

# Report

## Methods and systems to measure the environmental impact of individual vehicles in traffic.

Final report of the MOVE project

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# Report

## Methods and systems to measure the environmental impact of individual vehicles in traffic.

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**ABSTRACT**

This report presents the final results from the MOVE project financed by the BIA program. The project is a joint project with Acoustic One, Norsk Elektro Optikk AS (NEO), Norsonic, Vegdirektoratet (The Norwegian Public Roads Administration) and NTNU.


In this project, methods and systems to measure the environmental impact of individual vehicles in traffic has been investigated. The main objective has been to monitor the noise levels of passing vehicles in a traffic stream.

In order to monitor the speed and to categorize the vehicle, a radar system TOPO.bigbox from RTB GmbH, Germany has been used. In addition to the use of conventional microphone systems, a microphone array has been tested. An algorithm to acoustically separate the vehicles in a traffic flow has been developed and tested.

Initial tests of the system showed that it is feasible to identify vehicles in the traffic with abnormal noise levels (more than 100 dB(A)) even at moderate speeds.

A new gas detection device, LaserGas iQ<sup>2</sup>, developed by NEO has also been tested, which showed its ability to detect high CO levels of passing vehicles.


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## Executive summary

This is the final report of the MOVE project (**M**ethods and systems to measure the environmental impact **o**f individual **v**ehicles in traffic). The project, financed through the BIA program, has been a joint project with Acoustic One/Norsonic, SINTEF, Norsk Elektro Optikk AS (NEO), Vegdirektoratet (The Norwegian Public Roads Administration) and NTNU.

Acoustic One/Norsonic has primarily worked on the development of the Precision Sound & Vibration Analyser Nor150, which is planned to be the central control unit with communication to the other sensors as well as the integrated part of the monitoring system for measurement of traffic noise.

NEO has developed a new laser gas detection device, LaserGas iQ<sup>2</sup> (primarily for industrial use and not financed by this project). Tests using this equipment to measure CO have been made on passing vehicles within the MOVE project.

Vegdirektoratet (The Norwegian Public Roads Administration) has participated in the project committee as an observer together with the other parties

NTNU has been engaged in the tests and development of the algorithm for a microphone array in cooperation with SINTEF.

SINTEF has been responsible for tests and development of equipment used for detection of the noise of individual passing vehicles in traffic. Furthermore, SINTEF has been responsible for the lay-out of a demo for a web-solution for a monitoring system.

The monitoring equipment used for noise tests has been:

- Traffic registration system: TOPO.bigbox (vehicle speed, lane position and classification of vehicle category)
- Noise measurement system: Norsonic microphones and LabVIEW program to store and process noise signal from 3 microphones. In addition a microphone array with a maximum of 8 microphones has been used
- Meteorological monitor (air temperature, wind speed and direction, humidity, air pressure and precipitation (rain in mm))

An initial test has been performed on a location at E6 Klett, south of Trondheim over a period of approximately one week.

This test included the use of the microphone array and with the algorithm developed. One example of a result from the test was:

*It was feasible to acoustically separate two passenger cars driving in the same lane with a speed of 72 km/h and with a distance of approximately 15 m (which is less than 1 s separation time), using 4 microphones in the array.*

However, some events with a combination of heavy vehicles close to light vehicles seemed to be difficult to separate, using only 4 microphones. Further development of the algorithm and the array is therefore recommended.

Without the microphone array, a separation in time between successive or passing vehicles was used: no other vehicles within 3 seconds of the object to be measured. With this separation criterion approximately 12

% of the total passing vehicles could be measured as individual noise events. The use of a microphone array could increase this number considerably.

The TOPO.bigbox traffic registration system classifies vehicles into 8 categories (+1 for unidentified/hidden vehicles). Together with the noise data, this enables a more substantial analysis of the resulting database:

- Pass-by noise levels ( $L_{Amax}$ ) as a function of speed for all vehicle classes. This gives a possibility to check for noisy vehicles (with abnormal noise levels)
- Average level per vehicle class. This is of interest to evaluate the contribution of different classes of vehicles to the overall traffic noise level. Furthermore to check if two or more of the 8 classes can be combined, due to similar average noise levels.
- Analysis of the influence of meteorological condition, like air temperature and wetness of the road.

The tests performed at E6 Klett showed that it is feasible to identify noisy vehicles in traffic, as shown in figure 24 (page 30): Of more than 6000 passing cars, 6 cars had a pass-by level between 100-110 dB(A), at speeds between 60 and 80 km/h. This is clearly abnormal levels, and may be caused by illegal or modified engine/exhaust systems.

A simple test using both the noise monitor and the laser gas detection device was conducted. The test consisted of both measurements of 3 test vehicles and of random passing vehicles. The 3 test vehicles were driven with different oil temperature (from cold to warm engine) and with different driving modes (constant speeds and moderate acceleration).

For one of the test cars, only one condition was found where the measured CO level was above the background level:

- During acceleration from a low speed, even if the oil temperature had reached a normal level.

For the other tests or cars, the levels were close to the background level of CO.

The test of random passing vehicles showed that it was feasible to measure high CO levels (above the general "background" level) for a few vehicles. More tests are recommended, including detection of  $NO_x$ , which is more critical for local air pollution in urban areas.

In order to identify more technical details of the individual vehicles, one solution can be to read the license plate of the passing vehicles. This technology, called "Automatic Number Plate Recognition (ANPR)", is already established in Norway, where road authorities check if insurance and/or annual taxes have been paid. In a research project NONSTOP, ANPR is used to control the weight of heavy vehicles, by reading the license plate and by checking the allowed maximum weight in the vehicle database against measured weight ("weight-in-motion"). In the MOVE project, the procedure to use the same ANPR technology together with the vehicle database (AUTOSYS) has been outlined. The database would then give information on type approval year and production year of the vehicle, type of engine, manufacturer/model, etc.

To use the ANPR technology in Norway, an approval by the authorities responsible to protect privacy (Datatilsynet) is necessary.

The MOVE project has demonstrated the feasibility of methods to monitor the environmental impact of individual vehicles in traffic. However, further development and testing are needed to make a commercially working monitor.

The following recommendations for further work are given:

- Implementation of ANPR
- Tests of an integrated system with Nor150
- Further development of a public access system using internet
- Further development of the microphone array technology

- Develop procedures for processing and presentation of large amount of data ("big data")
- Further testing of the laser equipment from NEO, including measurements of NO<sub>x</sub>
- Investigations of the connection between measured noise emission levels and traffic noise calculation methods (e.g. reference values for different categories of vehicles)
- Include algorithm/system to detect studded tyres

## 1 Introduction

This report presents the findings and results from the MOVE project (project 219801/O30) financed by the Norwegian Research Council under the program BIA ("Innovasjonsprosjekt i næringslivet").

Project partners:

Acoustic One

Norsonic AS

SINTEF ICT

NTNU

Norsk Elektro Optikk AS (NEO)

Vegdirektoratet (The Norwegian Public Roads Administration) as an observer

Vegdirektoratet has been member of the steering committee, together with representatives from the project partners.

## 2 Background

The Norwegian Parliament has passed a bill for the reduction of noise annoyance in Norway by 10 % within the year 2020, with 1999 as the reference year. Many studies have shown that the most cost-effective measure to reduce the noise will be to reduce the source itself. For road traffic this can be done in several ways, like the introduction of more silent tyres, more silent vehicles and the use of low-noise road surfaces.

The use of more silent tyres/vehicles can be achieved by different measures, like more stringent noise limits (type approval) on an international level. On a local level, the use of economic or user incentives for tyres and/or vehicles in addition to low-noise road surfaces can be a tool to reduce road traffic noise.

Equipment to monitor general noise levels from road traffic such as  $L_{den}/L_{eq}$  etc. has long been commercial available. The same is the case for monitoring of the air quality in urban areas. However, methods and equipment to monitor the noise levels of individual vehicles have been limited. In some research projects in Europe and Japan the noise from individual vehicles in traffic have been measured. However, no commercial systems have been available.

One standardised method is based on the measurement of noise level from individual vehicle on a road: ISO 11819-1 (The Statistical Pass-by Method, SPB)<sup>1</sup>. The aim of this ISO method is to establish the contribution from the road surface to the overall traffic noise level, and as such is not directly suitable to monitor the environmental impact of different types of vehicles in traffic.

In the MOVE project, methods and equipment that allow such monitoring has been tested.

Laser based equipment developed by NEO, primarily to detect gases in an industrial environment, has been tested. In this project, the system is used to see if it is feasible to measure CO emission levels from passing vehicles (see chapter 5.3).



### 3 Monitoring principles

The noise emitted by a passing vehicle in traffic is dependent on a wide range of parameters:

- The type of vehicle and its condition
- The driving condition (speed, acceleration, gear, rpm, etc.)
- Meteorological conditions (temperature, wind speed/direction, road wetness)
- Road surface condition (texture, roughness)

To establish a link between the measured noise level and many of these parameters, several sensors are used:

- A radar system to monitor the speed of the vehicle, the position of the vehicle (driving lane) and vehicle category (if possible)
- An acoustical system to monitor the noise level from the passing vehicles, as well as the total noise dose over a defined period
- A meteorological system to monitor the weather conditions

All these sensor systems have been tested within this project.

## 4 Monitoring system

### 4.1 Traffic registration system

There are several systems commercially available. Based on experience from a testing program by SINTEF and the Norwegian Public Roads Administration (NorSIKT – Nordic System for Intelligent Classification of Traffic, 2012), a system, TOPO.bigbox, from the German company RTB GmbH & Co.KG was chosen.

TOPO.bigbox is a radar-based system that measures the speed of the car in two driving directions (approaching and receding lane). In addition the vehicles are categorized into 8+1 different classes, according to a German standard for classification of vehicles (TLS 2002).

The following classes are defined:

- 1) Passenger car (2 axles)
- 2) Passenger car + trailer, delivery van, delivery van + trailer (2-4 axles)
- 3) Truck (2-4 axles)
- 4) Truck + trailer (3-8 axles)
- 5) Road tractor (semitrailer), Road tractor + trailer (3-6 axles)
- 6) Bus (2-5 axles)
- 7) Motorcycle
- 8) Bike
- 9) Not classified

