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# Evaluation of integrated vehicle detector for usage in ports

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**Key words:** ITS, identification of vehicles, measuring devices, vehicle detectors

**Abstract**
This article presents equipment which monitors vehicles in sea ports and furthermore management of transshipment. A method and results of an integrated vehicle detector was presented. The studied unit represents the newest trend in building detectors, where one device applies a couple of detection methods. The studied device applied: passive infrared (PIR), ultrasonic and electromagnetic microwave radiation. The aim of the research was to describe how accurate the vehicle detector TT 298 acquires data. The evaluation pertained to: counting vehicles, describing structures according to the type, vehicle speed measurement.

## Introduction

In sea transport economic effectiveness, security, and environmental protection are inseparably connected to one another. Thus, it is important to create and integrate a system which would make it possible to effectively utilize people, port infrastructure and ships. Sea port management systems include port infrastructure management and loading operations. Steering and monitoring loading operations requires the identification of participants involved in the process, in particular vehicles driving around the port premises [1].

Advanced systems ITS (Intelligent Transportation Systems) make it possible to: react to emergency situations, manage transshipment areas, give access to vehicles, and more effectively utilize data which represent current situations at a given time in the port [2]. Vehicle detectors which acquire such data are an integral part of every modern traffic management system [3].

There is no one universal device which would be optimal for all purposes. Aside from the most commonly used induction loop, other detectors such as magnetic detectors, video detectors, microwave detectors, ultrasonic, infrared detector (PIR), pneumatic, piezoelectric, laser, and many others are applied [4].

As in every field of engineering there is constant progress, existing methods of detection are improved and new technology and devices are proposed [5].

The article presents methods and results of an integrated vehicle detector. The studied device represents the newest trend in building detectors, where one device uses: passive infrared, ultrasonic and electromagnetic microwave radiation. In Poland such a device has never undergone evaluation. Previous vehicle detector models made by this manufacturer were well made.

A practical effect that resulted from presented works was preparing a standpoint regarding traffic parameter tests, used for didactic purposes and carrying out research [6].

## Description of an Integrated Vehicle detector

A Swiss company called Asim passed on to the Department of Transportation a TT 298 detector for research purposes and for the use of students studying Road Traffic Control during lab classes from “Road Traffic Measurements”, as well as while carrying out their own research.

The TT 290 detectors combine three methods of detection in one device – detection applying microwaves, ultrasonic detection and infrared radiation detection. Passing vehicles generate output signals recorded by each sensor. These signals are separately processed by a microprocessor thanks to which it is possible to compare data obtained by each sensor, and enables one to verify if the device is functioning properly.

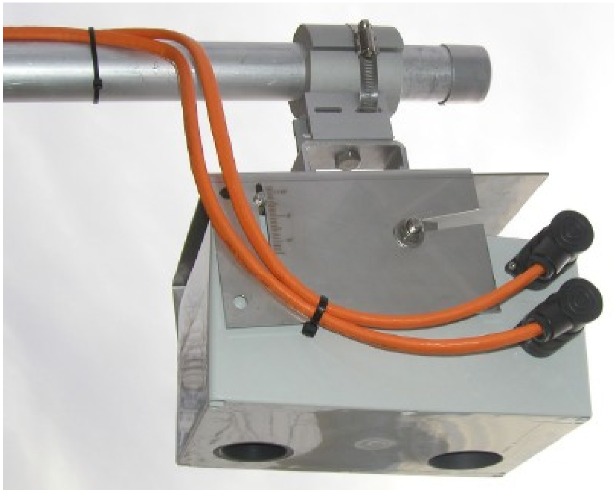


Fig. 1. Detector TT 298 [7]

#### How the TT 298 detector works

The microwave part of the device measure vehicle speed by using the Doppler Effect. The ultrasonic sensor scans the vehicles profile in order to determine the type of vehicle. A passive multichannel infrared radiation sensor makes it possible to assign acquired information to specific traffic lanes and activates ultrasonic detection. Detection through the use of infrared radiation makes it possible to identify vehicles travelling along forked lanes, as well as vehicles changing lanes.

Classification of structure types is based on length and contour of the vehicle. In the case of detector TT 298 it is possible to describe 8 classes of vehicles (in model: TT293 two, in model TT295 five). Vehicles which were unable to be assigned to a defined class are added to an additional group – unidentified. These were usually vehicles which were moving outside the detected area.

