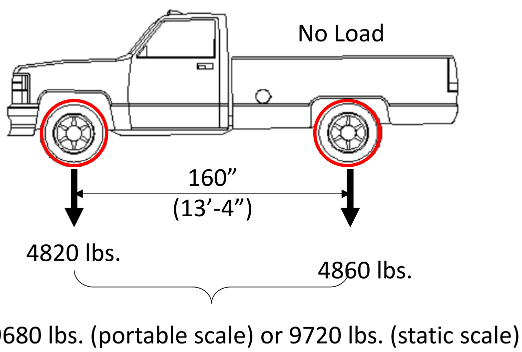
(b) Axle Weights and Spacings



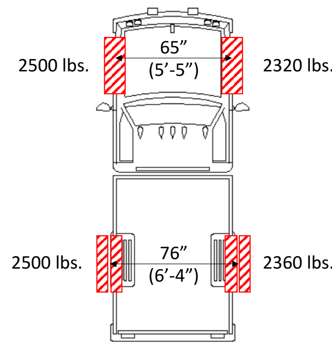
(c) Wheel Weights and Wheel Widths

Figure 9 – Truck R4, FHWA Class 5, 2-axle Dump Truck

(a) Test Truck R4



(b) Axle Weights and Spacings



(c) Wheel Weights and Wheel Widths

Figure 10 – Truck R5, FHWA Class 5, 2-axle Dump Truck (Class 3 with a dual rear tire)

3.4. Calibration Testing Plan and Process for Quartz Sensors

The testing process is summarized in Figure 11, which comprises three steps: calibration, verification, and optimization. The first step (calibration) is to determine the sensor factors based on the Class 9 trucks, and the second step (verification) is to verify the sensor factors for each truck determined throughout the first step. Then the verification results will be utilized to optimize the sensor factors to improve the accuracy based on the speeds and number of axles.

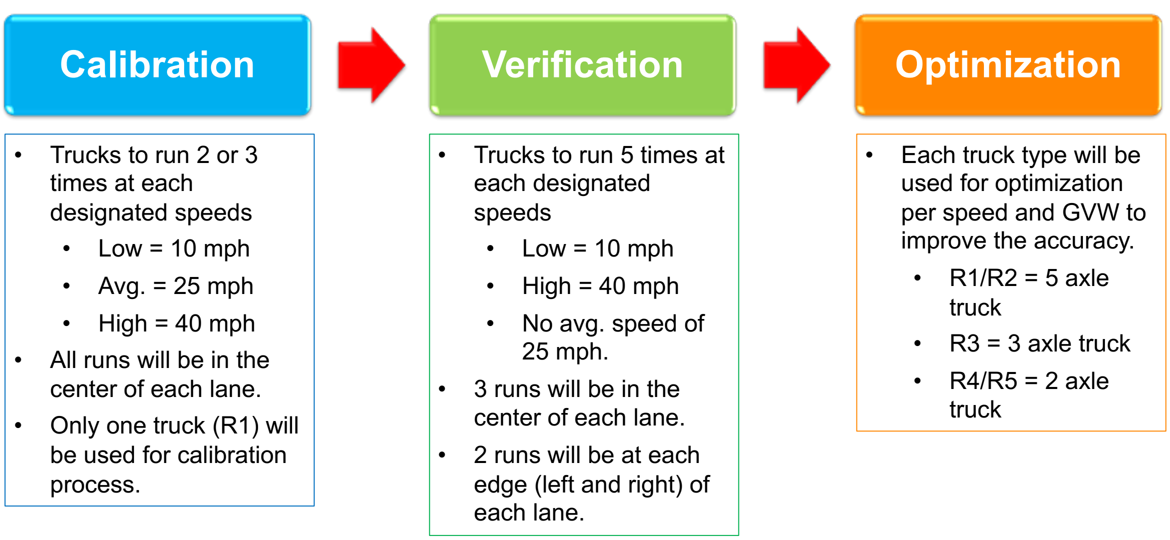


Figure 11 – Calibration Process for Quartz Sensors

Calibration Process

A total of 6 runs were made on the QB right lane according to ASTM E1318-09. All runs were designed to run in the center of the lane. It was planned to run at 3 speeds of 10, 25, and 40 mph; however, the low speed was changed to 15 mph because of traffic constraints and miscommunication with the driver. The test was performed from 11:22 PM on Saturday, 10/17/20, to 1:20 AM on Sunday, 10/18/20 (2 hours). Among 6 runs, a total of 5 runs for the R1 (Class 9, 3S2) truck were used to determine the calibration factors. Other trucks were not used for this calibration process but were used to check the repeatability between runs because the system is capable of providing single calibration factors. One run was discarded because all the right wheel loads of the R1 truck were significantly lower than the left wheel loads.

Table 13 summarizes the old (existing) calibration factors and new (this test) calibration factors. Sensors 1 and 3 are for the right wheel load, and sensors 2 and 4 are for the left wheel load. It shows that the calibration factors on the right wheel were changed by 24~25%, while those of the left wheel was changed by 6~7%. The changes of the right wheel were significantly greater than those of the left wheel, probably because the rutting on the right wheel path would be worse than the rutting on the left wheel path.

Table 14 summarizes the calibration runs for the R1 truck, and Figure 12 shows the GVW and its error using original calibration factors. The GVW errors using old calibration factors varied between 12% and 17%. When the new factors were applied, the errors fell to 5%.

Sensor ID	Old Calibration Factors	New Calibration Factors	Calibration Factor Change
1	1.12	0.83	-25%
2	1.04	1.10	+6%
3	0.98	0.75	-24%
4	1.01	0.95	-7%

Table 13. Calibration Factors

Run	Planned Speed (mph)	Actual Speed (mph)	S12 (160")	S23 (55")	S34 (211")	S45 (53")	Length (479")	GVW (79,080 lbs.)	GVW Error (%)
1	40	42.7	161	54	213	53	481	89,940	13.7
2	40	41.1	161	55	212	53	481	91,860	16.2
3	25	29.6	161	54	213	53	481	92,180	16.6
4	25	27.2	160	54	212	53	479	Excluded#	N/A
5	10	20.5	161	55	212	53	481	89,600	13.3
6	10	16.8	161	55	212	53	481	88540	12.0

Table 14. Spacing and GVW of the R1 Calibration Truck (Class 9, 3S2) per Run (# Run 4 was excluded because all right wheel loads were significantly lower than all the left wheel load as the truck was running close to the left lane stripping.)

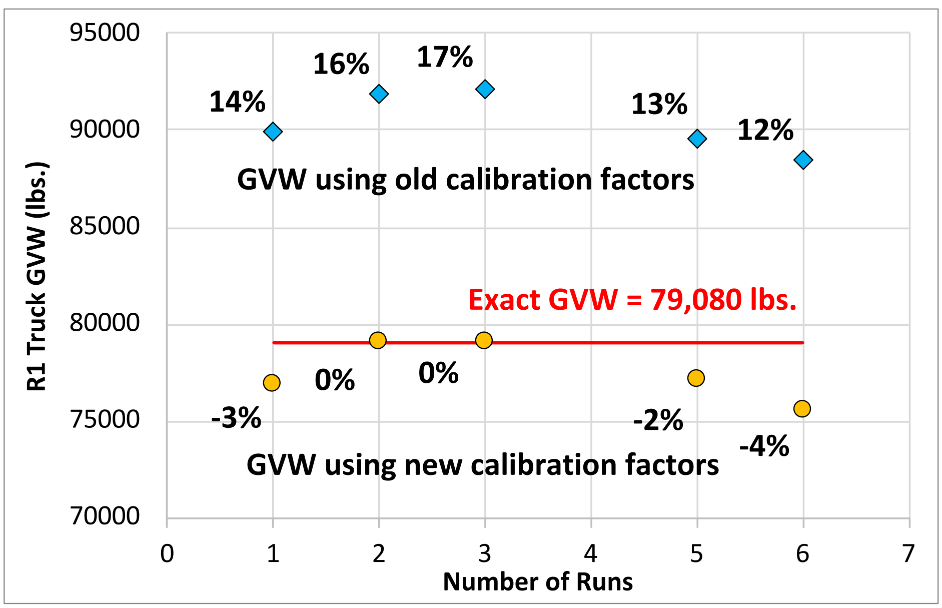


Figure 12 – GVW and Error of R1 Truck

Verification Process

After 6 runs, the new calibration factors were updated in the system before starting the verification runs. A total of 10 runs were planned in accordance with ASTM E1318-09; however, only 8~9 runs were made depending on the trucks because of the time constraints and truck malfunctioning. The verification runs started at 2:31 AM on Sunday, 10/18/20, and ended at 5:04 AM on Sunday, 10/18/20 (3.5 hours). There was no break during the calibration and verification processes.

During the verification process, two speeds of 10 mph (low) and 40 mph (high) were employed for 10 runs. Among 10 runs, 6 runs were planned to run in the center of the lane (normal cases), and 4 runs were planned to run near the left- and right-lane edges (abnormal cases). Figure 13 shows the truck positions (center, left, and right) within the lane described earlier. Normal cases are planned to update the calibration factors to optimize the accuracy. However, abnormal cases are designed to understand the system's accuracy and limits when the trucks do not run in the middle of the lanes because of the pavement rutting and quality. Figure 14 describes how pavement rutting could affect accuracy. Suppose the pavement is new, and no rutting is measured. In that case, the system accuracy is expected to be equal or similar between truck positions because the Quartz sensor can provide the same signal footprint regardless of position along with the sensor. However, when the pavement is aged and rutting is observed, the accuracy would not be the same with the sensor. In the ideal case (Figure 14(a)), the top surface of the Quartz sensor would be exposed to the top pavement surface for direct contact with the tire. However, at the BQE testbed on Pearl Street, because of the severe rutting, a part of the Quartz sensor was not exposed to the pavement surface and was embedded under the epoxy (see Figure 14(b)). The signal strength and shape will vary depending on the position of the wheel. For example, from Figure 14(b), the center will provide the strongest signal, followed by the right and left because the epoxy will reduce the pressure from the wheel. Therefore, only the normal cases (center) will be selected for the optimization process and used to determine the final accuracy.