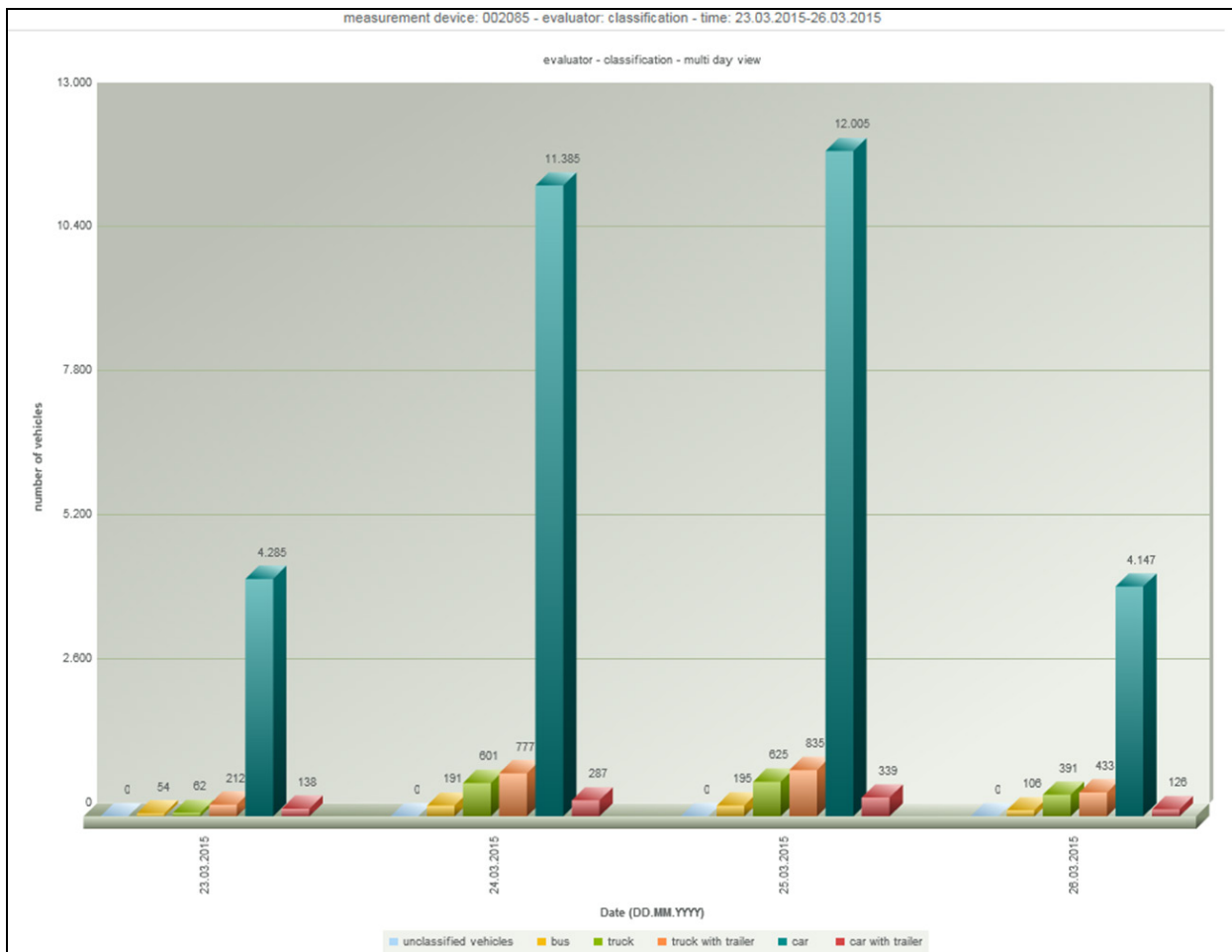
The classification is based on the measurement of vehicle length and number of axles.

Figure 1 show the TOPO.bigbox mounted on a mast for measurements.



**Figure 1: TOPO.Bigbox mounted by the road side (photo left: Torgeir Vaa, SVV, right: RTB)**

Measured data is transferred to a server in Germany by a GSM line, where the data (both raw and processed) can be downloaded on request. Another possibility is to go online on a web-site; [www.dd-web.de](http://www.dd-web.de). On this site one get processed data for the period requested, as shown in the figure below.



**Figure 2: Processed data from the TOPO-system. Number of measured vehicles per day.**

A file with raw data looks like this:

```

Fahrzeugeinzeldaten
, 7083
>> (1)
<< (2)
ControllerId: 2085
Zeit: 16.05.2014

Fahrzeugklasse 6 := nk Kfz
Fahrzeugklasse 2 := PkwA
Fahrzeugklasse 3 := Lkw
Fahrzeugklasse 8 := LkwA
Fahrzeugklasse 9 := Sattel-Kfz
Fahrzeugklasse 5 := Bus
Fahrzeugklasse 11 := Lfw
Fahrzeugklasse 7 := Pkw
Fahrzeugklasse 10 := Krad
Fahrzeugklasse 230 := Fahrrad

ID Datum           Richtung Geschwindigkeit (km/h)  Länge (dm)  Klasse  Klassen Bezeichnung
1  16.05.2014 13:19      2          54          22         10      KRAD
2  16.05.2014 13:19      2          50          54          7       PKW
3  16.05.2014 13:19      2          57          53          7       PKW
4  16.05.2014 13:20      1          63          48          7       PKW
5  16.05.2014 13:20      1          68          47          7       PKW
6  16.05.2014 13:20      1          68          48          7       PKW
7  16.05.2014 13:20      2          67          103         2       PKW_Anhäng
8  16.05.2014 13:20      1          59          49          7       PKW
9  16.05.2014 13:20      1          59          44          7       PKW
10 16.05.2014 13:20      2          72          39          7       nKl
11 16.05.2014 13:20      1          59          46          7       PKW
12 16.05.2014 13:20      1          70          47          7       PKW

```

**Figure 3: Raw data from TOPO.bigbox**

In addition to the radar, the TOPO.bigbox also has a microphone (electret) mounted on the side of the unit, as shown in figure 1. This microphone is intended to detect noisy vehicles, e.g. a motorcycle with illegal muffler system. Some measurements in Germany have been made to test this feature<sup>2</sup>. However, it is not suited to give a representative noise emission level for each pass-by of a vehicle, as the intention is for the MOVE project. For this reason, the available noise data from the TOPO system has not been processed in this project.

The TOPO.bigbox used in our project was modified in a way that allowed access to the raw data immediately after a measurement period, through a cable/serial port. This data was converted to a text-file, that later could be copied to excel-sheets. A line in the text-file would look like this:

*6.05.2014 13:20:17,021, approaching, axles: 207,266,000,000,000,000 approaching, vehicle-info: speed:068,length:048,class:001,audio:092*

The string shows the date and time, an approaching vehicle (nearest lane) and a code for number of axles. The speed of the vehicle is 68 km/h, the length is 480 cm, the class is "car" (001) and the measured audio signal by the electret microphone is 92 dB.

This data is then combined with the measured noise level (chapter 5.2).

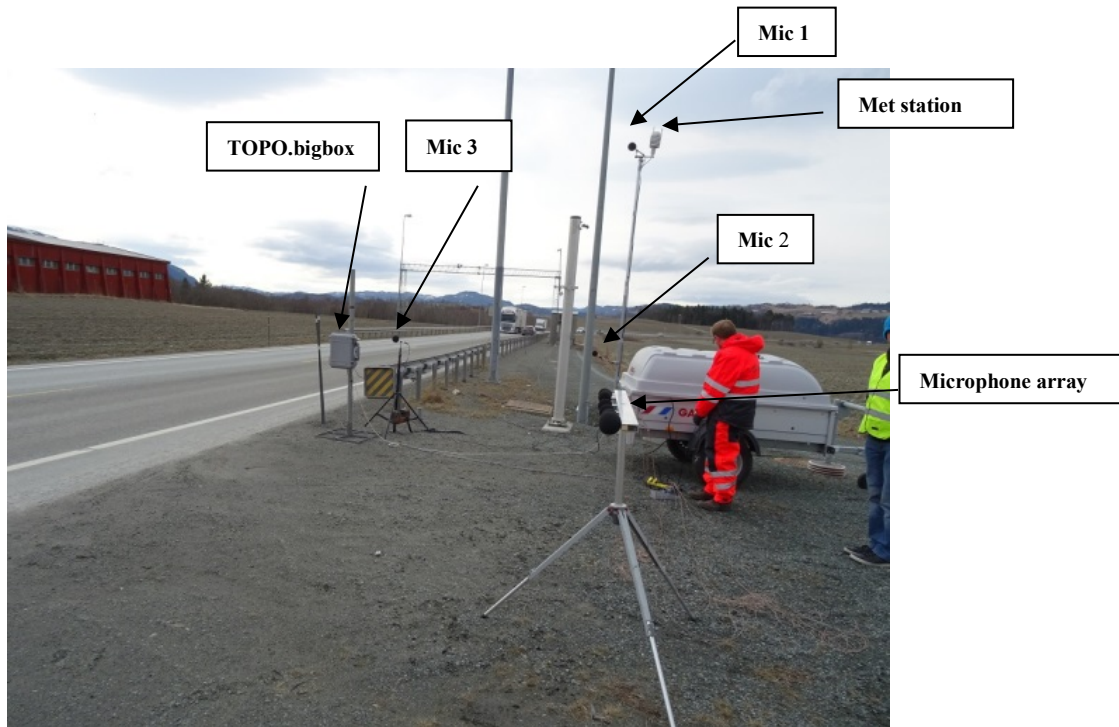
## 4.2 Noise measurement system

### 4.2.1 System used for the test program

During the test period, a simplified noise measurement system was implemented, mainly for practical reasons. The system was based on a laptop with several microphone input channels. A program in LabVIEW has been made for the calibration procedure and to measure the noise from 2 or 3 microphone positions simultaneously.

The maximum A-weighted noise level of a passing vehicle is synchronized (in time) with the data from TOPO.bigbox, for the analysis (see chapter 5.1). A time limit of 3 s was applied to be able to acoustically separate vehicles in a traffic flow. This means that within this time window, only one vehicle was allowed to pass the microphones. Experience from tests, showed that this time window probably should have been increased during rush hour at the test site, as the vehicle speed in that period was considerably reduced (to below 30-40 km/h).

Figure 4 shows the monitor at the test site with 3 microphones.



**Figure 4: Test site at E6 Klett with 3 microphones and array**

Microphone 2 and 3 was located 7,5 m from the centre line of each of the two lanes and at a height of 1,2 m. This is in accordance with the requirements in ISO 11819-1(SPB). Microphone 3 was at the same distance from lane 1 (closest lane) as mic.2, but at 3 m height. If such a monitoring system shall measure unattended over a longer period of time, it would be necessary to use a height of 3 m, to prevent any unwanted damage, thefts or unwanted sounds e.g. made by humans.

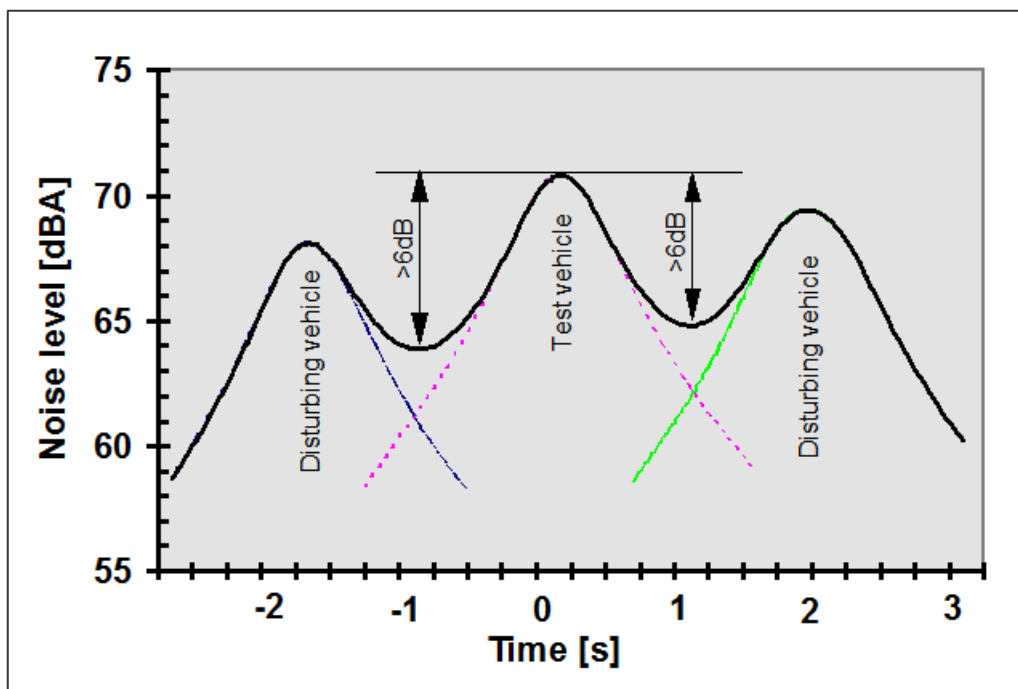
Acoustic One/Norsonic has developed the Precision Sound & Vibration Analyser Nor150 as part of the MOVE project. This unit is planned to be the central control unit with communication to the other sensors as well as the acoustical sensor in a future monitor system for measuring the noise from individual vehicles in traffic.