#### Detector TT 298: Areas of detection

A microwave sensor creates an area of detection in the form of a cone. An infrared radiation sensor creates two multichannel “curtains”. Between the PIR sensor “curtains” there is an ultrasonic detection sensor area which is in the form of a cone. The size of the detection areas depends on how high the detector is mounted.

The detector was designed in such a way that during installation on an overpass above the middle of a lane or on other road constructions, it would cover distinctly one traffic lane.

The angles between the cones are created by the microwave sensor, ultrasonic cone and infrared curtains are stable and define the geometry of the detection. Distance between these detection areas depends from how high the detector was installed and the angle of the detector in relation to the surface of the road.

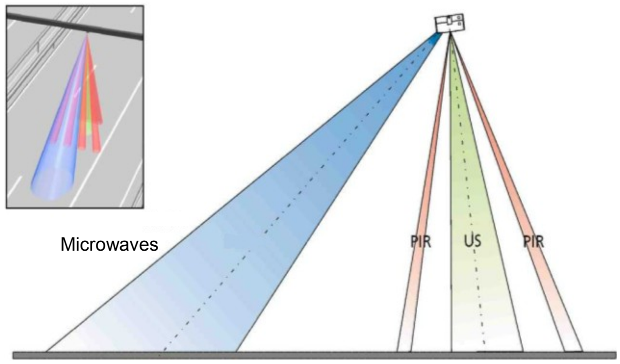



Fig. 2. Reciprocal positioning of the detection areas [8]

If the detector is installed in compliance with the manufacturers’ instructions, the width of specific areas should enable the detection of vehicles on one traffic lane.

In order to acquire an accurate measurement, the detector should be stably mounted. Vibration and wind effect should be limited to a minimum.

#### The detectors functions

*Counting of vehicles*

Applying three sensors allows a high accuracy in counting vehicles. Sporadic increased or decreased results may happen in exceptional situations like for example during traffic congestions, when cars are moving slowly and stopping frequently.

*Speed measurement*

The microwave detector allows the measurement of the speed of vehicles with high accuracy. If the speed measurement carried out by the detector shows constant deviation from the vehicles real speed (e.g. because of the way it is mounted), there is a possibility to correct the obtained value by a coefficient (described by a percentage) implemented through an Asim-T.exe program. Therefore, it is possible to avoid repeated calibration of the detectors positioning.

*Vehicle classification*

Every vehicle crossing the detection area is detected and individually classified. Classification takes place by analyzing length and vehicle profile. Segregation into different classes has been presented in table 1. Numbers assigned to each type of vehicle depends on its model and symbolizes a distinct type of vehicle in a file including detection results.

Table 1. Classification of vehicles according to distinct classes [8]

| Detector model | | TT293 | | TT295 | **TT298** |
|---|---|---|---|---|---|
| Vehicle class | | 2+1 | 2+0 | 5+1 | **8+1** |
| | Car | 32 | 32 | 1 | **7** |
| | Motorcycle | | | | **10** |
| | Delivery van | | | | **11** |
| | Not identified | 6 | | 6 | **6** |
| | Lorry/truck | 33 | 3 | | **3** |
| | Lorry / truck with trailer | | 4 | | **8** |
| | Articulated lorry/semi-trailer | | | | **9** |
| | Bus | | 5 | | **5** |
| | Car with trailer | | 2 | | **2** |

*Amount of time the detection area is occupied*

For each vehicle identified by the detector, the amount of time it is present in the area is calculated. This makes it possible to evaluate traffic congestion.

*Measurement of time intervals between upcoming cars*

The detector records the time between the passing of one car and the arrival of the next.

*Diagnostic Function: auto – control*

The device has the capability to carry out validity check tests for its actions. If there is any error in any of the functioning sensors the information is passed on, which results in a change in the status value in the information protocol. Information about the status of the detector should regularly be checked by the operator. The *scope* function in the Asim-T.exe program shows statuses which identify irregularities.

Table 2. Examples of diagnosed errors [8]

| Device status | Type of diagnosed errors |
|---|---|
| Radar fault | Microwave sensor error |
| IR1 fault | Infrared sensor error 1 |
| IR2 fault | Infrared sensor error 2 |
| Ultrasonic fault | Ultrasonic sensor error |
| Wrong-way driver | A vehicle driving against traffic is identified |
| Queue/Traffic jam | Queue / Traffic jam |
| Synchronisation fault | Synchronisation fault |

*Detection of vehicles driving in the wrong direction*

Detectors from the series TT 290 have the capability to detect vehicles moving in the wrong direction. This fact is determined after fulfilling certain conditions, which serve as security against false signals: infrared radiation detection areas are crossed by a vehicle in an inappropriate order; the vehicle was registered by an ultrasonic sensor.

