ADEC Technologies

ADEC TDC3 Classification Performance

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1 Introduction

The present document describes the classification accuracy of the TDC3-8. This test has been conducted at a test site operated by ADEC Technologies. The test site is equipped with a break-beam system (to acquire each vehicle's length and speed) and a video system (to manually verify the vehicle's class). The test was conducted over an extended period, involving nearly 50,000 vehicles.

2 Classification Performance

2.1 Absolute Vehicle Volume

The table below shows the occurrence of each vehicle class, as measured by the detector and manually verified. The "Actual Volume" shows the manually verified volume for each class. The columns to the right show the classes that the detector assigned these vehicles to. For example, there were 1170 motorcycles. 1096 of these were classified as such, 54 were classified as cars, 4 as vans.

Vehicle Class	Actual Volume	Detector classified vehicles (in left-most column) into classes in columns below							
		Motor-cycle	Car	Van	Car w/ trailer	Truck	Truck w/ trailer	Semi-trailer	Bus
Motorcycle	1,170	1,096	54	4					
Car	38,420	22	37,849	254	7				
Van	4,216		236	3,946	20	14			
Car with Trailer	719		31	17	646	12	2	9	1
Truck	1,436		5	36	5	1,329	6	41	12
Truck with Trailer	831		1	0	2	3	768	57	
Semi-Trailer	1,505		3	7	4	23	43	1,419	6
Bus	362			5		21	4	7	325
Phantom		1	25	0					
Total	48,659	1,119	38,204	4,269	684	1,402	823	1,533	344

Table 1: Absolute classification figures

2.2 Relative Vehicle Volume

The table below shows the relative volume of each vehicle class assigned by the detector.

Vehicle Class	Actual Volume	classified as							
		Motor-cycle	Car	Van	Car w/ trailer	Truck	Truck w/ Trailer	Semi-trailer	Bus
Motorcycle	2.40%	93.68%	4.62%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%
Car	78.96%	0.06%	98.51%	0.66%	0.02%	0.00%	0.00%	0.00%	0.00%
Van	8.66%	0.00%	5.60%	93.60%	0.47%	0.33%	0.00%	0.00%	0.00%
Car with Trailer	1.48%	0.00%	4.31%	2.36%	89.85%	1.67%	0.28%	1.25%	0.14%
Truck	2.95%	0.00%	0.35%	2.51%	0.35%	92.55%	0.42%	2.86%	0.84%
Truck with Trailer	1.71%	0.00%	0.12%	0.00%	0.24%	0.36%	92.42%	6.86%	0.00%
Semi-Trailer	3.09%	0.00%	0.20%	0.47%	0.27%	1.53%	2.86%	94.29%	0.40%
Bus	0.74%	0.00%	0.00%	1.38%	0.00%	5.80%	1.10%	1.93%	89.78%
Ghost	0.11%	1.85%	46.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	100.11%								

Table 2: Absolute classification figures

Note: Ghost vehicles are caused for example when a large vehicle is incorrectly split into two smaller vehicles. This leads to a minor over-count of 0.11%. The table shows that 2.4% of all vehicles were motorcycles, of these motorcycles, 93.68% were classified as such, 4.62% of them were incorrectly classified as cars, and 0.34% as vans. Of the 0.11% over-count "Ghost" vehicles, nearly half were cars, 1.85% were classified as motorcycles. The majority were classified as "unclassifiable" (TLS Class ID 6)

2.3 Detection Rates

Armed with these data, one can calculate the detection rates E1 and E2 as well as the statistically relevant detection rates (see Appendix A for details):

	Vehicle Class							
	Motor-cycle	Passen-ger car	Delivery van	Car with trailer	Truck	Truck with trailer	Semi-trailer	Bus
Detection Rate E1	93.68%	98.51%	93.60%	89.85%	92.55%	92.42%	94.29%	89.78%
Statistically significant detection rate PE1	92.13%	98.39%	92.82%	87.42%	91.07%	90.42%	93.00%	86.23%
Detection Rate E2	98.03%	99.08%	92.34%	94.71%	94.92%	93.38%	92.43%	94.75%
Statistically significant detection rate PE2	97.07%	98.98%	91.50%	92.83%	93.66%	91.48%	90.98%	91.95%