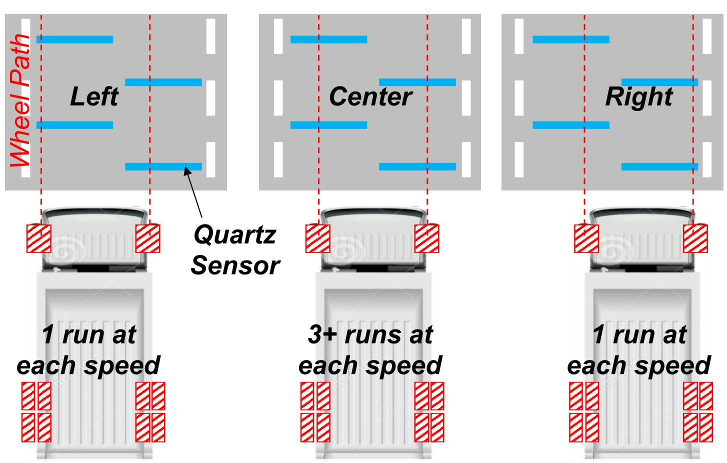
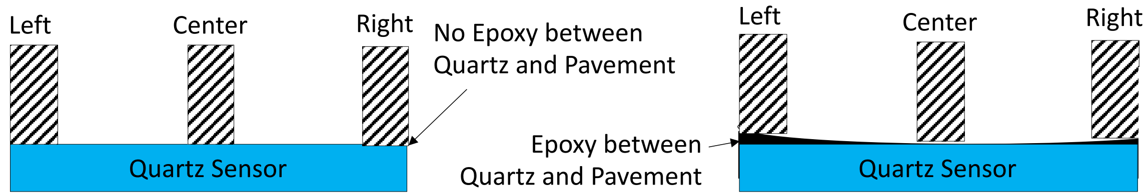


Figure 13 – Verification Run Position within the Lane



(a) Normal Case without Rutting (b) Abnormal Case with Rutting

Figure 14 – Pavement Rutting and Wheel Position

Optimization Process

The normal verification runs were then promoted to tune the calibration factors depending on the truck's speed. Speed is a key variable affecting weight accuracy because of the vehicle dynamic. Therefore, the optimization process will employ speed as a variable to improve accuracy.

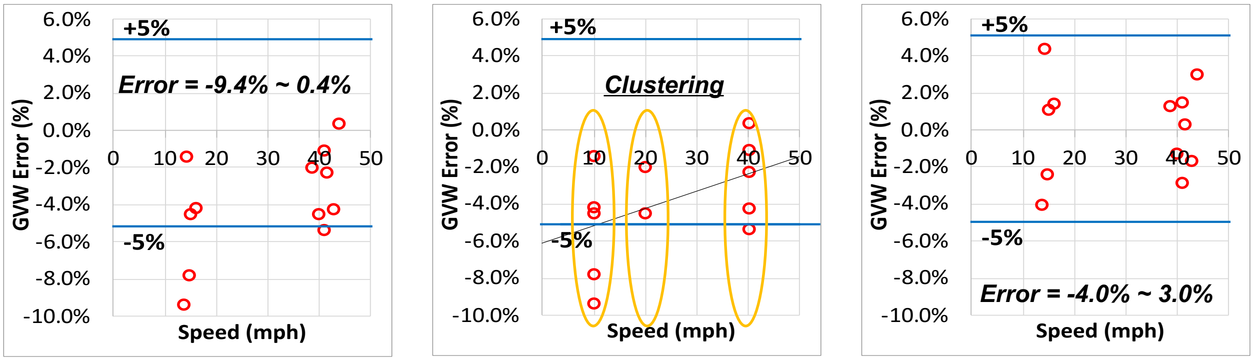
Figure 15 summarizes the optimization process for R1 and R2 trucks (5 axles), and the procedure is described below. The same procedure was applied to R3 (3 axles) and R4/R5 (2 axles) to determine the optimization factors. Different optimization factors for three truck groups (R1/R2, R3, and R4/R5) depending on the number of axles were applied to each speed range.

- Step 1 – Compile the verification test results of the truck with the same number of axles and plot the GVW error versus speed. The calibration factors were applied to determine the GVW and then compared to the static GVW to determine the GVW error.

$$\text{GVW Error} = (\text{GVW} - \text{GVW}_{static}) / \text{GVW}_{static} \ (\%)$$

- Step 2 – Cluster the error per speed range at ten mph, 20 mph, and 40 mph, and average the error at each speed range to determine the optimization factor in percentage. Each speed denotes more than (inclusive) this speed target but less than (exclusive) the next speed target. For example, 20 mph means a speed between 20.00 mph and 39.99 mph. The optimization factors for other speeds not determined by this process would be 0% (no correction).
- Step 3 – Determine the weight based on the optimization factor. The following equation will determine the optimized weight. If the optimization factor is positive, the weight is underestimated and will be increased by this factor.

$$\text{Optimized Weight} = \text{Weight} * (1 + \text{Optimization Factor in \%})$$



(a) (b) (c)

Figure 15 – Optimization Process; (a) Step 1 – plotting the GVW error vs. speed, (b) Step 2 – Clustering per speed range, and (c) Step 3 – updated GVW error vs. speed.

3.5. Calibration Test Results for Quartz Sensors

Table 15 through Table 19 summarize the overall accuracy of each calibration truck after the optimization process is completed. Some trucks' runs were not included in the calculation when the trucks were observed running at the edge of the lane because of the pavement rutting. Each table summarizes the GVW, front axle weight, and tandem axle weight and their weighing error for each run. In each table, the numbers below the error range in percentage indicate the maximum allowable error in percentage for each standard. The errors were then compared to three standards' requirements (ASTM, OIML, and COST). For example, ASTM Type III requires a 6% GVW error, 15% single axle weight error, and 10% tandem axle weight error to comply with its requirements.

Table 15 summarizes the overall accuracy for calibration truck R1 (Class 9, 3S2). Run 7 is not included in determining the compliance because the truck leaned to the left side, yielding low weight on all axles. This truck complies with all requirements of ASTM E1318-09 Type III. However, it does not comply with the single and/or tandem axle weight requirement of OIML R134-1 and COST 323 standards.

Table 16 summarizes the overall accuracy for calibration truck R2 (Class 9, 3S2 Split). Runs 4 and 7 are not included for compliance, as the truck leaned to the left side of the lane or even ran over the line stripping. Run 8 is not also included because of the high vehicle dynamic. Similar results are observed in truck R1. It complies with all ASTM Type III and GVW requirements and partial tandem axle weight requirements of OIML F10 and COST A(5).

Table 17 summarizes the overall accuracy of calibration truck R3 (Class 6). The test runs 6, 7, and 8 are not included in determining the compliance because the truck ran too close to the left of the lane yielding low weights on all axles. This truck complies with all the weight requirements of four (4) standards – GVW, single axle weight, and tandem axle weight.

Table 18 and Table 19 summarize the overall accuracy for Class 5 trucks (R4 and R5). Several runs are not included in determining the compliance because the trucks leaned to the left or right of the lane. Both trucks comply with all the weight requirements of four standards.

Axle Load and Wheel Load

Table 20 and Table 21 summarize the accuracy of all trucks' axle and wheel loads. All the axle and wheel weights comply with ASTM Type III requirements, while several weights do not comply with OIML F10 and COST A(5) except calibration truck R2. This truck has a trailer tridem axle, and the 2nd axle of the tridem was removed to mimic the Class 9 3S2 Split truck. During the axle weight measurement at the NYCDOT Fleet Yard in Corona, NY, it was observed that the pressure was not adequately set for the tandem axles yielding an imbalance between the tandem axles. The 4th and 5th axle weights of truck R2 were 9,820 lbs and 19,110 lbs. Figure 16 shows that the 5th axle tire was distorted while the 4th axle was not. Due to this imbalance, this tandem axle and wheel weights included a high dynamic reaction during the calibration test, yielding high error, as shown in red cells in Table 20 and Table 21. However, when the combined tandem axle weights are considered in Figure 8, the errors between the two axles were canceled out and the tandem axle weights complied with the standards' requirements.

Run #	Speed (mph)	GVW (lbs.) 79080	Error (%)	Front (lbs.) 11645	Error (%)	Drive T. (lbs.) 33522	Error (%)	Trailer T. (lbs.) 33913	Error (%)
1	40.9	80257	1.49	13034	11.93	32883	-1.91	34340	2.44
2	42.6	77732	-1.70	11166	-4.11	32472	-3.13	34094	1.71
3	43.8	81447	2.99	12377	6.29	32883	-1.91	36187	7.95
4	14.6	77179	-2.40	11455	-1.63	32079	-4.31	33645	0.37
5	16.0	80207	1.43	12577	8.01	31994	-4.56	35636	6.31
6	13.6	75888	-4.04	11603	-0.36	30914	-7.78	33370	-0.45
7#	~~40.0~~	~~65416~~	~~-17.28~~	-	-	-	-	-	-

Table 15. Overall Accuracy after Optimization for R1 (Class 9, 3S2) Truck (# Run 7 was excluded because the left run yielded low weight on all axles

Run #	Speed (mph)	GVW (lbs.) 73681	Error (%)	Front (lbs.) 12332	Error (%)	Drive T. (lbs.) 32509	Error (%)	Trailer T. (lbs.) 28840	Error (%)
1	38.4	74647	1.31	13147	6.61	33489	3.01	28011	-2.88
2	39.8	72745	-1.27	12920	4.77	31814	-2.14	28011	-2.88
3	41.4	73914	0.32	13239	7.36	33622	3.42	27053	-6.20
4[1)]	14.8	67100	-8.93	-	-	-	-	-	-
5	14.2	76904	4.37	13191	6.97	35085	7.92	28627	-0.74
6	14.9	74490	1.10	13382	8.51	33921	4.34	27187	-5.73
7[2)]	38.2	57510	-21.95	-	-	-	-	-	-
8[3)]	40.4	61968	-15.90	-	-	-	-	-	-
9	40.8	71554	-2.89	12377	0.37	32062	-1.38	27115	-5.98

Table 16. Overall Accuracy after Optimization for R2 (Class 9, 3S2 with a Split Axle) Truck (1) Run 4 was excluded because the truck was too close to the left, 2) Run 7 was excluded because the truck was on the left lane stripping, and 3) Run 8 was excluded because of high vehicle dynamics)