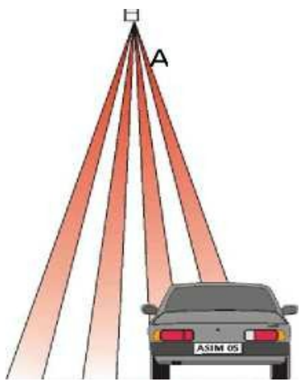
*Queue/ traffic jam*

If the vehicles are in the area of detection for longer than 6 seconds (manufacturer setting) and are constantly detected, the detector sets up a byte status on "Queue". Threshold value is 6 seconds and can be changed in the Asim-T.exe program within the range of: 6–60 seconds.

*Information pertaining to the traffic lane*

The detector presents information saying in which part of the lane was a vehicle detected by the infrared sensor. Information regarding positioning on the traffic lane („<" – left/ „>" – right) is given in regards to traffic direction labeled with a digit describing the type of vehicle, for example:

- \> 6 – Vehicle is on the right side of the lane, *unidentified class*;
- < 7 – Vehicle is on the left side of the lane, *passenger car class (*in accordance with table 1).




| address | time stamp [hh:mm:ss] | v [km/h] | length [m] | lane-info / class | occupancy [s] | time gap [s] | status | counter | sync.- timer |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 06:49:47 | 99 | 5.2 | > 7 | 0.21 | 1.74 | 0 | 81933 | 71.6925 |

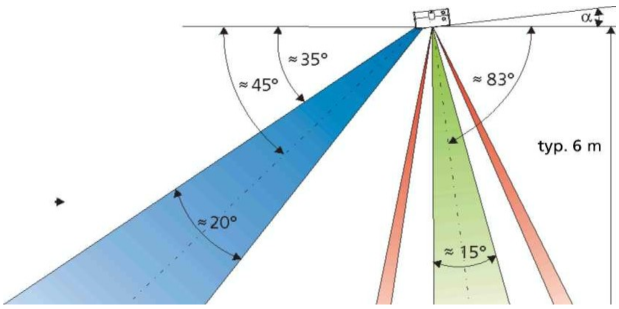
Fig. 3. The vehicle is on the right side of the lane and in compliance with output data from detector [8]

If the car is moving along the middle of the lane symbols such as <, > do not appear.

Figure 3 illustrates a situation when a car is distinctly driving along the right side of the lane and in compliance with the detectors output data pertaining to this situation.

#### Device installation instructions

In order for the detector to function properly the vehicles must pass through all the detector areas (Doppler radar, ultrasonic cone and infrared curtain) in an appropriate order, and vehicles from neighboring lanes cannot enter any of the detector areas. Recommended height of installation for model TT 298 is 5…6 meters (16 … 20 ft) depending on the road lanes width.




$\alpha = 7°$ in relation to the road pavement

Fig. 4. Reciprocal arrangement of the detector areas [8]

## Evaluation of the integrated vehicle detectors

The evaluation of the detector was based on research whose goal was to specify how accurate the TT 298 vehicle detector acquires data. The evaluation included the following device functions:

- counting vehicles;
- determining the vehicle structure type;
- vehicle speed measurement.

The evaluation also took under consideration the devices functionality and how easy is it to gather and analyze measured results. The measurements were recorded in Warsaw, in Praga on Płowiecka street. The measuring point was located at a pedestrian crossing [7].

Speed measurement was carried out by a detector verified by a separate radar meter. The entire research was registered on a digital carrier using a video camera in order to carry out visual verification of the detectors correctness (counting vehicles, describing the type of vehicles). The measurements were taken during three working days. Verification of detection was applied to 1005 vehicles. Speed was first measured and afterwards assigned to data acquired by detectors for 249 vehicles.

#### Counting and vehicle classification

Analysis of counting validity and classification was based on comparing detector results with a video image. Assigning the vehicle to appropriate classes based on how they look is not precise. At times it is not possible to determine whether a vehicle is a delivery van or truck; in most situations only information about its mass could help distinguish. It was assumed that vehicles which are difficult to precisely determine their class (based on observation) are considered correctly classified, if the detector assigned the given vehicle to one of the examined classes. Classification evaluation was carried out for vehicles which had a larger part of their contour in a detection area that was restricted by marks separating the lanes.