### 4.3 Microphone array

#### 4.3.1 Motivation to use an array

To be able to use a single microphone to measure the sound from one individual vehicle in traffic flow requires some limitations: One option is to use a fixed time window, where no other vehicles, either in the same or opposite lane, can be passing.

Another option can be to use the 6 dB requirement as specified in ISO 11819-1(SPB). This is best illustrated in figure 5. If the level is at least 6 dB lower on each side of the maximum level, this is an indication of a single pass-by, not acoustically disturbed by other vehicles.



**Figure 5: Illustration of the requirement for signal-to-noise ratio for individual vehicle pass-byes**  
(from ISO 11819-1)

By using just a single microphone and a time window for an approved single pass-by, one can only measure a certain percentage of the total passing vehicles. The percentage will of course depend on the traffic density at the location.

At the chosen test site at E6 Klett (see 5.2) a total of 77 241 passed the monitoring station during 8 days of measurements. Using a 3 s time window, we approved 9099 vehicles as single pass-byes, which is 12,4 % of the total.

In order to increase this number, a study to use a microphone array was conducted.

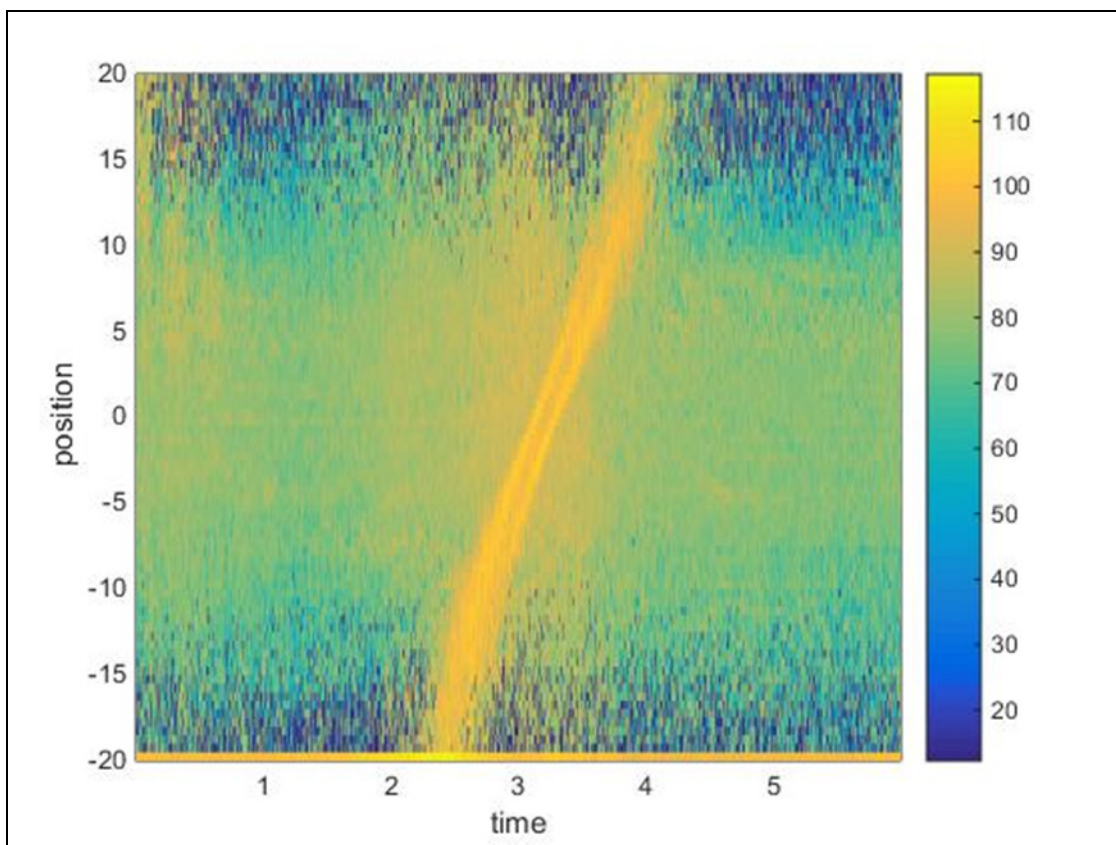
BASSt (Bundesanstalt für strassenverkehr) in Germany, together with a German company "Akustik Technologie Göttingen"<sup>3,4</sup>, has developed a system based on a microphone array technique to detect the noise level of individual vehicles in traffic. The main motivation for this project was to be able to perform measurements according to ISO 11819-1 (SPB) in a dense traffic situation on German motorways.

### 4.3.2 Theory for the array

Initially, a student at NTNU, Einar Ådnøy, was given a task as part of his Master thesis<sup>5</sup> to do a theoretical study on different algorithms for a microphone array. In his study, he was using synthesised signals and the outcome showed that it was feasible to use such an array together with the chosen algorithm to detect passing vehicles close to each other. His work was supervised by Dr. Audun Solvang at SINTEF ICT.

A French student, Lucas Ciret, following some courses at NTNU 2014/2015, was engaged in the project to continue the work of Ådnøy/Solvang, but to use real measurements of sound signal from passing of different vehicles at different speeds. Ciret's work was supervised by Dr. Gunnar Taraldsen, (formerly SINTEF ICT).

The task given to Lucas Ciret was to use a deconvolution approach for the mapping of acoustic sources with a phased microphone arrays to determine the trajectory of different types of vehicles measured at the E6 Klett test location (figure 4). From this estimation, he would then determine the minimum distance between two sound events (pass-by of a vehicle) which allows separating, in a proper way, these events. Given this minimum distance it will be possible to evaluate the noise produced individually by each vehicle. Figure 6 shows an example of such a trajectory of a pass-by of a single vehicle.



**Figure 6: Trajectory of the sound power level of a single vehicle pass-by**

The most famous approach for the mapping of acoustic sources was the “sum and delay” method until the mid-1990s, but this method was quickly outdated by “classical beamforming” approaches involving spectral processing to form cross-spectral matrices (CSM). However these methods presented some accompanying issues as side-lobe contamination. Deconvolution Approach for the Mapping of Acoustic Sources (DAMAS) was developed to demystify 2D and 3D array results, to reduce misinterpretation, and to more accurately quantify the position and strength of the acoustic sources. For a complete explanation of the algorithm, it is

recommended reading the work of Thomas F. Brooks & William M. Humphreys<sup>6</sup> and the work of Tarik Yardibi & Jian Li<sup>7</sup>.

A new method was proposed by Gunnar Taraldsen. This method is called ‘‘Correlation fitting method’’ and it is easier to implement in MATLAB. Moreover the resolution of the correlation problem is faster than the DAMAS resolution. The method is described in the following part:

Assume a set of sources in  $x_k, k=[1..K]$ , and a microphone array with M members  $x_m, m=[1..M]$ . The received signal is denoted  $y$ . The first step is to divide the time data received by each microphone in I segments of L samples. Then each segment is converted in L-points Fast Fourier Transform. The received signal can be expressed with the following formula in the frequency domain:

$$y_m = \sum_{k=1}^K A_{mk} * s_k + \varepsilon_m \text{ or } y = A * s + \varepsilon,$$

where  $s_k$  is the source signal in source position k,  $A_{mk}$  is the propagator coefficient from source point k to microphone m, and  $\varepsilon_m$  is the noise in microphone m. Assume free field propagation, so that:

$$A_{mk}(\omega_l) = \frac{1}{r_{mk}} * e^{-\frac{j r_{mk} \omega_l}{c_0}} \quad (1)$$

where  $r_{mk}$  is the distance between the source position k and the microphone m,  $c_0$  is the speed of sound ( $\approx 340\text{m/s}$ ) and  $\omega_l$  the frequency.

Assume that both  $s_k$  and  $\varepsilon_m$  are Gaussian processes,  $\text{Var}(s_k) = d_k$  and  $\text{Var}(\varepsilon_m) = \sigma_m^2$ , the source powers and noise power. Resulting in  $y \sim (0, \Sigma)$ . The covariance matrix is:

$$R = E(y * y^*) = ADA^H + \sigma^2 I \quad (2)$$

where  $D = \text{diag}(d_1, \dots, d_k)$ .

If we estimate the covariance matrix  $R$ , the problem is the resolution of the following equation:

$$\begin{aligned} & \text{argmin} \|\hat{R} - ADA^H - \sigma^2 I\| \\ & d_k, \sigma^2 \end{aligned} \quad (3)$$

subject to  $d_k \geq 0, \sigma^2 \geq 0$

As the number of sources is restricted the solution is sparse. One may assume many source points of which a restricted number of sources are not zero. Note that the expression above may be rearranged to an equation so that every member of  $\Sigma$  is fit to with its corresponding members from  $ADA^H + \sigma^2 I$ .

$$\hat{R}_{pq} = \sum_{k=1}^{K'} A_{pk} A_{kq}^* d_k + \delta_{pq} \sigma^2 \quad (4)$$

Such that  $\gamma = B\alpha$

Where  $\gamma_j = \hat{R}_{pq}, p=[1..M], q \geq p$ , when  $i \neq l$  separate equations for real and imaginary part is set up, further the unknown is  $\alpha = [d_1, \dots, d_{K'}, \sigma^2]$ . Note that  $K'$  now is assumed source positions, which can (and should) be much higher than the realistic number of sources K, and also larger than M.

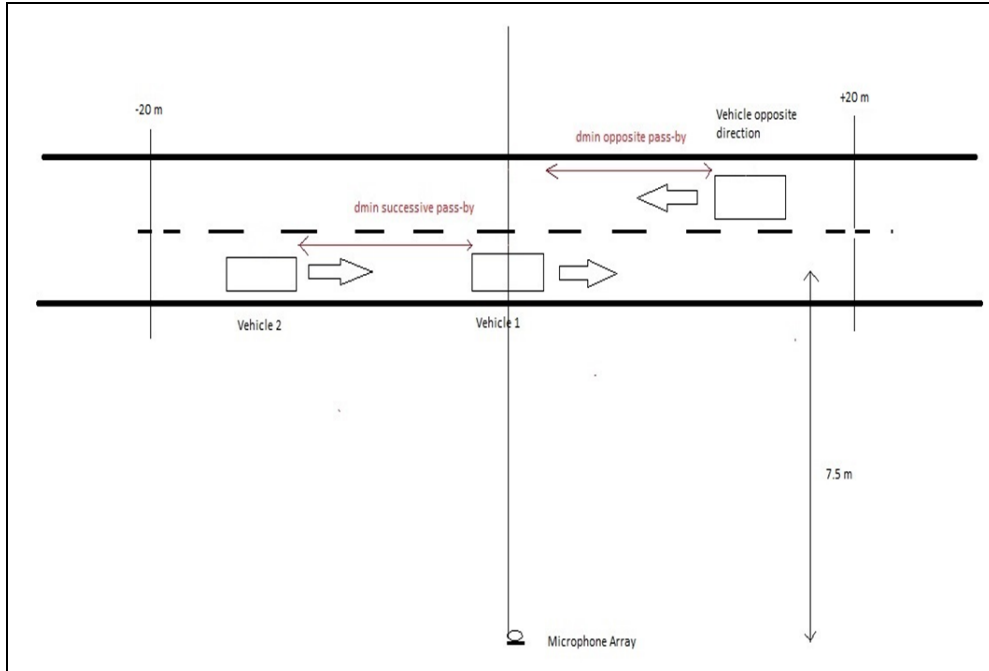
The total number of equations should be given by number of members above and on the diagonal,  $(M^2 + M)/2$ , every member but the diagonal (real numbers) will contribute two equations, so the total number of equations will be  $M^2$ .