Run #	Speed (mph)	GVW (lbs.) 71650	Error (%)	Front (lbs.) 21772	Error (%)	Tandem (lbs.) 49868	Error (%)
1	42.3	72034	0.55	21797	0.12	50237	0.74
2	42.4	71438	-0.28	21419	-1.62	50018	0.30
3	43.2	71577	-0.09	21300	-2.17	50277	0.82
4	16	71596	-0.06	21598	-0.80	49998	0.26
5	14.6	71678	0.05	21434	-1.55	50245	0.76
6*	17.2	63849	-10.88	-	-	-	-
7*	39.4	54930	-23.33	-	-	-	-
8*	40.3	66088	-7.75	-	-	-	-
9	43.1	71517	-0.17	21360	-1.89	50158	0.58

Table 17. Overall Accuracy after Optimization for R3 (Class 6) Truck (* Runs 6, 7, and 8 were excluded because the truck was too close to the left)

Run #	Speed (mph)	GVW (lbs.) 32580	Error (%)	Front (lbs.) 10233	Error (%)	Rear (lbs.) 22347	Error (%)
1	42.4	32777	0.60	10398	1.62	22379	0.14
2	39.3	33225	1.98	10718	4.74	22506	0.71
3	45.3	33491	2.80	10476	2.37	23015	2.99
4*	~~18.3~~	~~29431~~	~~-9.67~~	-	-	-	-
5*	~~12.7~~	~~26442~~	~~-18.84~~	-	-	-	-
6	17.4	32581	0.00	10573	3.32	22008	-1.52
7	38.9	31957	-1.91	10183	-0.49	21773	-2.57
8	40.9	31369	-3.72	9685	-5.36	21684	-2.97
9	42.8	32758	0.55	10109	-1.21	22649	1.35

Table 18. Overall Accuracy after Optimization for R4 (Class 5) Truck (* Runs 4 and 5 were excluded because the truck was too close to the right)

Run #	Speed (mph)	GVW (lbs.) 9720	Error (%)	Front (lbs.) 4840	Error (%)	Rear (lbs.) 4880	Error (%)
1	43.4	9996	2.84	5041	4.16	4955	1.54
2	39.2	9720	0.00	5065	4.64	4655	-4.61
3	42.2	9458	-2.70	4761	-1.63	4697	-3.76
4	12.4	10025	3.14	5199	7.41	4826	-1.11
5	12.9	9432	-2.96	4826	-0.29	4607	-5.60
6 1)	~~14.5~~	~~9520~~	~~-2.06~~	-	-	-	-
7 2)	~~42.1~~	~~11397~~	~~17.25~~	-	-	-	-
8 3)	~~42.9~~	~~2973~~	~~-69.41~~	-	-	-	-
9 4)	~~42.5~~	~~7799~~	~~-19.76~~	-	-	-	-

Table 19. Overall Accuracy after Optimization for R5 (Class 5, Pickup truck with dual rear tire) Truck (1) Run 6 was excluded because the truck was too close to the right, 2) & 4) Runs 7 and Run 9 were excluded because of high dynamic with leavy left wheel weight, and 3) Run 8 was excluded beause of the single-track vehicle warning and chaning lanes)

Figure 16 – Imbalance Weights of the Tandem Axle (Truck R2, Class 9 3S2 Split)

Truck	Axle 1 Error (%)	Axle 2 Error (%)	Axle 3 Error (%)	Axle 4 Error (%)	Axle 5 Error (%)
R1	-4.1 ~ 11.9	-7.7 ~ -5.0	-7.9 ~ -0.4	-8.8 ~ 1.3	3.2 ~ 12.4
R2	0.4 ~ 8.5	-5.8 ~ 7.9	1.6 ~ 8.0	-80.5 ~ -75.6	30.6 ~ 37.7
R3	-2.2 ~ 0.1	-2.1 ~ 0.0	1.6 ~ 3.0	N/A	N/A
R4	-5.4 ~ 4.7	-3.0 ~ 3.0	N/A	N/A	N/A
R5	-1.6 ~ 7.4	-5.6 ~ 1.5	N/A	N/A	N/A

Table 20. Axle Load Accuracy after Optimization

Wheel	Axle 1 Error (%)	Axle 2 Error (%)	Axle 3 Error (%)	Axle 4 Error (%)	Axle 5 Error (%)
R1 Left	-14.0 ~ 9.2	-13.6 ~ 5.7	-13.3 ~ 6.7	-15.7 ~ 4.2	-2.8 ~ 18.9
R1 Right	6.8 ~ 14.9	-10 ~ 4	-7.9 ~ 7.4	-7.3 ~ 4.9	0.3 ~ 17.1
R2 Left	-1.7 ~ 18.4	-11.9 ~ 14.3	0.5 ~ 16.2	-84.1 ~ -75.6	27.1 ~ 49.9
R2 Right	-1.9 ~ 7.1	-10.2 ~ 5.7	-3.0 ~ 4.0	-80.8 ~ -73.2	21.4 ~ 39.6
R3 Left	3.9 ~ 8.5	3.7 ~ 6.4	7.7 ~ 11.8	N/A	N/A
R3 Right	-10.9 ~ -6.1	-10.8 ~ -4.9	-6.7 ~ -4.9	N/A	N/A
R4 Left	3.8 ~ 12.6	-2.7 ~ 9.9	N/A	N/A	N/A
R4 Right	-15.4 ~ 0.6	-8.2 ~ 0.9	N/A	N/A	N/A
R5 Left	-1.3 ~ 10.1	-21.9 ~ -12.6	N/A	N/A	N/A
R5 Right	-2.0 ~ 4.5	-2.1 ~ 11.4	N/A	N/A	N/A

Table 21. Wheel Load Accuracy after Optimization

3.6. Summary of Calibration Test

Table 22 summarizes the calibration results, and the following summary could be made.

- Quartz sensors were able to comply with accuracy requirements for all standards (ASTM, OIML, and COST).
- The maximum error for GVW is 4.4%, within 5%, and much less than 10%.
- The maximum error for wheel, single axle, and tandem axle weight is within the requirement for Type III ASTM E1318-09.
- The calibration test could be performed using one Class 9 truck as the calibration factors cannot cover different trucks.
- The verification test would need other types of trucks for optimization. If Class 7 and Class 10 (not covered by this test) were employed, the accuracy for other trucks would be improved.
- Accuracy varies depending on truck speed. However, the speed variance could be eliminated by the optimization process.
- Severe rutting was observed. Accuracy could be improved by re-paving before future installation.
- Calibration factors drifted slightly after the initial calibration in 2019. Routine calibration every 6 months (or seasonal) is recommended.

Standards	GVW	Single	Tandem	Wheel
Quartz Results (maximum error, %)	4.4	12.4	8.0	18.9*
ASTM Type III	6 %	15 %	10 %	20 %
Compliance* (%)	100	100*	100*	99*
Compliance (%)	100	88	88	87
OIML F10	5 %	8 %	8 %	-
COST A(5)	5 %	8 %	7 %	-

Table 22. Calibration Summary (* R2 axle 4 and axle 5 are not included)

Section 4 – Overweight Violation per Permissible Error for Gross Vehicle Weight, Single Axle Weight, and Tandem Axle Weight

The team processed the WIM data collected between October 2019 and May 2022 to evaluate the number of overweight violations depending on the permissible error for the GVW, single, and tandem axle weights.

4.1. Number of OW Trucks with Permissible Error

"Total Number of Trucks" is the average daily truck traffic (ADTT), and "Violation" is the number of trucks that violate the GVW (G), single (S or Sgl), tandem (T or Tan), and/or Federal Bridge Formula (FBF) limits. Five scenarios plus one control case were considered. The control case sets the limits for the GVW, single weight, and tandem weight per Federal law (GVW = 80 kips, single = 20 kips, and tandem = 34 kips). Five scenarios include different thresholds considering some margin of permissible errors (10~15% for GVW, 20~30% for single weight, and tandem weight) to consider the inherent weighing errors in WIM systems. The permissible errors were determined based on the feedback from NYCDOT. Table 23 summarizes the overweight limit.

Table 24 and Table 25 summarize the average daily count for each OW category and scenario for QB and SIB, respectively. Figure 17, Figure 18, and Figure 19 show the same information on the average daily count in graphical ways. Figure 20 shows the number of violations per scenario.

OW Violation	Weight Limit
G = Gross Weight	80 kips
S = Single Weight	20 kips
T = Tandem Weight	34 kips
FBF = Federal Bridge Formula	W = 500 x (LN/(N-1) + 12N + 36

Table 23. Overweight Limit

The following observations were found:

- The number of OW trucks is reduced when the permissible error is higher.
- OW trucks are significantly reduced when the permissible error for single and tandem weight is higher. The change in the number of OW for higher permissible errors for GVW is less significant than in other cases.

- There will be approximately 435 OW trucks for both directions if Scenario 1 is selected (GVW exceeds the Federal limit plus 10% (88 kips), the single axle weight and tandem weight exceed the Federal limit plus 20% (24 kips and 40.8 kips, respectively).