Even though the detector detected 61 vehicles (from a total of 1005 registered vehicles) it did not classify them. It was not determined that the vehicles whose contour was in the larger part of the detected area were not classified. Classification verification carried out by the detector was applied to 944 sample vehicles.

Vehicles which were very close to the monitored lane did not cause detection error. An example is when a parked truck with a semi-trailer was parked on a neighboring lane. This did not disturb the way the detector functioned.

#### Evaluation ratio for vehicle classification

In order to evaluate the detector quality, ratios were introduced which checked effectiveness of detection. The first most intuitive ratio is the relation of the amount of vehicles from class $x$ properly identified by the detector (verified on the basis of analyzed video recording) in relation to the total amount of vehicles from class $x$ (calculated according to analyzed video recording).

$$\mathrm{E1}_x = \frac{M_x}{L_x} \tag{1}$$

$\mathrm{E1}_x$ – ratio describing the correctness of classifying vehicles type $x$;

$M_x$ – amount of vehicles belonging to class $x$ which were correctly identified by the detector;

$L_x$ – total amount of vehicles per one class (calculated according to an analyzed video image).

The indicator $\mathrm{E1}_x$ has a binomial distribution because of it proportion. It is known that for a sufficiently large number of experiments (at least 100), the limit cumulative distribution of the binomial distribution is the distribution function of the normal distribution (theorem de Moivre-Laplace).

The following modification of the classical formula for the confidence interval of proportion, in this case the indicator $E1_x$, with the level of significance equal 0.05 [9]:

$$\frac{1}{L_x+Z^2}\left\{M_x+\frac{Z^2}{2}-Z\sqrt{M_x\left(1-\frac{M_x}{L_x}\right)+\frac{Z^2}{4}}\right\}\leq \mathbf{E1}_x$$
$$\leq\frac{1}{L_x+Z^2}\left\{M_x+\frac{Z^2}{2}-Z\sqrt{M_x\left(1-\frac{M_x}{L_x}\right)+\frac{Z^2}{4}}\right\} \quad (2)$$

$\mathbf{E1}_x$ – value of $E1_x$ index in the general population;
$M_x$ – amount of vehicles belonging to class $x$ which were correctly identified by the detector;
$L_x$ – total amount of vehicles per one class (calculated according to an analyzed video image);
$Z$ – 1.96 (the value represents a 95% confidence interval factor coming from a large amount of samples).

The lower limit of the confidence interval in the formula (2) is adopted as the parameter describing the effectiveness of detection [9]. After the transformation formula for the lower limit, this parameter determines the efficiency of detection is as follows:

$$P_{E1,x}=\frac{2M_x+Z^2-Z\sqrt{Z^2+4M_x\left(1-\frac{M_x}{L_x}\right)}}{2\left(L_x+Z^2\right)} \quad (3)$$

$P_{E1,x}$ – a parameter describing detection effectiveness considering the size of the sample.

A factor, which has an effect on the quality of vehicle classification, is incorrect assignment to a specified $x$ class by the vehicle detector. In order to analyze the influence of incorrectly assigning vehicles or phantoms (vehicles which in reality didn't exist but were registered by the detector) against reliability of classification, an additional ratio $E2_x$ should be added where:

$$E2_x=\frac{M_x}{C_x} \quad (4)$$

$E2_x$ – ratio specifying proper classification of type $x$ vehicles, taking under consideration errors resulting from assigning vehicles from other classes to the examined $x$ class;
$M_x$ – class $x$ vehicles properly identified by the detector;
$C_x$ – total amount of vehicles registered by the detector for each class.

In table 3 the column called *vehicles from video* presents a % of each type of vehicle which was identified on video. The next columns present a % of vehicles identified by the detector. The sum of vehicles exceeds 100% because phantoms were added. In table 4 the ratio value for $E1_x$ and $E2_x$ are presented for each type of vehicle. Tables 5 and 6 present ranges in which $\mathbf{E1}_x$ and $\mathbf{E2}_x$ appear with a confidence interval of 95%.

Table 4 presents ratio values set according to rules presented earlier for each type of vehicle. Tables 5 and 6 present ranges in which $\mathbf{E1}_x$ and $\mathbf{E2}_x$ appear with a confidence interval of 95%.