To resume, to resolve the correlation fitting problem one has to solve the least square non negative problem describe by equation (4).

This part had been already written in MATLAB by Audun Solvang. Lucas Ciret had then the job to program the part for the detection of the pass-by and the trajectory estimation for the detected pass-by.

### 4.3.3 Test of microphone array

A test of the array with different microphone configurations was made at a roadside, with a set-up as shown in figure 7.



**Figure 7: Test arrangement for microphone array**

The microphone array is placed 7,5 m from the centre line of the nearest lane and at 1,2 m height. We are interested in the detection of the pass-by in the first lane, which means that we want to estimate the trajectory of the car passing from the left to the right. In the following of this report, this kind of pass-by is called “direct pass-by”. The pass-by in the other direction is called “opposite pass-by”.

The first microphone in the array is positioned at  $x = 0$ . The code is built to analyse the source power between the two extreme positions: -20 m on the left and +20 m on the right. The total length of the array is 1 m and we have eight microphones space in a way to avoid having the same distance twice with a minimum spacing of 52 mm. Due to this property, the array is best adapted for a frequency range of 190 to 3200 Hz. As the maximum sound level of a car is around 1000 Hz at 80 km/h (dominated by tyre/road noise) this frequency range is suitable for our needs.

The data received by each microphone are stored in a MATLAB file in order to be easily accessed by the process.



**Figure 8: Microphone array used for test**



During the test of the array at the location E6 Klett, an array of eight microphones (Norsonic Nor1207/BNC) was used. The system runs at a 51,2 kHz sampling rate. Calibration was done for all microphones using a 114 dB 1 kHz class 1 sound level calibrator.

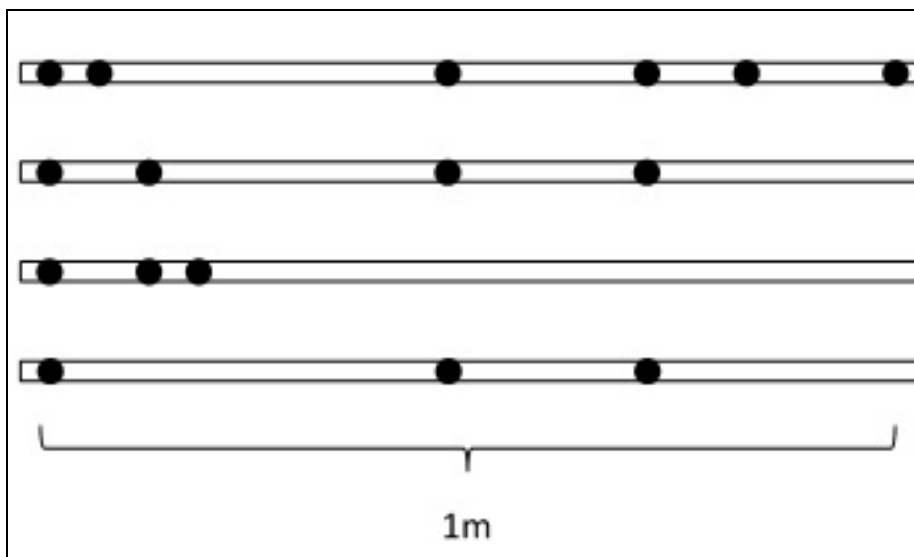
As the measurements were made in a real environment, it was almost impossible to obtain data for each scenario that could be investigated. It was therefore decided to record a single pass-by for each type of vehicle in order to mix them in the code to have the different cases. The following three main scenarios were investigated:

- Two successive pass-by of the same class of vehicle
- Two successive pass-by of two different classes of vehicle
- Cross pass-by with a single passenger car

#### 4.3.3.1 Microphone configurations

Even if the array has 8 microphones, only 4 different configurations, varying from 3 to 6 microphones were used, as shown in figure 9:

- Configuration 1: 6 microphones
- Configuration 2: 4 microphones
- Configuration 3: 3 microphones
- Configuration 4: 3 microphones



**Figure 9: Array configurations**

During the first tests, the distance from the array to the nearest lane was 7,5 m. This distance was used for testing and input to the analysis.

As shown in figure 9, a total of 4 microphone configurations were tested.

To have an estimation of the efficiency for each configuration, the average increase of the minimum detection distance compared to the configuration 1 (reference) was computed, see table 1.

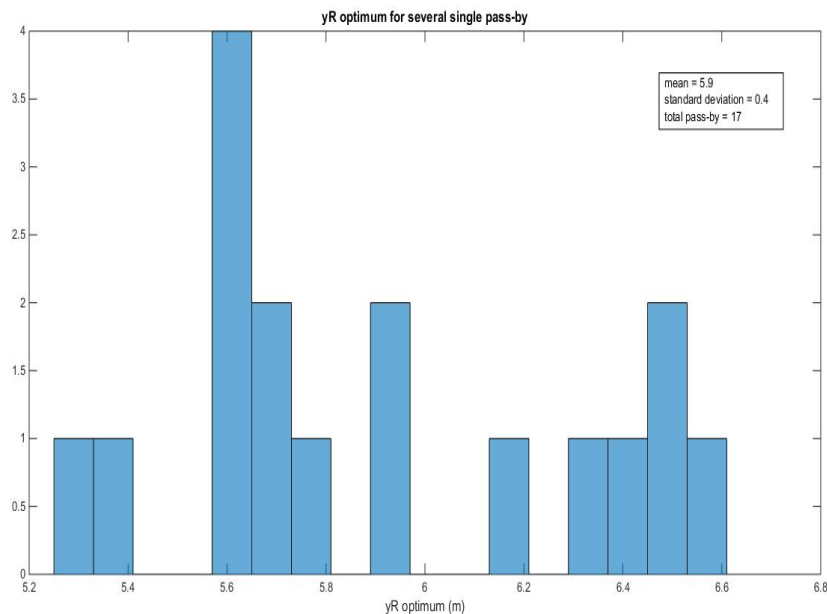
**Table 1: increase of minimum detection distance for different array configurations**

Config 2	2%
Config 3	95%
Config 4	80%

Even if there is a degree of uncertainty to these (theoretical) results, it was concluded that **configurations 3 & 4 (3 microphones only) give too poor resolutions and cannot be used for the aim of the project**. Then the rest of the study was made without the configurations 3 & 4.

#### 4.3.3.2 Influence of distance from source to array

The first results showed that the accuracy of estimation of the trajectory of the sound power could be improved by using the real vehicle speed signal from the radar. The study also revealed that the estimation could be improved by changing the fixed distance  $y_R$  from the source to the array. Initially, this distance was 7,5 m. By varying this distance for all the single pass-by recorded, an optimum distance for the value of the sound power was found, as shown in figure 10.



**Figure 10: Histogram for optimum  $y_R$**

Even if the values in table 2 are based on a limited number of types of vehicles, it was used as a good estimation of the trajectory for the pass-by.

**Table 2: Estimation of  $y_R$  optimum for different vehicles/speeds**

Vehicle/Speed(km/h)	$y_R$ optimum (m)	min deviation (s)	deviation for 5,9m (s)
truck/69	5,4	0,0046	0,0422
bus/64	6,6	0,0027	0,0328
passenger/72	5,6	0	0,0265
semi-trailer/73	5,7	0,0044	0,0055

The rest of study was made with  $y_R = 5,9$  m

This value (5,9 m) corresponds approximately to the distance between the middle of the lane and the array (7,5 m) minus half of the width of the lane (1,5 m)

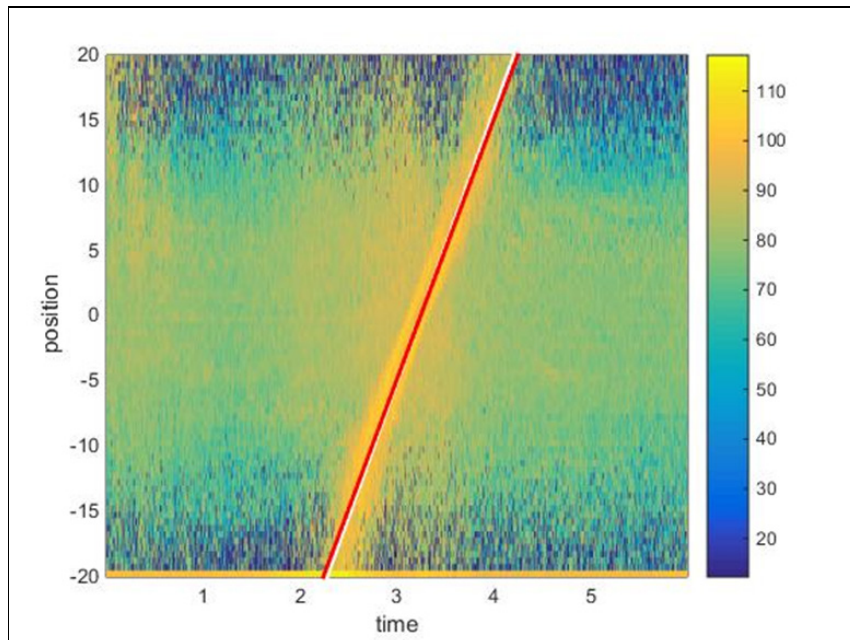
Since the noise at speeds above 40 km/h is dominated by tyre/road noise, this is confirmed by this simulation; the dominating noise is coming from the tyres nearest to the array, which is close to 5,9 m.

#### 4.3.3.3 Estimation of maximum frequency, $f_{Max}$

A simulation of varying the maximum frequency included in the estimation of sound power was made. The frequency was varied from 2500 to 15000 Hz, with configuration 1 and 2. This simulation concluded that a maximum frequency of 5000 Hz was sufficient. This is also in line with the fact that most of the tyre/road noise is dominating in the frequency range of 800-1250 Hz.

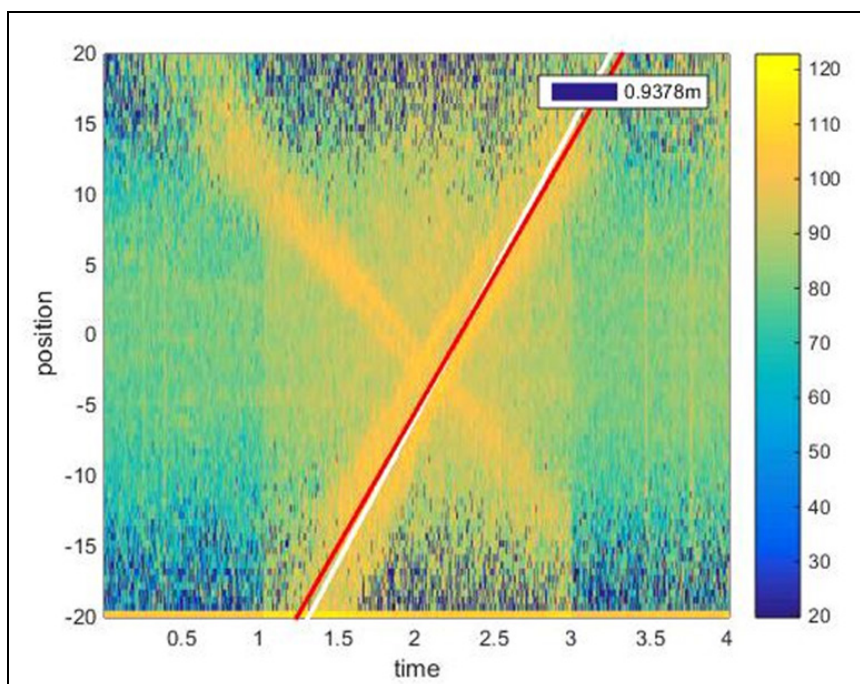
#### 4.3.3.4 Estimation of trajectory

Figure 11 show the estimated trajectory (red curve) and the correct (white) for a single pass-by of a car at 72 km/h.