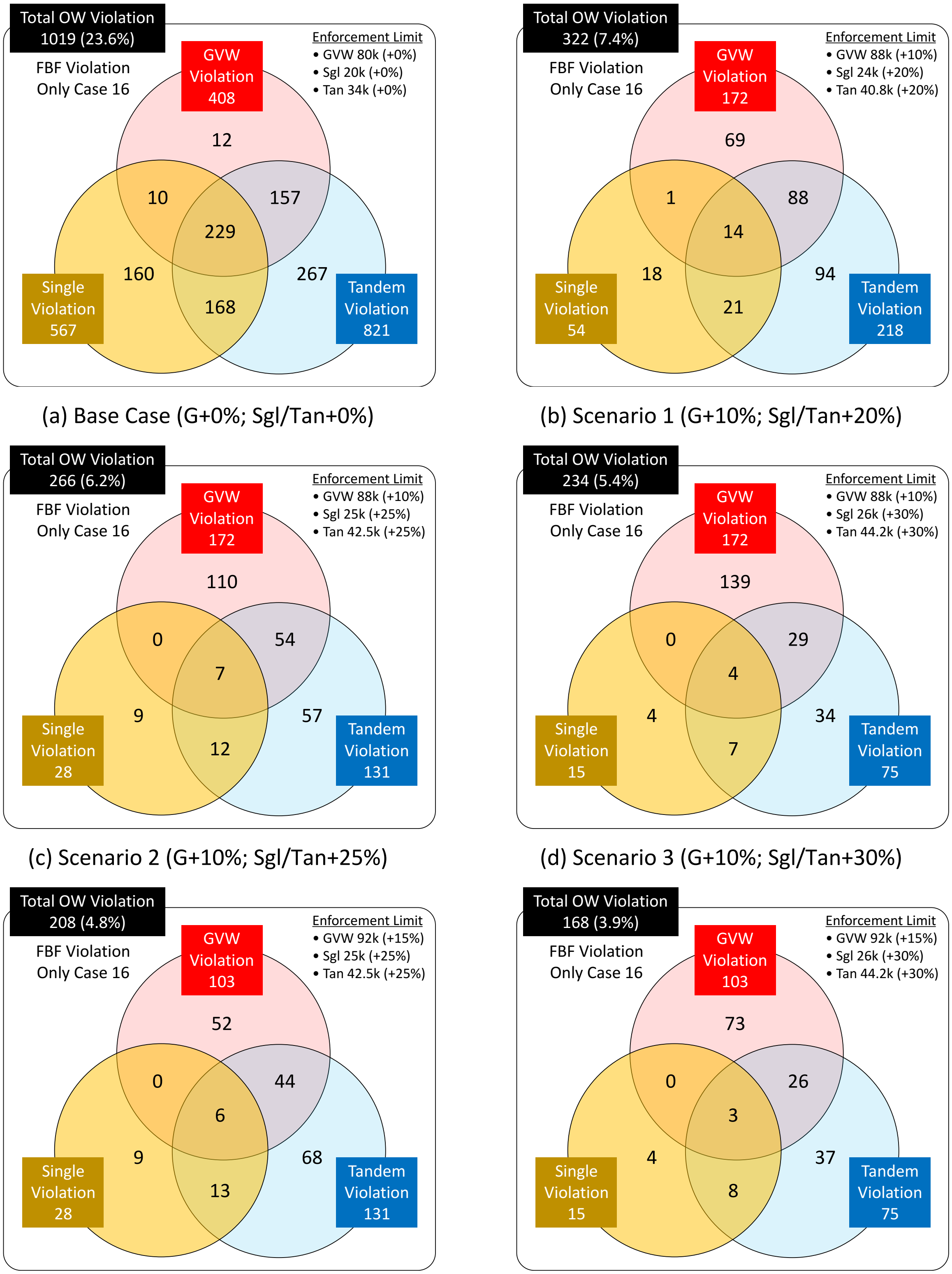
On average, two-thirds of OW trucks violate one violation (either GVW, single, tandem, or FBF), and one-third of OW trucks violate two or three.

Scenario	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Gross legal limit + % permissible error	**0%**	**10%**	**10%**	**10%**	**15%**	**15%**
Single/Tandem legal limit + % permissible error	**0%**	**20%**	**25%**	**30%**	**25%**	**30%**
Total Number of Trucks	4325	4325	4325	4325	4325	4325
Total OW Violation (GVW/Sgl/Tan/FBF*)	1019 (23.6%)	322 (7.4%)	266 (6.2%)	234 (5.4%)	208 (4.8%)	168 (3.9%)
Total GVW Violation (any of Sgl/Tan/FBF)	408 (9.4%)	172 (4%)	172 (4%)	172 (4%)	103 (2.4%)	103 (2.4%)
Total Sgl Violation (any of GVW/Tan/FBF)	567 (13.1%)	54 (1.2%)	28 (0.6%)	15 (0.3%)	28 (0.6%)	15 (0.3%)
Total Tan Violation (any of GVW/Sgl/FBF)	821 (19%)	218 (5%)	131 (3%)	75 (1.7%)	131 (3%)	75 (1.7%)
One Violation (either GVW/Sgl/Tan/FBF)	455 (10.5%)	197 (4.6%)	192 (4.4%)	193 (4.5%)	145 (3.4%)	130 (3%)
Two Violations (Two of GVW/Sgl/Tan)	335 (7.7%)	110 (2.5%)	66 (1.5%)	36 (0.8%)	57 (1.3%)	34 (0.8%)
Three Violations (All of GVW/Sgl/Tan)	229 (5.3%)	14 (0.3%)	7 (0.2%)	4 (0.1%)	6 (0.1%)	3 (0.1%)

Table 24. Average Daily Count of OW Violation for QB (10/16/19 – 5/15/20, 186 days)

Scenario	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Gross legal limit + % permissible error	0%	10%	10%	10%	15%	15%
Single/Tandem legal limit + % permissible error	0%	20%	25%	30%	25%	30%
Total Number of Trucks	3506	3506	3506	3506	3506	3506
Total OW Violation (GVW/Sgl/Tan/FBF*)	397 (11.3%)	113 (3.2%)	97 (2.8%)	88 (2.5%)	86 (2.5%)	76 (2.2%)
Total GVW Violation (any of Sgl/Tan/FBF)	106 (3%)	48 (1.4%)	48 (1.4%)	48 (1.4%)	35 (1%)	35 (1%)
Total Sgl Violation (any of GVW/Tan/FBF)	190 (5.4%)	34 (1%)	24 (0.7%)	17 (0.5%)	24 (0.7%)	17 (0.5%)
Total Tan Violation (any of GVW/Sgl/FBF)	278 (7.9%)	49 (1.4%)	32 (0.9%)	22 (0.6%)	32 (0.9%)	22 (0.6%)
One Violation (either GVW/Sgl/Tan/FBF)	244 (7%)	83 (2.4%)	76 (2.2%)	72 (2.1%)	66 (1.9%)	61 (1.7%)
Two Violations (Two of GVW/Sgl/Tan)	111 (3.2%)	23 (0.7%)	16 (0.5%)	11 (0.3%)	15 (0.4%)	11 (0.3%)
Three Violations (All of GVW/Sgl/Tan)	43 (1.2%)	7 (0.2%)	6 (0.2%)	4 (0.1%)	5 (0.1%)	4 (0.1%)

Table 25. Average Daily Count of OW Violation for SIB (10/11/19 – 5/15/20, 191 days)



(a) Base Case (G+0%; Sgl/Tan+0%)

(b) Scenario 1 (G+10%; Sgl/Tan+20%)

(c) Scenario 2 (G+10%; Sgl/Tan+25%)

(d) Scenario 3 (G+10%; Sgl/Tan+30%)

(e) Scenario 4 (G+15%; Sgl/Tan+25%)

(f) Scenario 5 (G+15%; Sgl/Tan+30%)