Table 3: Detection rates

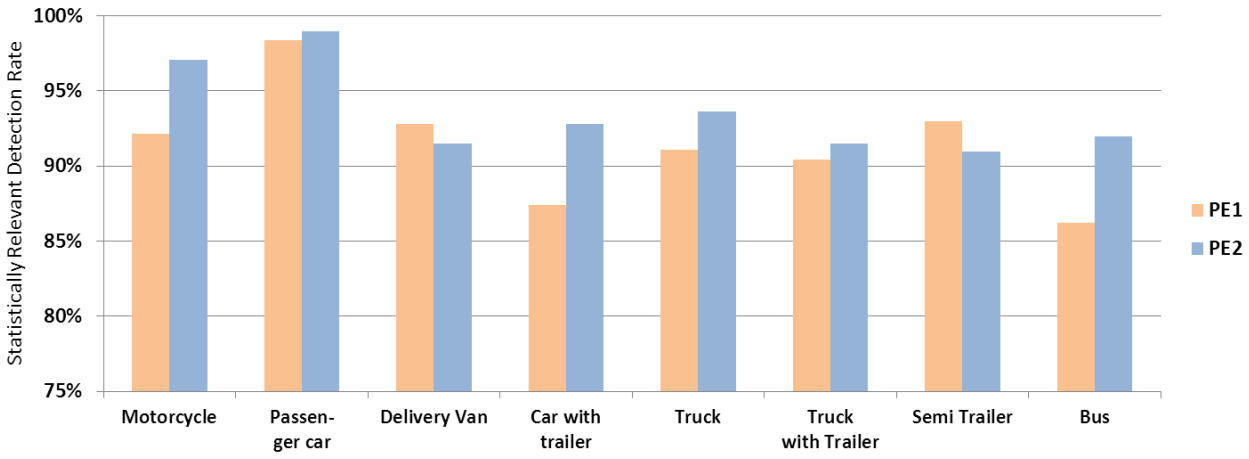

Figure 1: Graphical representation of detection rates / classification performance

Appendix A: Detection Rates Calculation

General Information about TLS Classification

According to TLS for classification in 8+1 vehicle classes respectively detectors are divided into three accuracy groups. The classification criteria are based on shape, weight and usage of the vehicles. An incorrectly classified vehicle must be marked as such.

Ambiguous classification

Despite diligent working methods it is occasionally very difficult or even impossible to classify a vehicle. The distinction between delivery van and truck uses the legal maximum weight. Some types of vehicles (for example the Mercedes Sprinter) can even be manufactured in different editions (not distinguishable on a picture) with different legal maximum weight, resulting in identically looking vehicles belonging to different classes. Ambiguous cases are decided in favor of the detector.

Lane changing vehicles

According to TLS lane changing vehicles may be removed from the assessed data set. Lane changing vehicles are those that change the lane within the detection zone from an adjacent, also observed lane or from an unobserved lane to an observed lane. In certain cases interpretation of the same situation varies. In every case the decision whether a vehicle is a lane changing vehicle is done with outmost diligence. It is to be noted that the elimination of lane changing vehicles causes the sum of detected vehicles through the entire test site to deviate from the actual sum of vehicles passed.

Analysis

According to TLS the detection rate E1x is to be evaluated for each vehicle class x:

$$E1_x = \frac{M_{x,x}}{S_x}$$

E1 describes the fraction of correctly identified vehicles Mx,x of a class x in relation to the actual number Sx. Because only a limited number of vehicles can be examined for practical reasons, the binomial distribution is used using a standard 95% confidence interval (TLS 2002, S. IV. 1-2ff):

$$P_{E1,x} = \frac{2 \cdot M_{x,x} + Z^2 - Z \cdot \sqrt{Z^2 + 4 \cdot M_{x,x}\left(1 - \frac{M_{x,x}}{S_x}\right)}}{2 \cdot (S_x + Z^2)}$$

P	statistically relevant detection rate
$M_{x,x}$	Number of correctly classified vehicles
Z	1.96 (95% percentile of normal distribution)
S_x	Total number of vehicles