Below there are ranges which include an $\mathbf{E1}_x$ and $\mathbf{E2}_x$ ratio with a confidence interval of $(1-\alpha)$ = 95%. The ranges have been set in accordance with formula (2). The scale of the range is strictly con-

Table 3. Percentage participation of each type of vehicle recorded on video and its classification according to the detector [own study]

| Type of vehicle | Vehicles from video [%] | Vehicles classified by the detector [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Motor-cycles | Car | Delivery Van | Car w/trailer | Truck | Truck w/trailer | Truck w/ Semi-trailer | Buses |
| Motorcycle | | – | – | – | – | – | – | – | – |
| Passenger car | 81.78 | 0.65 | **99.35** | – | – | – | – | – | – |
| Delivery van | 10.28 | – | 4.12 | **94.85** | 1.03 | – | – | – | – |
| Car w/trailer | 0.53 | – | – | – | **60.00** | 40.00 | – | – | – |
| Truck | 3.39 | – | – | 3.13 | – | **90.63** | – | – | 6.25 |
| Truck w/trailer | 0.00 | – | – | – | – | – | – | – | – |
| Truck w/semi-trailer | 2.65 | – | – | – | – | 8.00 | – | **88.00** | 4% |
| Buses | 1.38 | – | – | – | – | 15.38 | – | – | **84.62** |
| *„Phantoms”* | *0.21* | – | *50.00* | *50.00* | – | – | – | – | – |
| *Total* | 100.21 | – | – | – | – | – | – | – | – |

Table 4. $E1_x$ and $E2_x$ ratio values for different vehicle classes [own study]

| Class | Motorcycle | Passenger | Delivery | Car w/trailer | Truck | Truck w/ trailer | Truck w/semi-trailer | Buses |
|---|---|---|---|---|---|---|---|---|
| E1(%) | – | 99.35% | 94.85% | 60% | 90.63% | – | 88% | 84.62% |
| E2(%) | – | 99.35% | 97.87% | 75% | 82.86% | – | 100% | 78.57% |

nected with the amount of samples, as well as with which vehicles were more often detected and classified by the detector (passenger cars, delivery vans). These ranges are "narrower" and allow a more reliable evaluation of detection effectiveness.

Table 5. Range, in which there is a detection effectiveness ratio regarding $E1_x$ for $\alpha = 0.05$ [own study]

| Class | Confidence interval $(1 - \alpha) = 95\%$ |
|---|---|
| Passenger car | $98.50\% \leq \mathbf{E1}_x \leq 99.72\%$ |
| Delivery van | $88.50\% \leq \mathbf{E1}_x \leq 97.78\%$ |
| Car with trailer | $23.07\% \leq \mathbf{E1}_x \leq 88.24\%$ |
| Truck | $75.78\% \leq \mathbf{E1}_x \leq 96.76\%$ |
| Truck w/ trailer | – |
| Truck w/ semi-trailer | $70.04\% \leq \mathbf{E1}_x \leq 95.83\%$ |
| Buses | $57.76\% \leq \mathbf{E1}_x \leq 95.67\%$ |

Table 6. Range, in which there is a detection effectiveness ratio regarding $E2_x$ for $\alpha = 0.05$ [own study]

| Class | Confidence interval $(1 - \alpha) = 95\%$ |
|---|---|
| Passenger car | $98.49\% \leq \mathbf{E2}_x \leq 99.72\%$ |
| Delivery van | $92.57\% \leq \mathbf{E2}_x \leq 99.41\%$ |
| Car with trailer | $30.06\% \leq \mathbf{E2}_x \leq 95.44\%$ |
| Truck with trailer | – |
| Truck | $67.32\% \leq \mathbf{E2}_x \leq 91.90\%$ |
| Truck w/semi-trailer | $85.12\% \leq \mathbf{E2}_x \leq 100\%$ |
| Buses | $52.41\% \leq \mathbf{E2}_x \leq 92.43\%$ |

The detector detected 1005 vehicles, of which two were phantoms and 61 were not classified as most of them found themselves on a different lane. If the measurement range included detectors on all the lanes, it could with all likelihood assume that the vehicle would be classified on a neighboring lane. In order to obtain a real number of vehicles in a given area, one should only consider classified vehicles. During measurements the device detected 946 vehicles. Based on analyzed video recordings there were 944 vehicles. This means that two of the vehicles were "phantoms" – they didn't really exist. Thus, resulting in a vehicle counting error of 0.2%.