Figure 17 - Average Daily Count of OW Violation per Scenario for QB

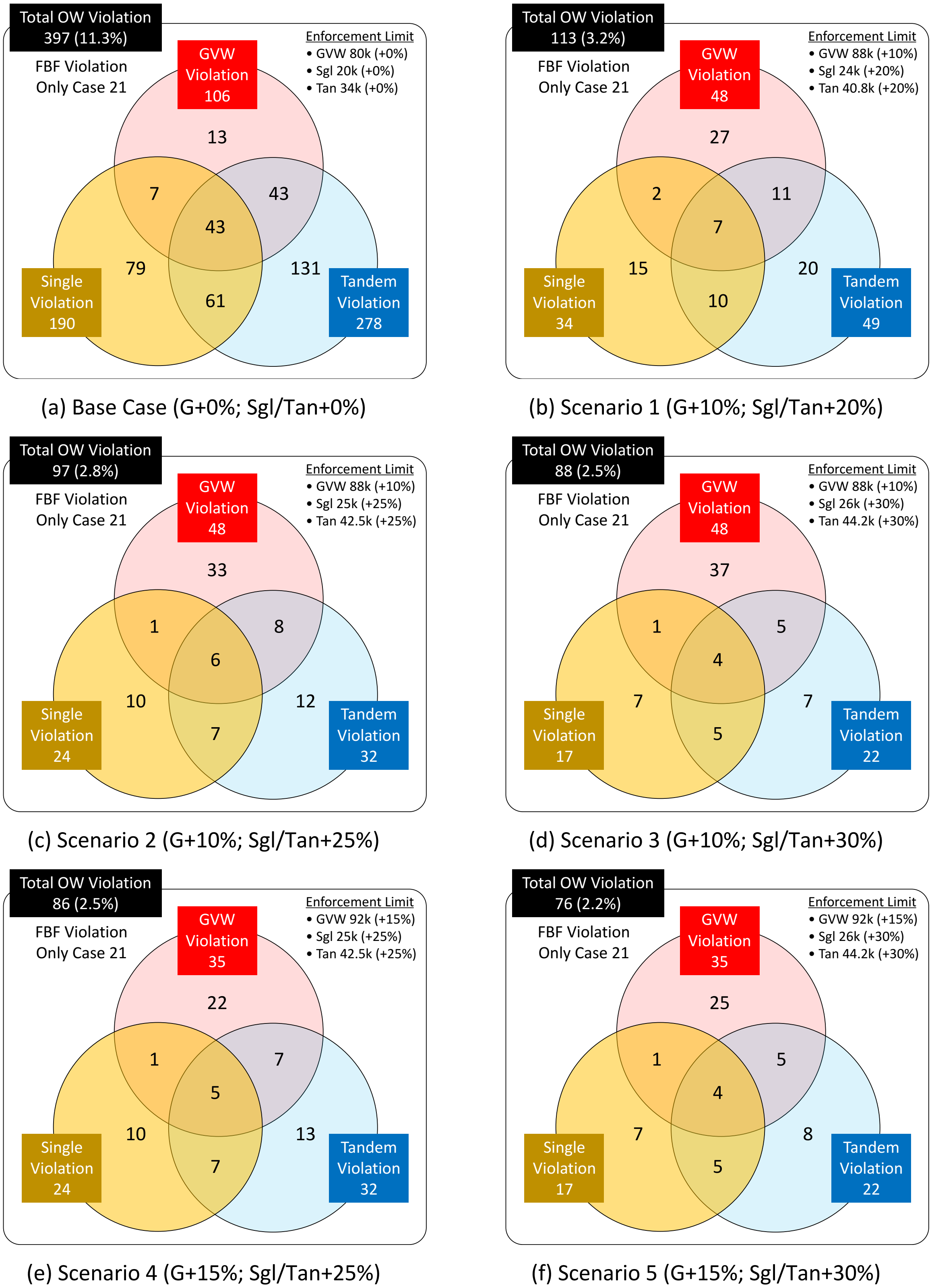
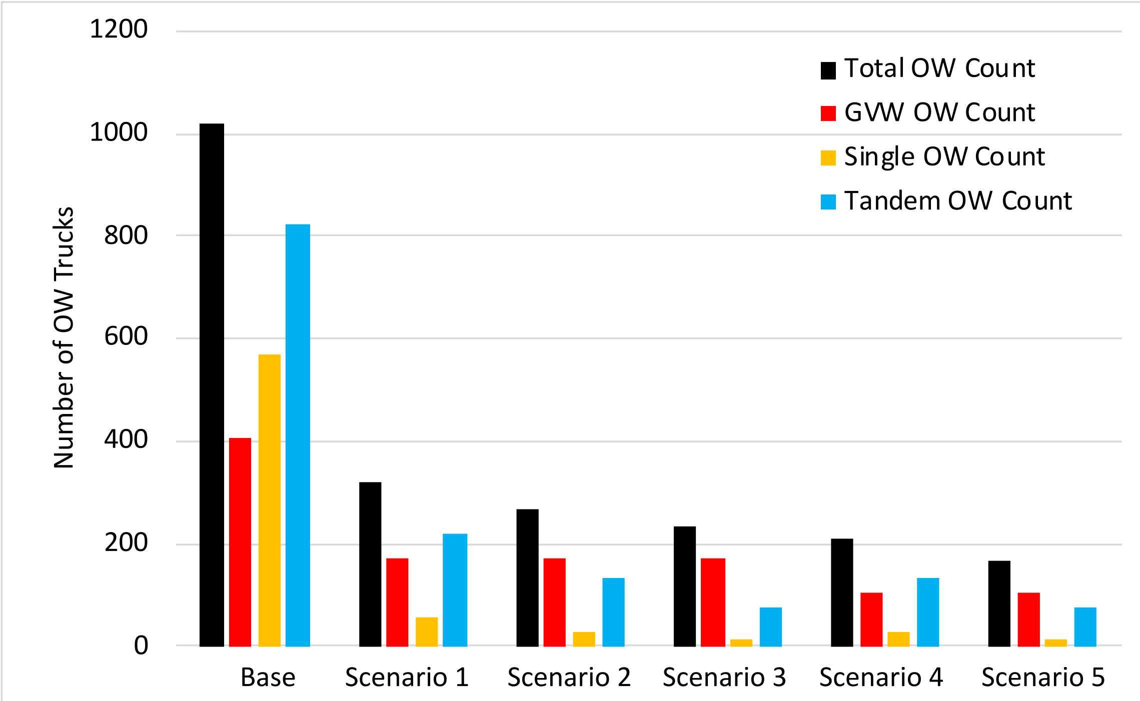
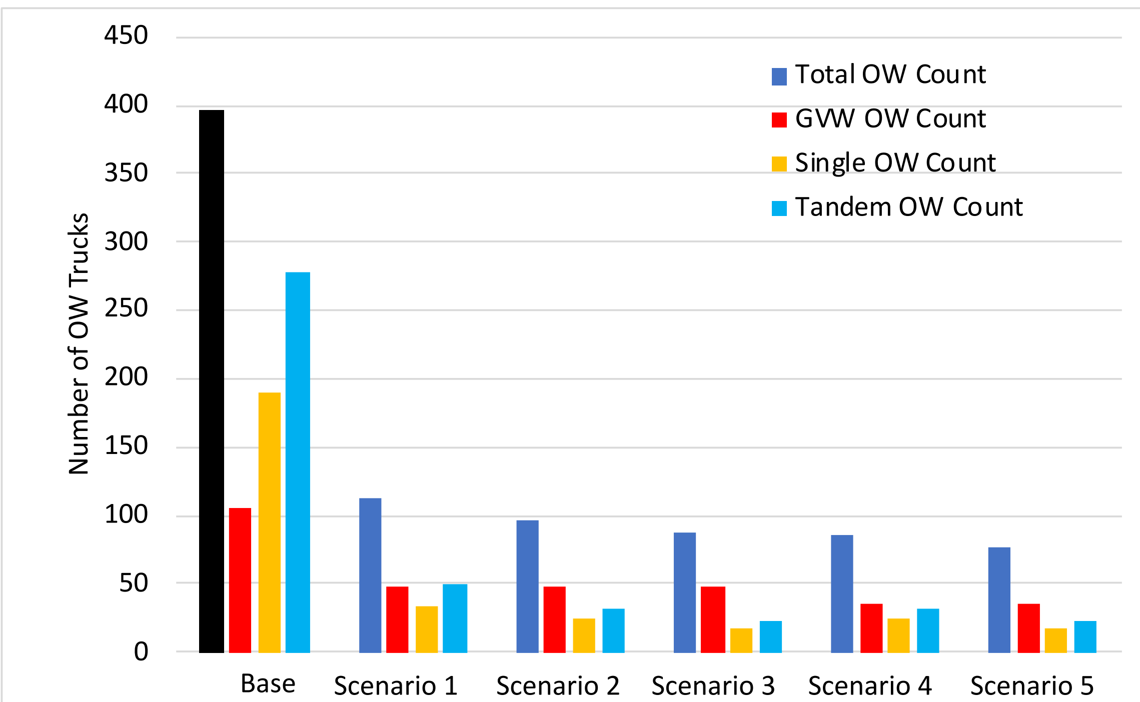


Figure 18 - Average Daily Count of OW Violation per Scenario for SIB

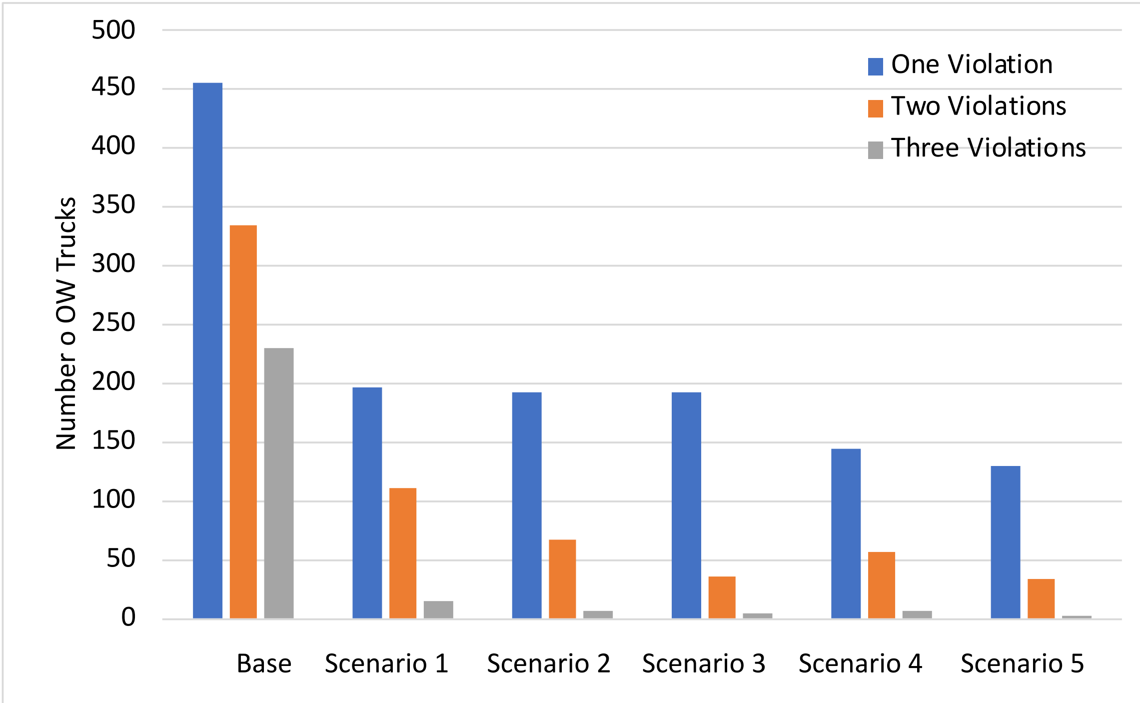


(a) QB

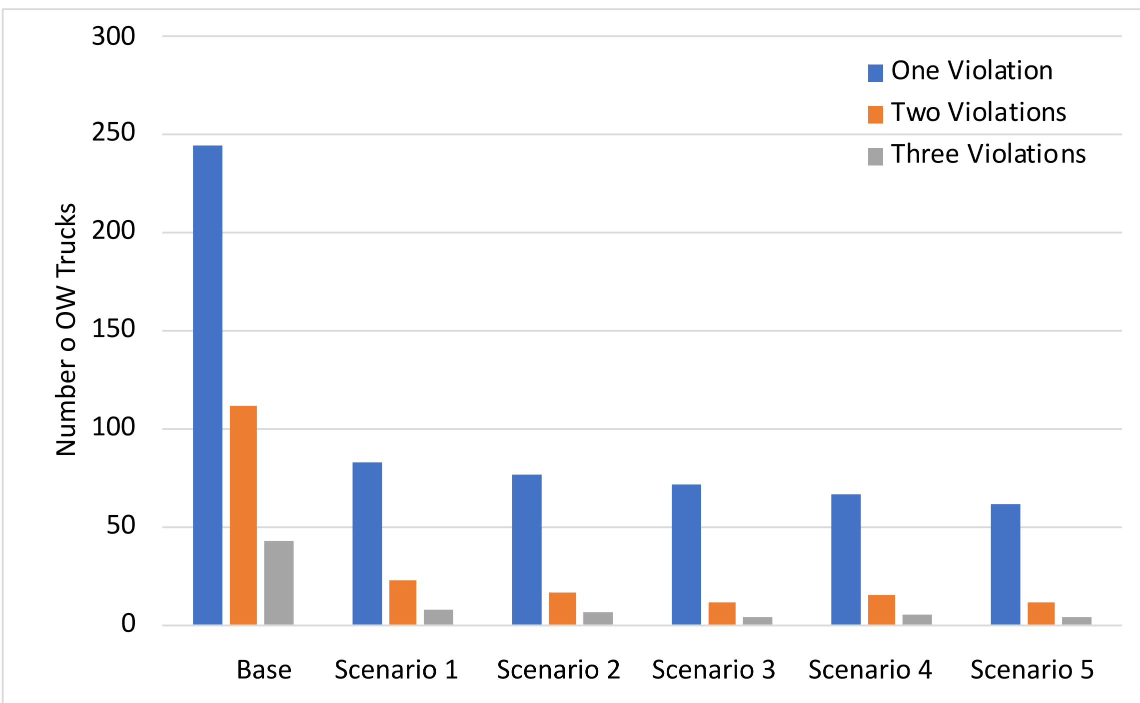


(b) SIB

Figure 19 – Summary of Average Daily Count of OW Violation per Scenario for SIB



(a) QB



(b) SIB

Figure 20 - Number of Violations for Scenario

4.2. Summary of the Estimated Number of OW Trucks after Enforcement

Figure 21 shows an example of the change in the number of trucks after enforcement. The data were obtained from the Korea Expressway Corporation, where they implemented the enforcement pilot study in the 2010s.