Rearranging the equation above provides the detection rate E1 using a given level of confidence

$$\frac{1}{S_x + Z^2} \cdot \left(M_{x,x} + \frac{Z^2}{2} - Z \cdot \sqrt{M_{x,x} \cdot (1 - E1) + \frac{Z^2}{4}} \right)$$

$$\leq E1 \leq$$

$$\frac{1}{S_x + Z^2} \cdot \left(M_{x,x} + \frac{Z^2}{2} + Z \cdot \sqrt{M_{x,x} \cdot (1 - E1) + \frac{Z^2}{4}} \right)$$

For the assessment of the 8+1 classes test, TLS specifies three accuracy groups (A1-A3) and the lowest required accuracy level E_{min} per class and group. To pass the test for a class, the statistically relevant detection rate of the lowest accuracy level A3 must be met or exceeded. In addition, depending on the required detection rate, minimum sample sizes M_{min} must be observed:

	Group A1		Group A2		Group A3	
	E_{min}	M_{min}	E_{min}	M_{min}	E_{min}	M_{min}
Vehicles (any)	99%	1552	97%	497	95%	292
Motorcycle	90%	139	85%	88	80%	62
Passenger Car	97%	497	95%	292	90%	139
Delivery Van	90%	139	85%	88	80%	62
Car with Trailer	90%	139	85%	88	80%	62
Truck	90%	139	85%	88	80%	62
Truck with Trailer	95%	292	90%	139	85%	88
Tractor with Trailer	95%	292	90%	139	85%	88
Bus	90%	139	85%	88	80%	62

The statistically relevant detection rate depends on the detection rate and the size of the sample set from the entire population. An increasing size of the sample set moves the statistically relevant detection rate towards the observed detection rate whereas a small sample set affects the results negatively. As a result, the statistically relevant detection rate has to be regarded as a critical component when determining the quality of the detector using a test at reasonable efforts. During the data-gathering phase of this test, information of 48,659 vehicles has been collected. As expected, most of the vehicles are passenger cars. Vehicles of certain classes (such as motorcycles, buses, cars with trailers) are less frequent than vehicles from other classes, but because of the sizable sample set it is possible to make a statistically relevant statement about the classification accuracy of nearly all vehicle classes.

The accuracy of a particular class can be affected by incorrectly classified vehicles of other classes, resulting in an increased count of the observed class. For example: 100 motorcycles pass through the detection zone and are correctly assigned to the motorcycle class. During the same period, 200 of the 10,000 cars are incorrectly assigned to the motorcycle class. As a result, the detection rate for

motorcycles would be 100%. If a large number of the cars were correctly classified as well, the results for both motorcycles and cars would be good, despite the fact that the number of motorcycles detected exceeds the actual number by 200%. An additional criterion is therefore used to verify whether the minimum required detection rate is met after deducting the number of "phantom" detections and incorrect classifications from other classes. The value E2 provides information about this:

$$E2_i = 1 - \frac{\sum_{x=1}^{9} M_{x,i} - M_{i,i}}{S_i}$$

E2 in essence equals "1 minus the rate of incorrect detections", whereby the rate of incorrect detections is not in relation to the total number of vehicles in a class but instead to the total number S of vehicles of a certain class i. Because the consequences of incorrect detections also depend on the total number of vehicles, the analysis is conducted using a predetermined blend of vehicles that is calculated from the observed number of vehicles on the monitored lane and the preset fraction. The computation of E1 does not take into account the "phantom" detections; instead, they significantly influence the computation of E2. TLS however does not describe how to handle the phantom detections in relation to a pre-determined blend of vehicle types: The "phantom" detection rate at prevalent conditions during the test period is available through the recording process. This rate however cannot be easily adopted to a given blend of vehicles, since it primarily depends on the vehicles travelling on neighboring lanes. It can be assumed that also here the driving behavior (distance from observed lane), as well as the shape (ground clearance, length etc.) of the vehicles affect the phantom detection rates of the observed lane. The phantom rate of a lane obviously varies according to its location (middle-lane → two neighboring lanes, near or far lane → one neighboring lane) and the types of the vehicles traveling on the adjacent lane(s). PE2 is calculated according to the description above as "1 minus statistically relevant, not exceeded detection rate". This approach allows the calculation the of the incorrect classification rate exceeding 100% (whenever phantom-detections are observed), which formally prevents calculating PE2 (square root of a negative number). In these cases, the statistically relevant detection rate PE2 is not provided.