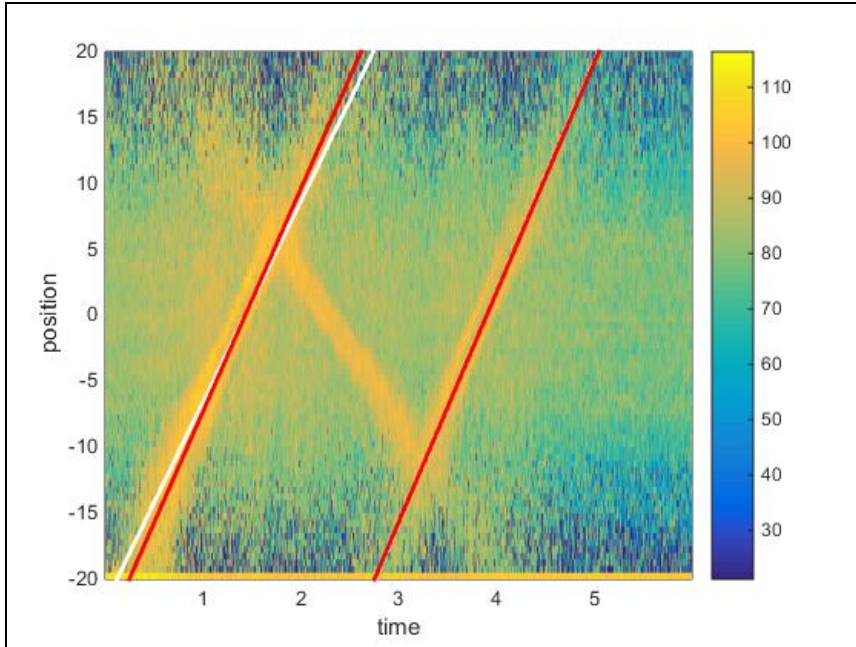
**Figure 11: Estimated (red) and true (white) trajectory of a single pass-by, car at 72 km/h**

When there are vehicles passing each other in the two lanes, a trajectory can look like figure 12. In such a case, one cannot separate this into two single acoustic events.



**Figure 12: Trajectory of mixed pass-by**

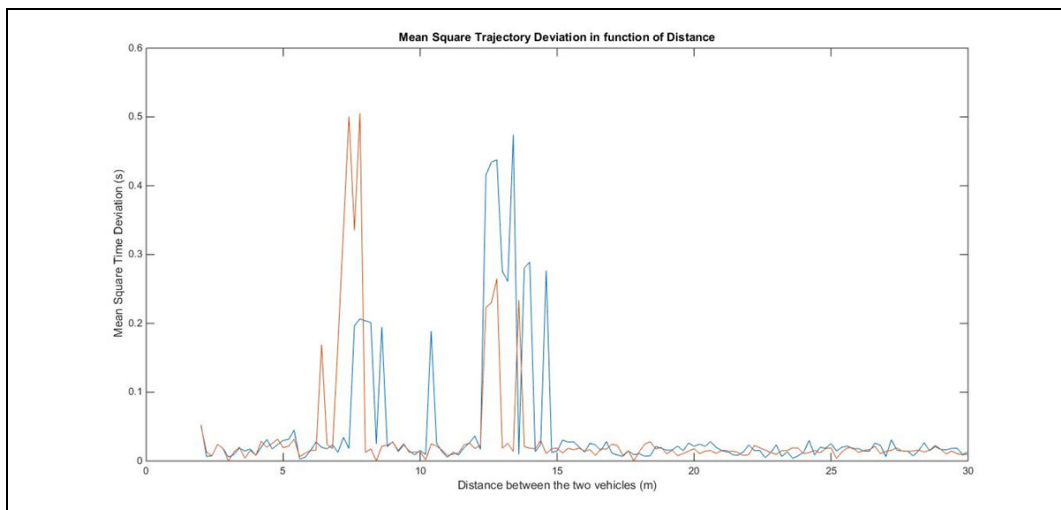
Based on this estimation of the trajectory, the minimum distance between two successive vehicles was investigated theoretically by delaying or increasing the distance between these two vehicles as shown in figure 13 (the trajectory for each pass-by is from a real measurement).



**Figure 13: Two consecutive pass-by**

For each time situation (0 to 5 sec), the mean square trajectory deviation (MSD in seconds) is calculated.

Figure 14 show such a calculation for two successive pass-byes of passenger cars at 72 km/h.

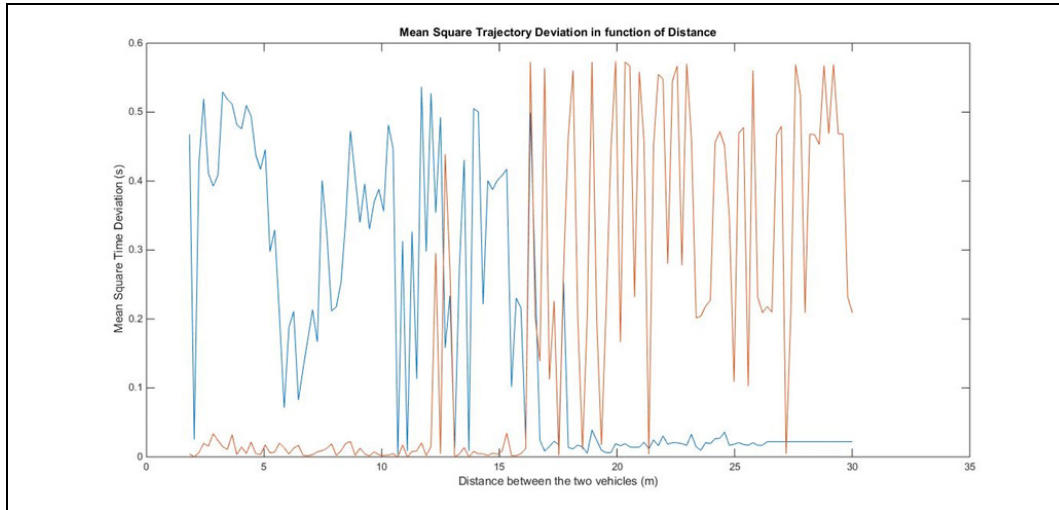


**Figure 13: Mean Square Deviation for two passenger cars**

Below approximately 15 m, there are high levels of the MSD value, which means that it is not possible to separate vehicles with a distance below 15 m.

Similar calculations were done for other combinations of vehicle types, speeds and driving directions.

Some combinations of vehicles, like a semitrailer followed by a passenger car, proved to be difficult to separate, using only 4 microphones and the estimation technique. An example of this is shown in figure 14.



**Figure 14: Estimation of MSD for a semitrailer and a passenger car**

Table 3 summarize the findings for different combinations of vehicles, either following each other in the same lane or crossing each other. Note that this is based on a simulations (by decreasing the distance between two trajectories) and not on "real" pass-byes.

Note that the results in the table are based on configuration 2, with 4 microphones only.

**Table 3: Estimation of minimum distance between two vehicles, based on configuration 2.**

Successive Pass-By				
Vehicle 1/Vehicle 2	Passenger car (72km/h)	Semi-trailer (73km/h)	Bus (64km/h)	Truck (69km/h)
Passenger car (72km/h)	17 m	problem	8 m	14 m
Semi-trailer (73km/h)	problem	3m	problem	problem
Bus (64km/h)	8 m	problem	problem	13 m
Truck (69km/h)	14 m	problem	13 m	10,5 m

Cross Pass-By				
Opposite/Direct	Passenger car (72km/h)	Semi-trailer (73km/h)	Bus (64km/h)	Truck (69km/h)
Passenger car (72km/h)	15 m	7,5 m	17,5 m	5 m

It should be noted that 72 km/h is equivalent to 20 m/s. A separation distance of 17 m means that this (simulated) time between the two passes is less than 1 s, which normally is very unsafe and rare. A 3 second recommended safe distance is then equivalent to 60 m separation distance.

As table 3 shows, there are some combinations of vehicles which seem problematic to separate acoustically. However, there should be possibilities for improvements and to solve this problem, both related to the algorithm used and the number of microphones.

For further work, the following actions are recommended:

- To use configurations with more than 4 microphones, like in configuration 1 (figure 9)
- To use the real data (speed) from the radar system to adjust sensible parameters in the algorithm
- To compare the sound levels estimated by the array with real pass-by noise measurements, in order to introduce correction factors (both maximum levels and frequency band levels)

#### 4.4 Meteorological system

The noise emitted by a vehicle pass-by is influenced by the meteorological conditions.

This influence is mostly related to the tyre/road noise.

It is clearly audible that the tyre/road noise is different on a wet surface, than on a dry, especially if there is a lot of water on the surface. It is the higher frequencies (above 1 kHz) which are influenced by the wetness of the surface.

In addition to the wetness, there is also a significant influence of the temperature (air or road surface) on the tyre/road noise from passenger car tyres. For heavy vehicle tyres, this influence is less.

Several investigations<sup>8,9</sup> have shown that the lower the temperature, the higher the tyre/road noise. The temperature is speed and road surface dependent, as shown in table 4. The reference air temperature is +20°C.

Measurements done by SINTEF in 2005 in the SILENCE project on SPB<sup>10</sup> type of measurements showed an average of -0,092 dB/°C for passenger cars (speed range 65-85 km/h), which is similar to the proposal from ISOWG27 ("Temperature effects").

**Table 4: Proposed temperature coefficients in dB/°C for the SPB method. Based on measured air temperature<sup>8,9</sup>.**

Road surface category	Light vehicles (category 1)		Heavy vehicles (categories 2a & 2b)	
	50 km/h	80 km/h	50 km/h	80 km/h
Dense asphaltic surfaces (like DAC, SMA, chip seals)	-0.09	-0.09	-0.03	-0.05
Cement concrete surfaces of all types	-0.07	-0.07	-0.03	-0.04
Porous asphalt surfaces (not seriously clogged)	-0.05	-0.05	-0.01	-0.02

In addition to temperature and road wetness, the noise level can be influenced to some degree by the wind. Even if the measuring distance is small (7,5 m from the centre line of the road), a strong downwind (wind from the source to the microphone) or in the opposite direction may influence the noise level. In the SPB standard a maximum wind speed of 5 m/s is allowed.

For the test program in the MOVE project the met station wxt520 from Vaisala was used.

The following parameters were available:

- Air temperature
- Wind speed and direction
- Air pressure

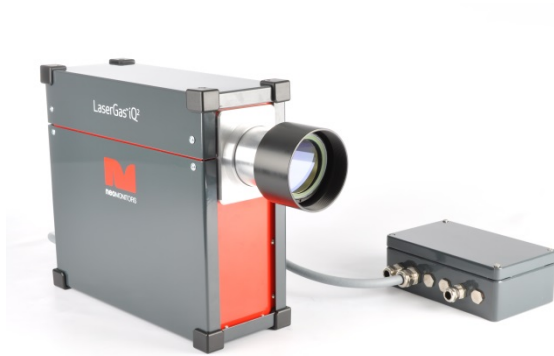
- Humidity
- Precipitation (rain in mm)

These parameters were logged every second, and thus can be allocated to a single pass-by of a vehicle.