Before the enforcement, the number of total trucks was 70,510, while the numbers of OW trucks for GVW > 80 kips and GVW > 88 kips were 13,035 (18.5% of the total truck) and 6,874 (9.7% of the total truck), respectively.

After 3 weeks of the enforcement (from Week 4), the average number of trucks remained the same (69,237), while the average number of OW trucks for GVW > 80 kips was reduced to 9,817 (14.2% of the total truck), and that for GVW > 88 kips was reduced to 1,590 (2.3% of the total truck)

Figure 22 shows the percentage change in the number of OW trucks against the number of trucks on Week 1. The number of OW trucks for GVW > 80 kips was reduced by 24.7%, while the number of OW trucks for GVW > 88 kips was decreased by 76.9%.

Once the automated enforcement is applied, overweight trucks are expected to be reduced drastically. Suppose we assume that all OW violations (GVW, single axle weight, tandem weight, and FBF) will be reduced at a similar rate for Scenario 1 (77%). In that case, the number of OW trucks could be estimated as summarized in Table 26.

The estimated number of trucks that violate the GVW, single axle weight, and tandem would be approximately 100 per day when Scenario 1 is applied. If the permissible error is increased (Scenarios 2 ~ 4), the number of OW trucks would be even lower.

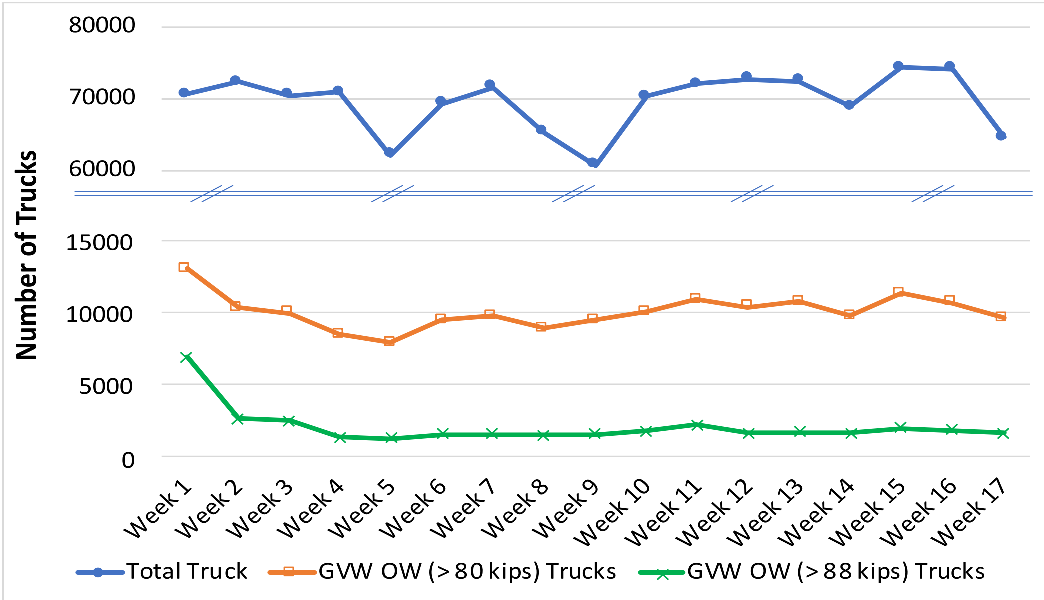


Figure 21 - Change in the Number of OW Trucks after Enforcement (Week 1 = start of enforcement)

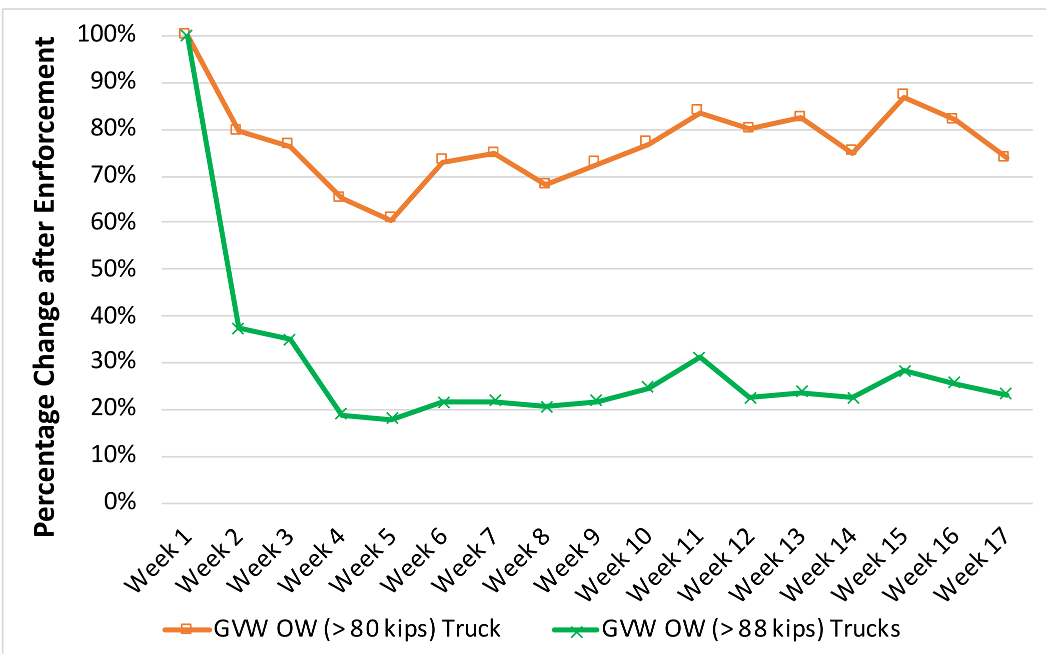


Figure 22 - Percentage Change in the Number of OW Trucks after Enforcement (Week 1 = start of enforcement)

Scenario 1 G +10%; S/T +20%	QB Current	QB Estimate	SIB Current	SIB Estimate	BQE Total Current	BQE Total Estimate
Total Number of Trucks	4325	4282	3506	3472	7832	7754
Total OW Violation (GVW/Sgl/Tan/FBF*)	322 (-7.4%)	74 (1.7%)	113 (-3.2%)	26 (0.7%)	435 (5.6%)	100 (1.3%)
Total GVW Violation (regardless of Sgl/Tan/FBF)	172 (-4%)	40 (0.9%)	48 (-1.4%)	11 (0.3%)	220 (2.8%)	51 (0.7%)
Total Sgl Violation (regardless of Tan/Tan/FBF)	54 (-1.2%)	12 (0.3%)	34 (-1%)	8 (0.2%)	88 (1.1%)	20 (0.3%)
Total Tan Violation (regardless of GVW/Sgl/FBF)	218 (-5%)	50 (1.2%)	49 (-1.4%)	11 (0.3%)	267 (3.4%)	61 (0.8%)
One Violation (either GVW/Sgl/Tan)	197 (-4.6%)	45 (1.1%)	83 (-2.4%)	19 (0.5%)	280 (3.6%)	64 (0.8%)
Two Violations (two out of GVW/Sgl/Tan)	110 (-2.5%)	25 (0.6%)	23 (-0.7%)	5 (0.1%)	133 (1.7%)	30 (0.4%)
Three Violations (All of GVW/Sgl/Tan)	14 (-0.3%)	3 (0.1%)	7 (-0.2%)	2 (0.1%)	21 (0.3%)	5 (0.1%)

Table 26. Estimated Number of Total OW Trucks after Enforcement at BQE2

Section 5 – Conclusions and Recommendations

This study presented the effort to summarize different WIM standards, develop the calibration procedure for the A-WIM system, and implement the calibration procedure to prove that the A-WIM system can comply with ASTM E1318-09 Type III accuracy.

Three prevailing WIM standards were compiled and compared. The calibration procedure of ASTM E1318-09 is more straightforward than two other standards of COST 323 and OIML R134-1, but it provides an excellent methodology to calibrate the system. However, ASTM E1318-09 should accept additional calibration trucks to optimize the calibration factors depending on the truck types and speeds. For the BQE testbed, Class 6 and Class 5 trucks are the two prevailing trucks other than Class 9 trucks. Additional trucks would require excessive calibration/optimization tests, which would be exhausted; however, this optimization procedure is crucial to meet the accuracy and compliance level and the Type-Approval test requirement.

The calibration and optimization tests were performed at the BQE testbed. The results show that Quartz sensors could comply with GVW accuracy requirements for all three prevailing standards (ASTM, OIML, and COST). The maximum error for GVW was 4.4%, below 6% at 95% compliance. Quartz sensors could also comply with single (15%) and tandem (10%) weights within the requirement for Type III ASTM E1318-09. However, that is not the case for COST 323 and OIML R134-1. Several readings of the single and tandem axle weight exceeded the accuracy requirement. It is worth noting that the BQE testbed's pavement conditions were not ideal, and the team found rutting of > 10 mm. Albeit the site only complied with ASTM E1318-09 Type III and did not meet the requirement for COST 323 and OIML R134-1, the accuracy and compliance could be improved if the pavement work were done to smoothen the roadway surface.