#### Speed measurement accuracy research

Speed was measured by detector TT 298 and compared with results obtained by Rapid 1, which served as a reference. A declared radar error equaled ±3 km/h for speeds reaching 100 km/h and ±3% for higher speeds. Evaluation of speed measurement accuracy carried out by detector TT 298 is burdened with uncertainty resulting from the reference devices' high error level.

Some of the speed measurement results were rejected for the following reasons:

- vehicle speed was measured by a radar, but the detector even though it detected the vehicle did not determine its type and as a result did not register its speed;
- difference between the speed measurements were so high that there were doubts as far as determining whether the measurements pertained to the same vehicle.

While taking measurements the speed of 249 vehicles was measured. After rejecting doubtful results, 235 measurements passed to further analysis.

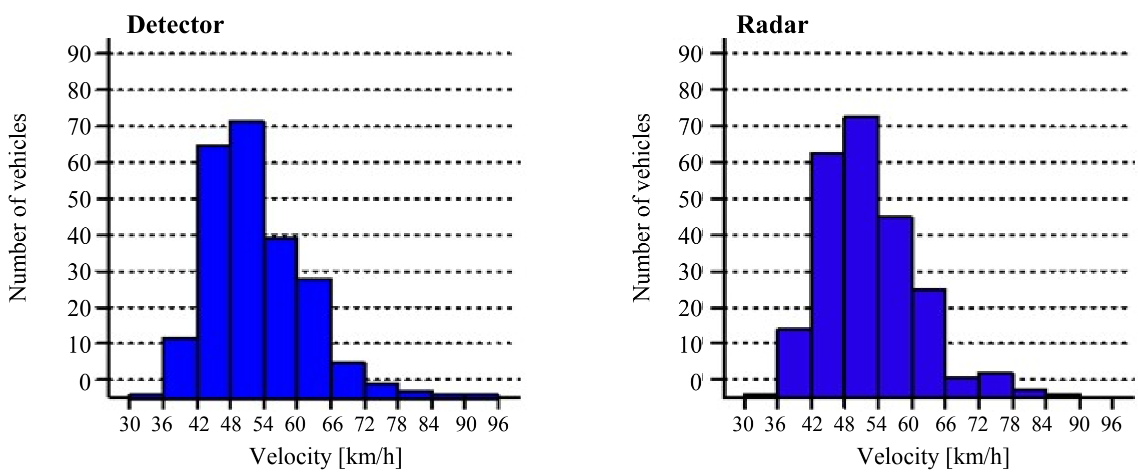



Fig. 5. A breakdown of vehicle speed specified by detector TT 298 and a reference radar [7]

Table 7. Speed measurement results [own study]

| | Radar | Detector |
|---|---|---|
| Amount of measurements | 235 | 235 |
| Average speed (km/h) | 52.87 | 52.06 |
| Standard speed deviation (km/h) | 9.15 | 8.77 |
| Lowest measured speed (km/h) | 35.10 | 33.00 |
| Highest measured speed (km/h) | 90.70 | 86.00 |

The difference between average speed figures measured by a radar and a detector amounted to 81 km/h (the average vehicle speed measured by a reference meter amounted to 52.87 km/h, while the detectors gave a result of 52.87 km/h). This means that the average encompassed vehicle speed decreased by 1.5% according to the reference speed meter.

The standard deviation value is also similar (for measurement values made by a mobile radar the standard deviation amounted to 9.15 km/h, and in the case of the detector: 8.77 km/h).

Even without considering the radar detection error it can be stated that the speed measurement obtained by detector TT 298 are very similar to measurements made by the radar.

## Conclusions

The research made by the integrated vehicle detector Asim TT 298 made a multi-aspect device evaluation possible. The main goal of the measurements carried out on one of Warsaw's streets, was to describe the accuracy of the most vital data obtained by the detector. The results of the speed measurements acquired by the detector were in accordance with microwave radar reference indicators.

Vehicle counting error amounted to a mere 0.2%. Determining vehicles according to type was also accurate; in particular vehicles whose sample was substantial. Classification effectiveness of passenger cars was 99% and delivery vans 95%. Detector evaluation allows one to make a conclusion that this is a device that makes it possible to acquire exact results with very easy installation and handling. It seems that this device would find proper usage in sea ports, where traffic requires not only finding their presence but also to determine the type. The authors do not know of examples of such installations. A significant limitation is its requirement to be located on an axis over moving traffic.

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