The met station is shown in figure 4.

#### 4.5 CO measurement system

Norsk Elektro Optikk AS (NEO) has developed a new laser based gas detection system, LaserGas iQ<sup>2</sup>. This is a gas detection system which can be tuned to detect a single gas based on a transceiver unit, and a reflector, as shown in figure 15 and 16.



**Figure 15: LaserGas iQ<sup>2</sup> transceiver unit**



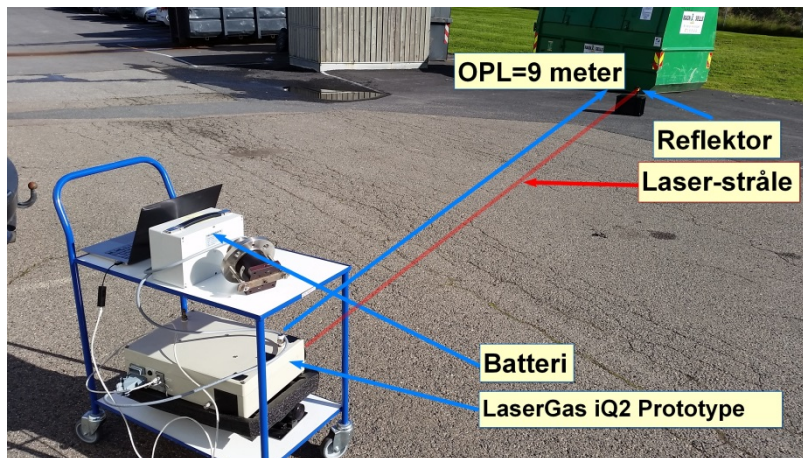
**Figure 16: Reflector unit**

A divergent laser beam is sent out from the basic unit. This beam is then sent back from the reflector. This reflector can be placed at a distance from 1 to 20 m from the basic unit. The instrument can be used together with a 24 V battery module.

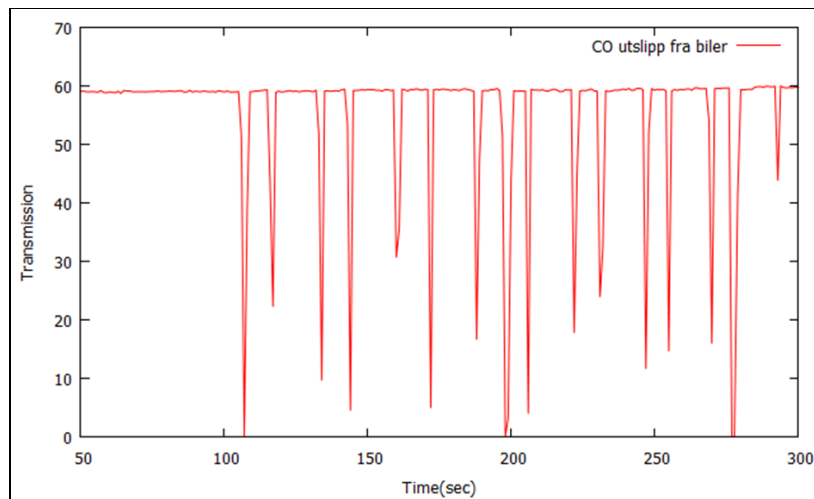
For our project, the unit was calibrated to detect CO with the unit ppm\*meter, with an averaging time of 1 s.

Before using the laser system on a road side test, NEO did some initial tests on a parking area, as shown in figure 17. The distance between each unit was 9 m. A car with a petrol engine was used for the test with different speeds and engine loading to vary the amount of CO from the vehicle. When the vehicle is passing the beam, the transmission is interrupted, as shown in figure 18.



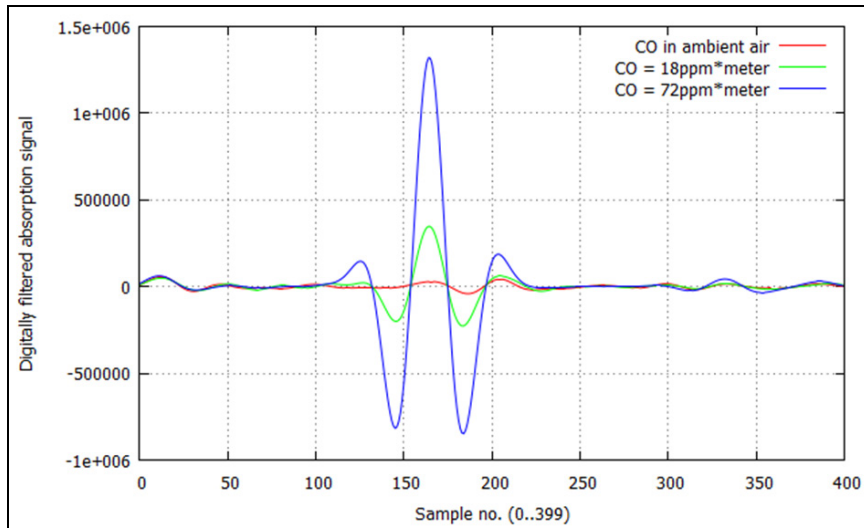


**Figure 17: Test of LaserGas iQ<sup>2</sup> prototype on a parking area**

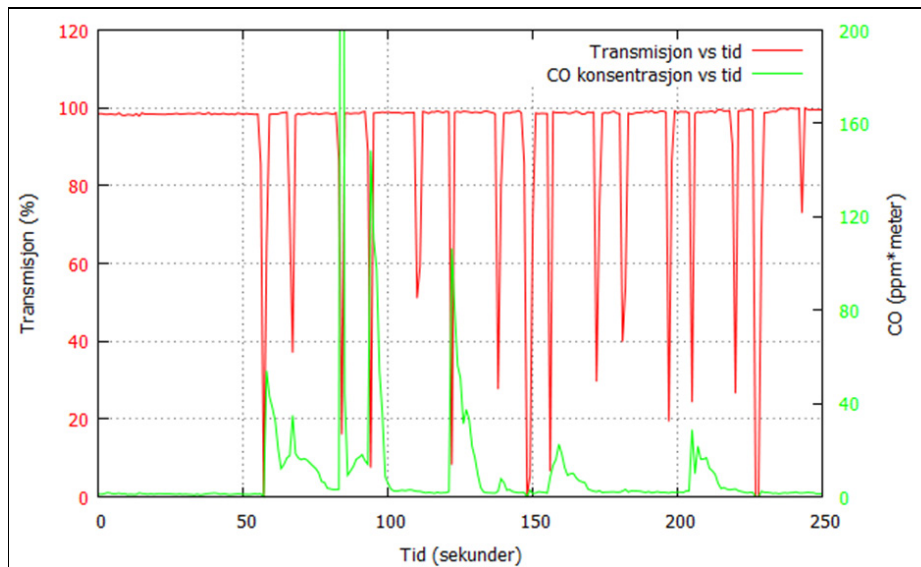


**Figure 18: Transmission as a function of time. Drop-outs is a passing vehicle**

Figure 19 show the measurements of the CO spectrum for two different concentrations of CO and figure 20 some of the pass-byes with different CO levels, together with the transmission. This test indicated that it would be feasible to measure the concentration of CO also from road side measurements and from unknown vehicles.



**Figure 19: CO spectrum of two different concentrations of CO, together with the ambient level of CO**



**Figure 20: Transmission and CO concentration as a function of time. Test with a single passenger car**

## 5 Test program

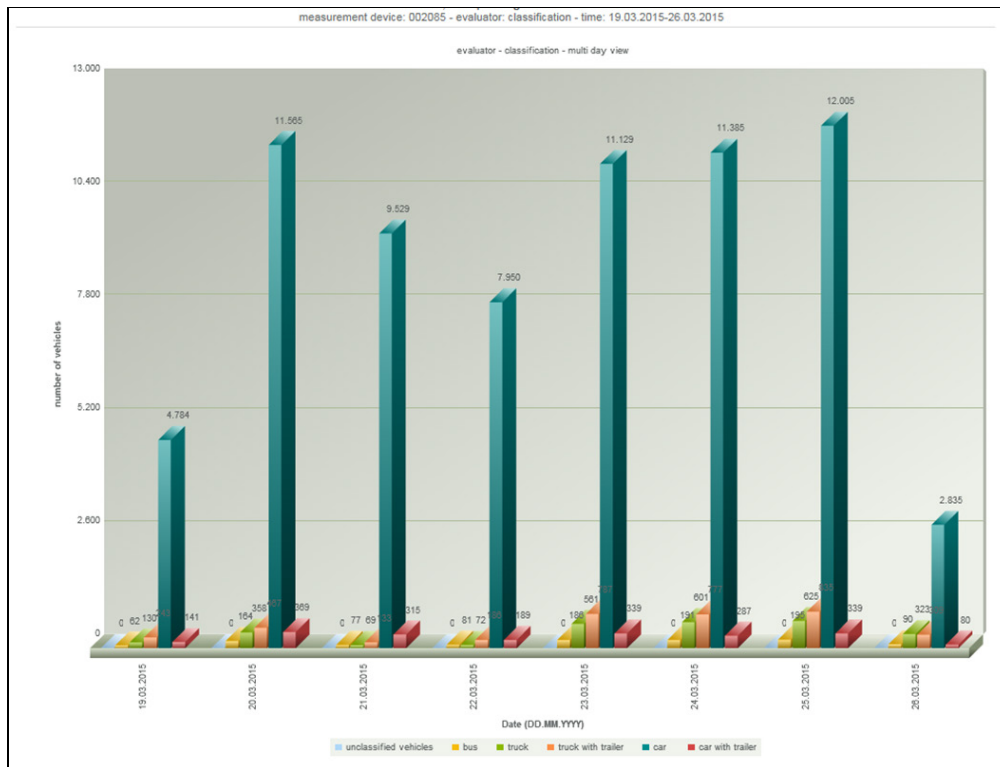
### 5.1 Calibration measurements

Initial tests were performed using a single known vehicle. This test was primarily to align the storage time of each of the measuring components. The TOPO radar unit stores the speed of a vehicle at different times, depending on the driving direction. An approaching vehicle is detected and stored earlier than a vehicle coming from the other direction. The noise unit, however, measure the passing vehicle at the same time, independent of the driving direction. Because of this situation, it was necessary to perform calibration tests to make sure that the data from the TOPO and the noise unit was aligned to the same vehicle.

It was found that this time difference was speed independent.

## 5.2 Noise measurements

A test of the system as shown in figure 4 was conducted at E6 Klett over the period 19-26.3.2015. In that period, a total of 77 241 vehicles were detected by the TOPO.bigbox, as shown in figure 21. This figure shows the total vehicles transferred to the website in Germany. The vehicles were classified into 5+1 classes. Of these, we have measured the approved pass-by (not any other vehicles within a 3 s time window) of 9099 vehicles (12,4 %).



**Figure 21: Measured vehicles by TOPO during the test period.**

For the modified TOPO system, we have access to raw data from the serial port. However, not all data transferred to the website was available through the serial port. In the actual period, a total of 26 138 vehicles was measured and categorized into the 8+1 classes, as shown in figure 3.