Based on the preliminary analysis of the change in the number of trucks after the enforcement, direct enforcement would reduce the number of overweight trucks. The number of 10% overweight trucks (GVW between 80 and 88 kips) would be reduced by 24.7%, while the number of > 10% overweight trucks (GVW over 88 kips) would be reduced even more (76.9%).

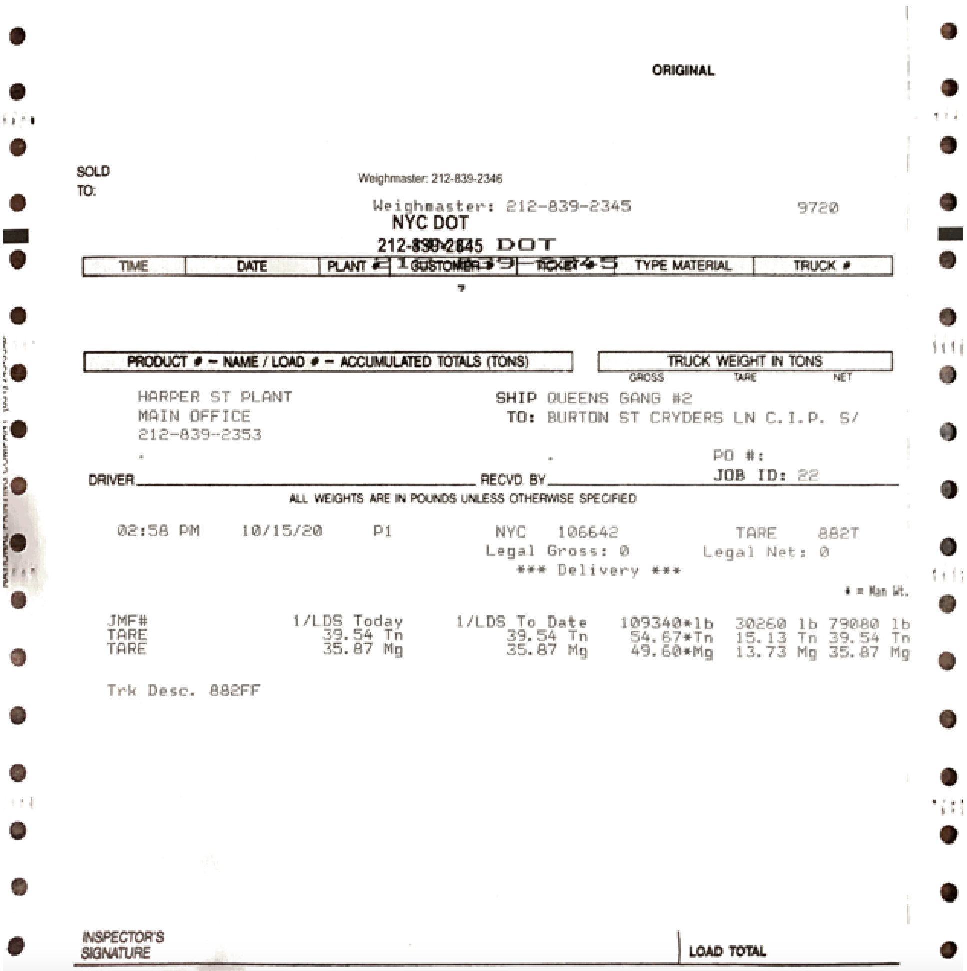
References

1. Nassif, H., K. Ozbay, H. Wang, R. Noland, P. Lou, S. Demiroluk, D. Su, C.K. Na, J. Zhao, and M. Beltran. (2016) Impact of freight on highway infrastructure in New Jersey. Final Report FHWA-2016-004, NJDOT
2. Nassif, H., K. Ozbay, C.K. Na, and P. Lou. (2021) Feasibility of Autonomous Enforcement using A-WIM system to Reduce Rehabilitation Cost of Infrastructure, C2SMART Tier 1 University Transportation Center, Year 3 Final Report, 2021
3. NJDOT Office of the Attorney General (2010), Annual Vehicle Size and Weight Limit Enforcement Certification

Appendix I – Adjusted Weight and Spacing Information, and Weight Certificates

Truck R1 – Class 9, 3S2

Class 9 (3S2) Truck R1	882T + trailer					
Spacing	**Axle1**	**Axle2**	**Axle3**	**Axle4**	**Axle5**	
Distance (in)	0	160	215	426	479	
Spacing (in)	**160**	**55**	**211**	**53**		
Spacing (ft)	**13'-4"**	**4'-7"**	**17'-7"**	**4'-5"**		
Width	**Front**	**Rear/Tander**	**Rear/Trailer**			
Spacing (in)	81	76	72			
Spacing (ft)	**6'-9"**	**6'-4"**	**6'-0"**			
Weight	**Axle1**	**Axle2**	**Axle3**	**Axle4**	**Axle5**	**GVW**
Left (lb)	6108	8601	8601	8230	8070	
Right (lb)	5537	8120	8200	9272	8341	
Axle Weight	**11645**	**16721**	**16801**	**17502**	**16411**	**79080**


ORIGINAL

SOLD TO:

Weighmaster: 212-839-2346

Weighmaster: 212-839-2345 9720

NYC DOT

212-839-2345 DOT

TIME | DATE | PLANT # | CUSTOMER # | TICKET # | TYPE MATERIAL | TRUCK #

PRODUCT # – NAME / LOAD # – ACCUMULATED TOTALS (TONS)

TRUCK WEIGHT IN TONS: GROSS TARE NET

HARPER ST PLANT
MAIN OFFICE
212-839-2353

SHIP TO: QUEENS GANG #2
BURTON ST CRYDERS LN C.I.P. S/

PO #:
JOB ID: 22

DRIVER ______ RECVD BY ______

ALL WEIGHTS ARE IN POUNDS UNLESS OTHERWISE SPECIFIED

02:58 PM 10/15/20 P1 NYC 106642 TARE 882T
Legal Gross: 0 Legal Net: 0
*** Delivery ***

* = Man Wt.

JMF#	1/LDS Today	1/LDS To Date	109340*lb	30260 lb	79080 lb
TARE	39.54 Tn	39.54 Tn	54.67*Tn	15.13 Tn	39.54 Tn
TARE	35.87 Mg	35.87 Mg	49.60*Mg	13.73 Mg	35.87 Mg

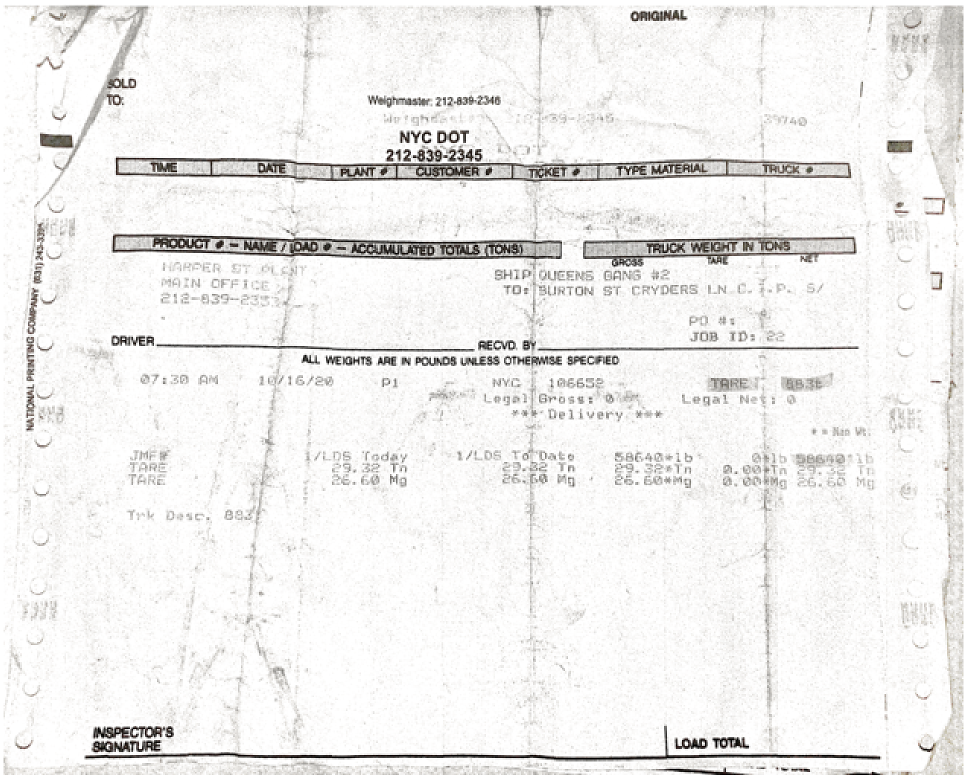
Trk Desc. 882FF

INSPECTOR'S SIGNATURE

LOAD TOTAL

Truck R2 – Class 9, 3S2 Split

Class 9 Split	Truck R2	883T + 172T				
Spacing	**Axle1**	**Axle2**	**Axle3**	**Axle4**	**Axle5**	**Axle6**
Distance (in)	0	160	214	680	735	790
Spacing (in)	**160**	**54**	**466**	**55**	**55**	
Spacing (ft)	**13'-4"**	**4'-6"**	**38'-10"**	**4'-7"**	**4'-7"**	
				9'-2"	Axle 5 was removed	
Width	**Front**	**Rear/Tander**	**Rear/Trailer**			
Spacing (in)	80	78	77			
Spacing (ft)	**6'-8"**	**6'-6"**	**6'-5"**			
Weight	**Axle1**	**Axle2**	**Axle3**	**Axle4**	**Axle6**	**GVW**
Left (lb)	6350	8115	8025	5054	9720	
Right (lb)	5981	8274	8095	4735	9331	
Axle Weight	**12332**	**16389**	**16120**	**9789**	**19051**	**73680**



ORIGINAL

SOLD TO:

Weighmaster: 212-839-2346

NYC DOT
212-839-2345

TIME	DATE	PLANT #	CUSTOMER #	TICKET #	TYPE MATERIAL	TRUCK #

PRODUCT # – NAME / LOAD # – ACCUMULATED TOTALS (TONS)

TRUCK WEIGHT IN TONS — GROSS — TARE — NET

HARPER ST PLANT
MAIN OFFICE
212-839-2353

SHIP QUEENS GANG #2
TO: BURTON ST CRYDERS LN C.I.P. 5/

PO #:
JOB ID: 22

DRIVER ______ RECVD. BY ______

ALL WEIGHTS ARE IN POUNDS UNLESS OTHERWISE SPECIFIED

07:30 AM 10/16/20 P1 NYC 106652 TARE 883T
Legal Gross: 0 Legal Net: 0
*** Delivery ***

* = Man Wt.