In table 5, the total number of vehicles with a noise level measured by the LabVIEW/PC system is shown for all the 8 categories (category number refers to figure 3). This is less than measured with the TOPO system, as the noise was measured only during 24-26<sup>th</sup> of March. During this period, a total of 9002 vehicles with approved noise levels were registered. Together with 281 non-classified/hidden vehicles, the total is 9283 vehicles.

**Table 5: Total number of vehicles per vehicle class**

No	Vehicle class/category	Number of measured vehicles
1	Class 7 Cars	7033
2	Class 2 Cars and delivery vans + Trailer	183
3	Class 11 Delivery vans	729
4	Class 3 Trucks	318
5	Class 5 Bus	70
6	Class 8 Truck + Trailer	260
7	Class 9 Road tractor + Trailer	391
8	Class 10 Motorcycles	18
9	Class 6 Unidentified/hidden vehicles	281
<b>Total</b>		<b>9283</b>

### 5.2.1 Influence of rain/wetness

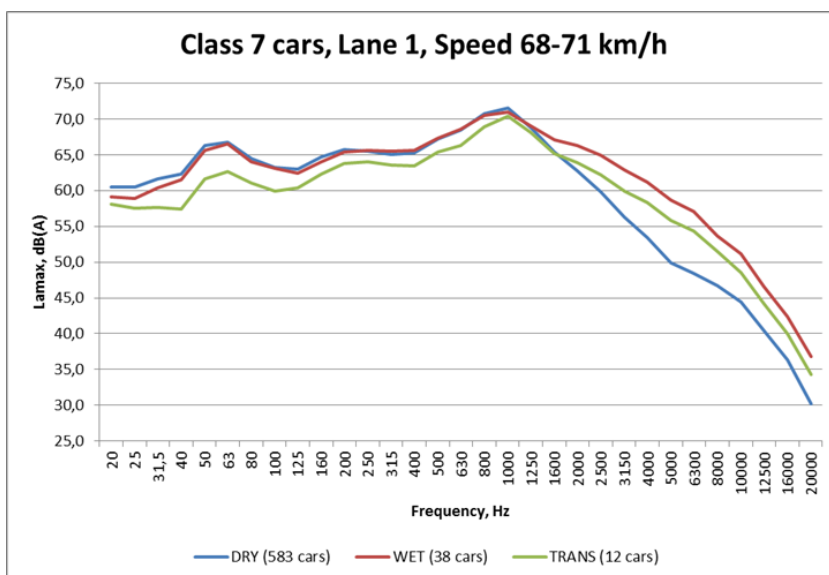
During this test period, there were several periods with rain.

Based on the data for wetness from the met station, we have categorised the measured vehicles into 3 periods:

- 1) Totally dry (long time since any rain)
- 2) Totally wet (rain is registered)
- 3) Transition surface (rain has stopped; the surface is drying up, but may have some wetness).

The transition period is at least 10 minutes after last rainfall. The time to dry up will depend on the traffic load at the time.

The separation of these 3 periods is best illustrated using the frequency spectra, as shown in figure 22. In this figure, the frequency spectra for cars in the speed range of 68-71 km/h are shown.



**Figure 22: Frequency spectra for cars on a dry, wet or a surface drying up (Trans)**

The results show that a wet surface only influences the frequency spectra above approximately 1250 Hz. It is merely a high frequency phenomenon. Furthermore, it is necessary to remove pass-byes on a surface drying up. At least a 10-20 minutes slot time after the rain has stopped should be allowed, depending on the traffic volume at the time. Less traffic means a longer drying-up time.

### 5.2.2 Influence of microphone positions

The normal position to measure noise from vehicles is at 7,5 m from the centre line of the lane, and at a height of 1,2 m. This is defined in both the type approval noise standard for vehicles (ISO 362-1/2)<sup>11,12</sup> and in the Statistical Pass-by Method (ISO 11819-1).

If one shall monitor the individual noise from vehicles on a dual lane road, there are then two options:

- 1) To use a single microphone at 7,5 m distance from the nearest lane and then introduce a correction factor for the vehicles passing at a longer distance.
- 2) To use two microphones, 7,5 m from each of the lanes.

At the test site E6 Klett, some measurements were done with both a single microphone and with two microphones, as shown in figure 3.

Microphone 2 is 7,5 m from the nearest lane (lane 1) and 11,2 m from the other lane (lane 2).

If each vehicle is regarded as a point source ( $20 \cdot \log(d1/d2)$ ), the correction factor would be + 3,5 dB. This means the noise levels in lane 2 measured with microphone 2 shall have a correction +3,5 dB to be comparable with the levels measured in lane 1.

However, simultaneously measurements using both mic 2 and 3 were made, thus enable a direct comparison between the two microphone signals.

Based on a limited number of cars (14), the difference was found to be 2,3 dB, with a standard deviation of 0,67 dB. This is less than the theoretical difference, based on a point source. However, the source is moving, and has a distributed configuration (front and rear tyres). If the car is defined as a line source (which is done for a traffic flow of cars), then the correction factor would be 1,74 dB. The measured difference is indicating that the passing car is somewhere between a point and a line source.

To have a fixed/permanent monitoring station with microphones at a height of 1,2 m may be a risk for damage and perhaps thefts. It would be safer to use a higher position like 3-5 m. This is normally always done in other countries like the Netherlands, when a SPB type of measurements is performed.

For our test, it was therefore added a microphone positions at 3 m height (Mic 1 in figure 3), together with the position at 1,2 m.

- 1) For vehicles in lane 1 (closest to microphones):  
Theoretically difference ( $20 \cdot \log(d1/d2)$ ) = 0,56 dB  
Measured difference: 1.5 dB, standard deviation 0,86 dB
- 2) For vehicles in lane 2:  
Theoretical difference: 0,23 dB  
Measured difference 1,2 dB, standard deviation 0,83 dB

There is obviously a discrepancy between the theoretical values and what we measure. It is recommended to increase this type of comparison measurements if a correction factor shall be introduced.

### 5.2.3 Measured noise levels on dry surfaces

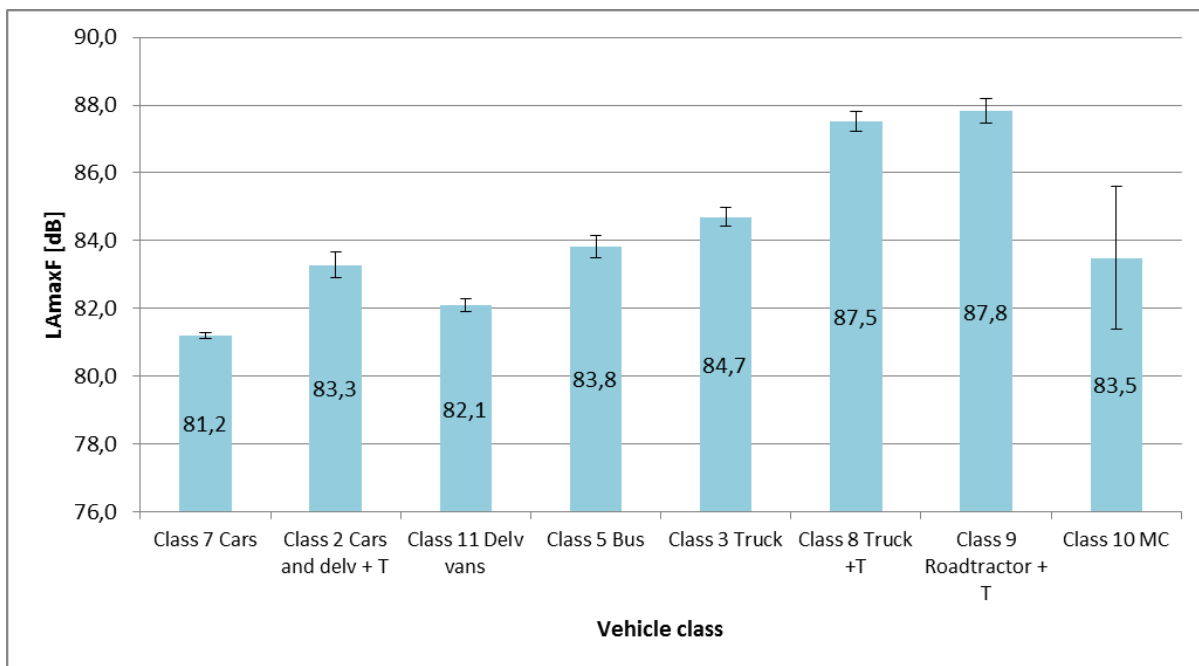
Because of the findings in chapter 5.2.1, only the measured levels from vehicles on a dry surface and with a microphone position at 7,5 and at a height of 1,2 m is used to compare the noise levels from the different categories.

In table 6, the *average* noise level for each of the categories is shown, together with the standard deviation. For this comparison, only the levels from lane 1 are included, to avoid any influence of correction factors (see chapter 5.2.2). All levels are corrected to a reference speed of 70 km/h (= posted speed at the location), using the relationship  $35 \cdot \log(v/v_{ref})$ . It should be noted that only vehicles with a speed above 40 km/h is used for calculation of average levels (see also chapter 5.2.3.1).

In figure 23, the levels are shown, including the 95 % confidence intervals.

**Table 6: Measured average A-weighted noise level (dB) for 8 classes of vehicles, reference speed = 70 km/h**

Class	Cars	Cars/deliv. +Trailer	Deliv. vans	Bus	Truck	Truck + Trailer	Road truck +Trailer	MC
Number	3939	103	335	54	175	84	175	9
$L_{average}$ , dB	81,2	83,3	82,1	83,8	84,7	87,5	87,8	83,5
St.dev, dB	2,2	2,0	1,7	1,2	1,9	1,3	2,4	3,2



**Figure 23: Measured average A-weighted noise level (dB) for 8 classes of vehicles. Reference speed = 70 km/h**

The difference in noise levels are highly correlated to the number of axles of the passing vehicles. Class 2 (light vehicles with a trailer) has normally 3-4 axles, while class 7 (cars) and class 11 (delivery vans) has 2 axles).

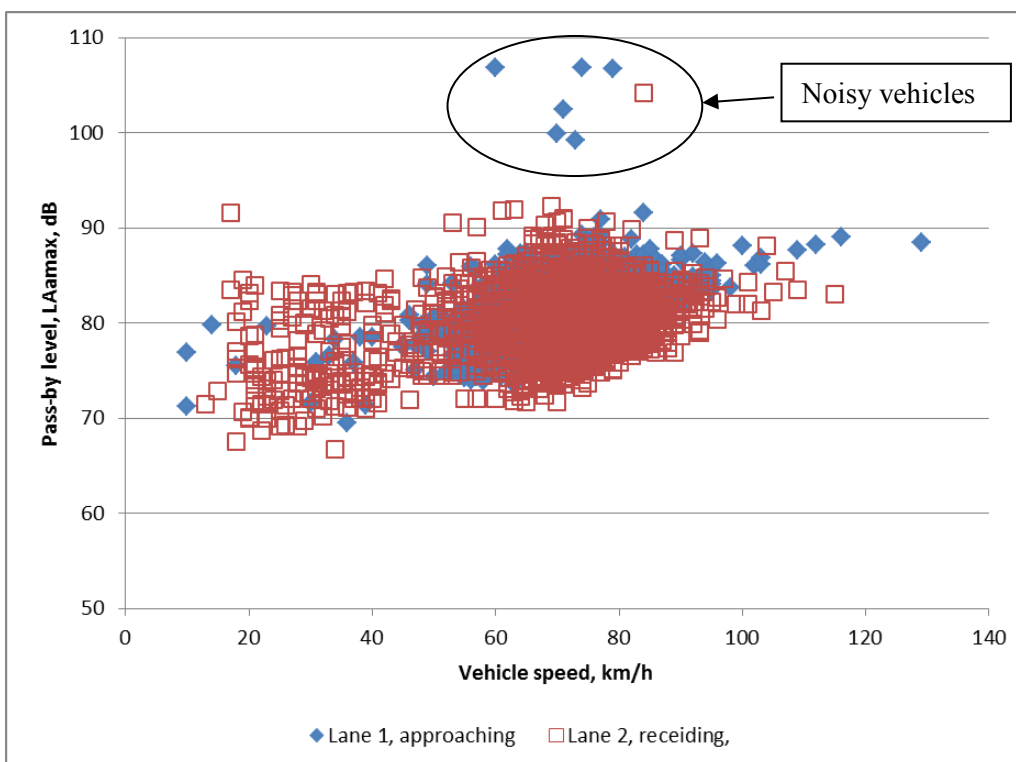
Class 5 (bus) and class 3 (truck) has normally up to 3 axles, while class 8 and 9 has normally 4 or more axles.