JMF#	1/LDS Today	1/LDS To Date	58640*lb	0*lb	58640*lb
TARE	29.32 Tn	29.32 Tn	29.32*Tn	0.00*Tn	29.32 Tn
TARE	26.60 Mg	26.60 Mg	26.60*Mg	0.00*Mg	26.60 Mg

Trk Desc. 883

INSPECTOR'S SIGNATURE

LOAD TOTAL

NATIONAL PRINTING COMPANY (631) 243-3395

Truck R3 – Class 6

Class 6	Truck R3	242FF		
Spacing	**Axle1**	**Axle2**	**Axle3**	
Distance (in)	0	208	264	
Spacing (in)	**208**	**56**		
Spacing (ft)	**17'-4"**	**4'-8"**		
Width	**Front**	**Rear/Tandem**		
Spacing (in)	84	73		
Spacing (ft)	**7'-0"**	**6'-1"**		
Weight	**Axle1**	**Axle2**	**Axle3**	**GVW**
Left (lb)	10967	12897	12575	
Right (lb)	10806	12012	12384	
Axle Weight	**21772**	**24909**	**24959**	**71640**

ORIGINAL

SOLD TO:

Weighmaster: 212-839-2346

Weighmaster: 212-839-2345 11640

NYC DOT

212-839-2345 DOT

TIME	DATE	PLANT #	CUSTOMER #	TICKET #	TYPE MATERIAL	TRUCK #

PRODUCT # – NAME / LOAD # – ACCUMULATED TOTALS (TONS)

TRUCK WEIGHT IN TONS (GROSS / TARE / NET)

HARPER ST PLANT
MAIN OFFICE
212-839-2353

SHIP QUEENS GANG #2
TO: BURTON ST CRYDERS LN C.I.P. S/

PO #:
JOB ID: 22

DRIVER ______ RECVD BY ______

ALL WEIGHTS ARE IN POUNDS UNLESS OTHERWISE SPECIFIED

12:28 PM 10/15/20 P1 NYC 106638 TARE 242 ff
Legal Gross: 0 Legal Net: 0
*** Delivery ***

* = Man Wt.

JMF#	1/LDS Today	1/LDS To Date	71640*lb	0*lb	71640 lb
TARE	35.82 Tn	35.82 Tn	35.82*Tn	0.00*Tn	35.82 Tn
TARE	32.50 Mg	32.50 Mg	32.50*Mg	0.00*Mg	32.50 Mg

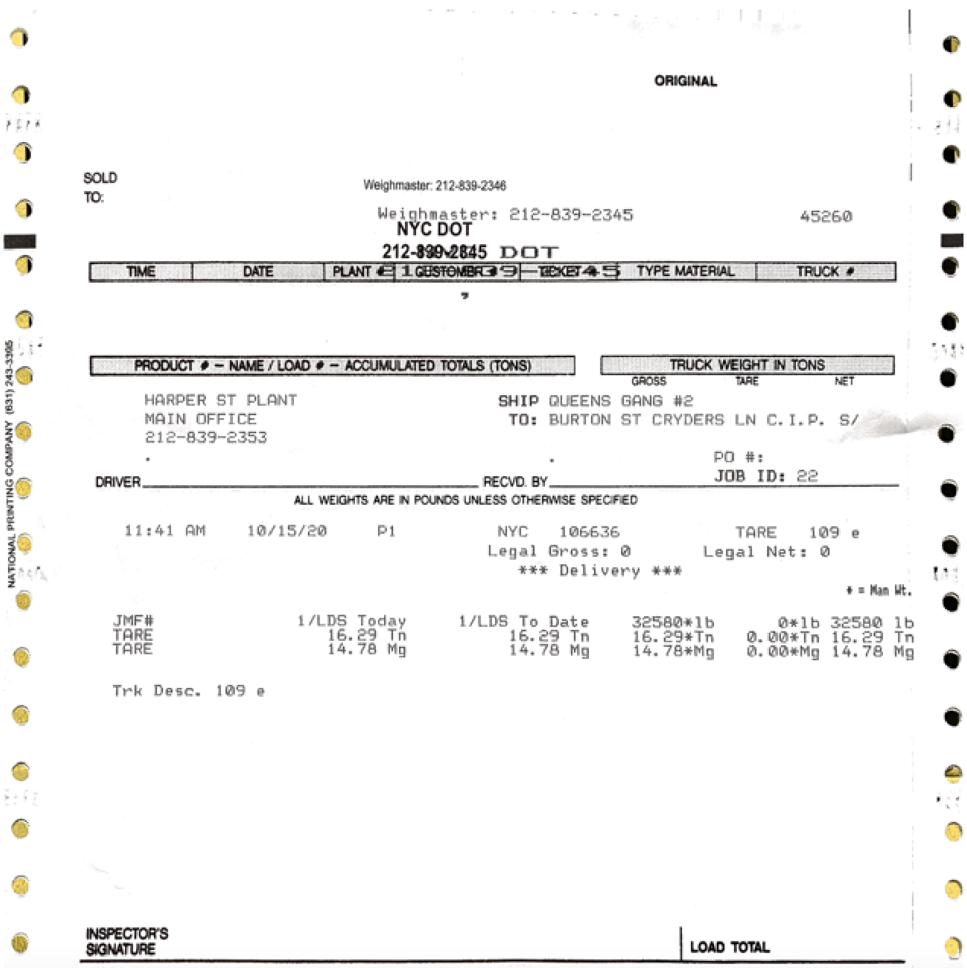
Trk Desc. 242ff

INSPECTOR'S SIGNATURE

LOAD TOTAL

Truck R4 – Class 5

Class 5	Truck R4	109E	
Spacing	**Axle1**	**Axle2**	
Distance (in)	0	230	
Spacing (in)	**230**		
Spacing (ft)	**19'-2"**		
Width	**Front**	**Rear/Tandem**	
Spacing (in)	83	73	
Spacing (ft)	**6'-11"**	**6'-1"**	
Weight	**Axle1**	**Axle2**	**GVW**
Left (lb)	5332	11323	
Right (lb)	4902	11023	
Axle Weight	**10233**	**22347**	**32580**


ORIGINAL

SOLD TO:

Weighmaster: 212-839-2346

Weighmaster: 212-839-2345 45260

NYC DOT

212-839-2345 DOT

TIME	DATE	PLANT	CUSTOMER	TICKET	TYPE MATERIAL	TRUCK #

PRODUCT # – NAME / LOAD # – ACCUMULATED TOTALS (TONS)	TRUCK WEIGHT IN TONS (GROSS / TARE / NET)

HARPER ST PLANT
MAIN OFFICE
212-839-2353

SHIP QUEENS GANG #2
TO: BURTON ST CRYDERS LN C.I.P. S/

PO #:
JOB ID: 22

DRIVER ______ RECVD. BY ______

ALL WEIGHTS ARE IN POUNDS UNLESS OTHERWISE SPECIFIED

11:41 AM 10/15/20 P1 NYC 106636 TARE 109 e
Legal Gross: 0 Legal Net: 0
*** Delivery ***

* = Man Wt.

JMF#	1/LDS Today	1/LDS To Date	32580*lb	0*lb 32580 lb
TARE	16.29 Tn	16.29 Tn	16.29*Tn	0.00*Tn 16.29 Tn
TARE	14.78 Mg	14.78 Mg	14.78*Mg	0.00*Mg 14.78 Mg

Trk Desc. 109 e

INSPECTOR'S SIGNATURE

LOAD TOTAL

NATIONAL PRINTING COMPANY (631) 243-3395

Truck R5 – Class 5

Class 5	Truck R5	1197B	
Spacing	**Axle1**	**Axle2**	
Distance (in)	0	159	
Spacing (in)	**159**		
Spacing (ft)	**13'-3"**		
Width	**Front**	**Rear/Tandem**	
Spacing (in)	65	76	
Spacing (ft)	**5'-5"**	**6'-4"**	
Weight	**Axle1**	**Axle2**	**GVW**
Left (lb)	2510	2510	
Right (lb)	2330	2370	
Axle Weight	**4840**	**4880**	**9720**

ORIGINAL

SOLD TO:

Weighmaster: 212-839-2346

Weighmaster: 212-839-2345 45440

NYC DOT

212-839-2345 DOT

TIME	DATE	PLANT #	CUSTOMER #	TICKET #	TYPE MATERIAL	TRUCK #

PRODUCT # – NAME / LOAD # – ACCUMULATED TOTALS (TONS)

TRUCK WEIGHT IN TONS: GROSS TARE NET

HARPER ST PLANT
MAIN OFFICE
212-839-2353

SHIP QUEENS GANG #2
TO: BURTON ST CRYDERS LN C.I.P. S/

PO #:
JOB ID: 22

DRIVER ____ RECVD BY ____

ALL WEIGHTS ARE IN POUNDS UNLESS OTHERWISE SPECIFIED

02:56 PM 10/15/20 P1 NYC 106641 TARE 1197b
Legal Gross: 0 Legal Net: 0
*** Delivery ***

* = Man Wt.

	1/LDS Today	1/LDS To Date			
JMF#			9720*lb	0*lb	9720 lb
TARE	4.86 Tn	4.86 Tn	4.86*Tn	0.00*Tn	4.86 Tn
TARE	4.41 Mg	4.41 Mg	4.41*Mg	0.00*Mg	4.41 Mg

Trk Desc. 1197b

INSPECTOR'S SIGNATURE

LOAD TOTAL