The results also show that the largest spread in levels is for the motorcycles. However, the number of measured motorcycles is small (16).

## 5.2.4 Noise levels as a function of speed, all classes

In figure 24, all the measured noise levels from class 7, cars are shown. All measurements are on a dry surface.

It should be mentioned that all levels in lane 2 (red dots) are uncorrected, and thus on average should be somewhat higher than the levels in lane 1 (blue dots). The number of vehicles measured is different from the numbers given in table 5, as only the levels on a dry surface are shown. No temperature correction factor has been applied.



**Figure 24: Measured A-weighted noise levels of cars (class 7) as a function of vehicle speed.**  
**No of vehicles= 6585**

From this figure, it is clear that the noise levels of vehicles below approximately 40 km/h are influenced by other vehicles at this location, because the fixed 3 s separation time is too short. Normally, the noise levels below 40 km/h would be between 60 and 70 dB.

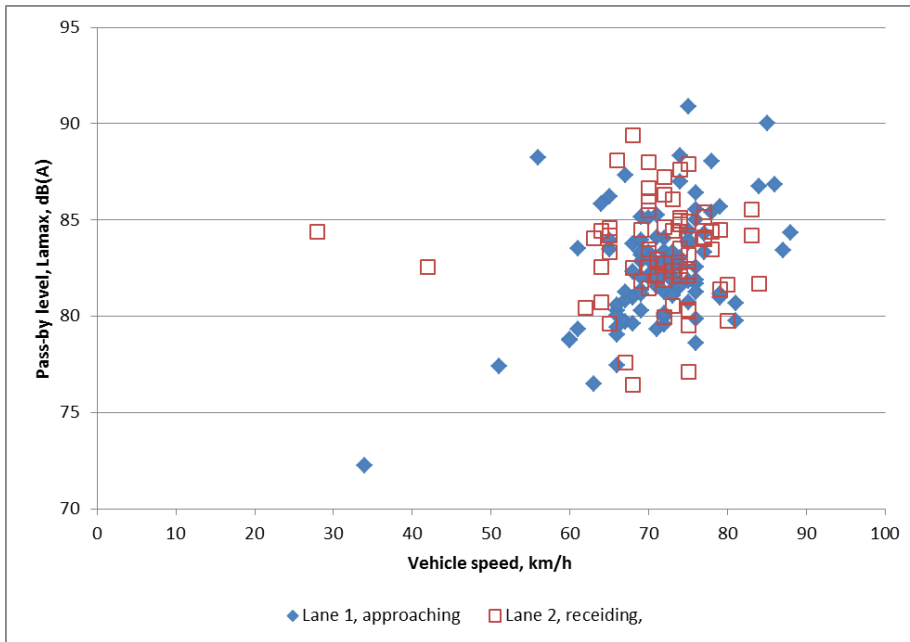
The low speed is related to vehicles passing the monitor during rush hour. With a fixed separation time of 3 s, it is obvious that the level from one car is influenced by other cars, either in front or behind the object. To solve this problem, an increase of this time window could be one solution, but then fewer vehicles will be measured. Using a microphone array which is able to separate vehicles even at low speed is another solution.

The figure shows that there is passing vehicles (6) in this class that has an abnormal high noise level, approximately 20-25 dB **higher** than the average. The measured pass-by levels are in the range 100-107 dB, at a "normal" speed of 60-80 km/h. It is obvious that these vehicles can be a nuisance to the environment and

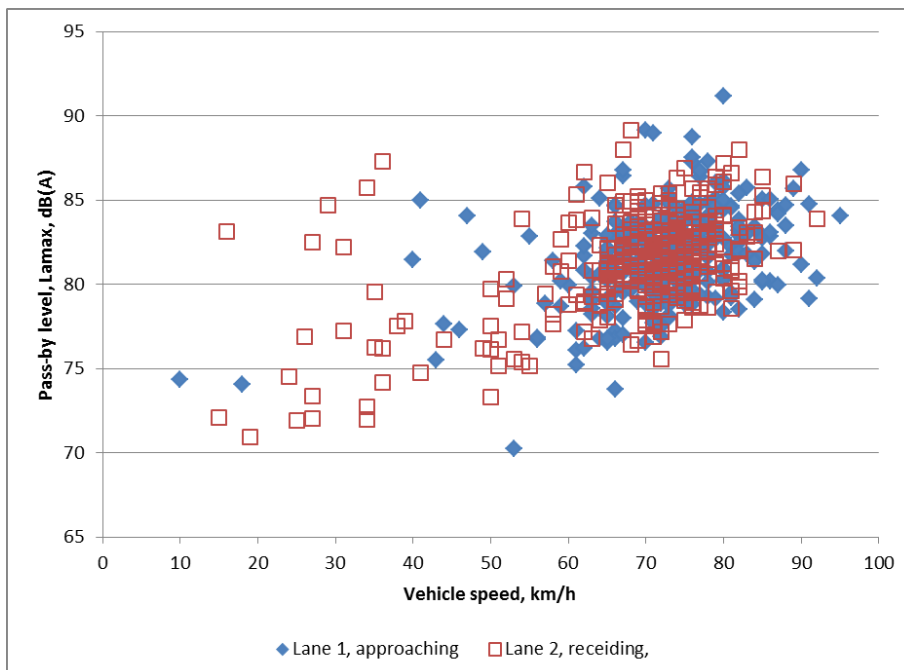
should be avoided. This can be done, either by the standard periodical check of technical condition of the vehicle, or by a roadside control based on such a monitoring system.

A number plate recognition system (see chapter 6) could also be used to identify the type of vehicle (engine type, year of production, etc.) and then be a tool to check the vehicle.

Figures 25 to 31 show the measured noise levels of other 7 classes.

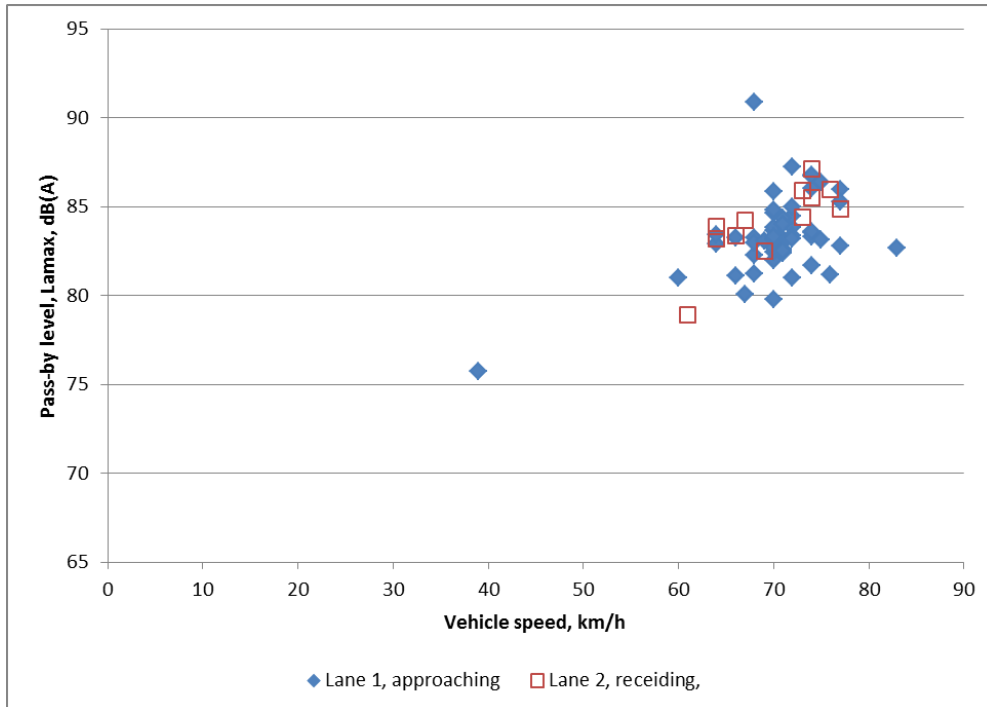


**Figure 25: Measured A-weighted noise levels of cars and delivery vans with a trailer (class 2) as a function of vehicle speed. No of vehicles = 175**

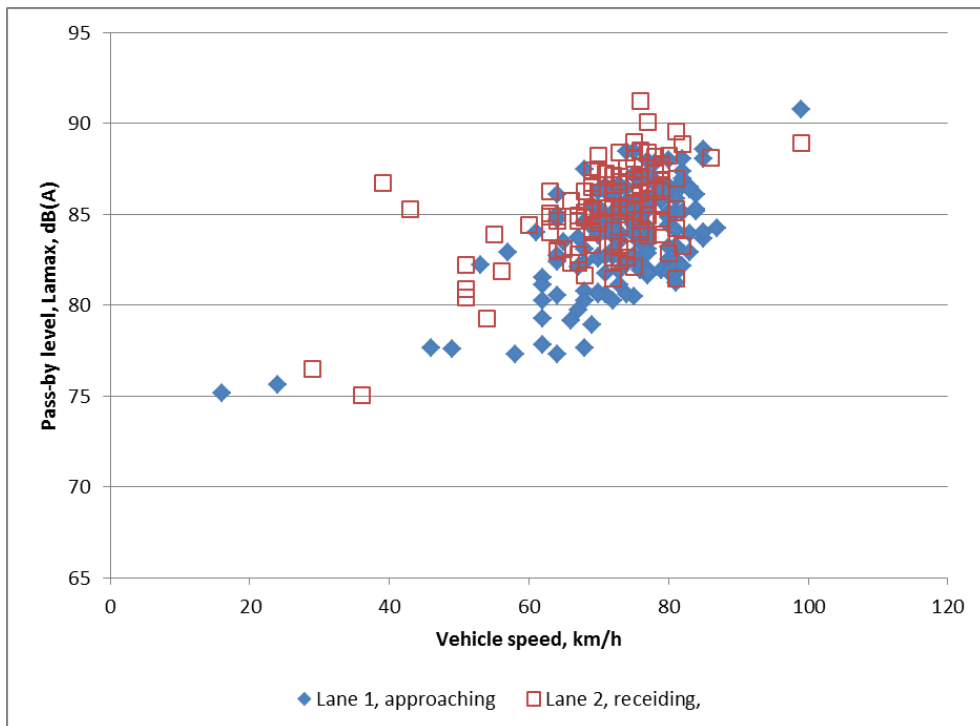


**Figure 26: Measured A-weighted noise levels of delivery vans (class 11) as a function of vehicle speed. No of vehicles= 671**

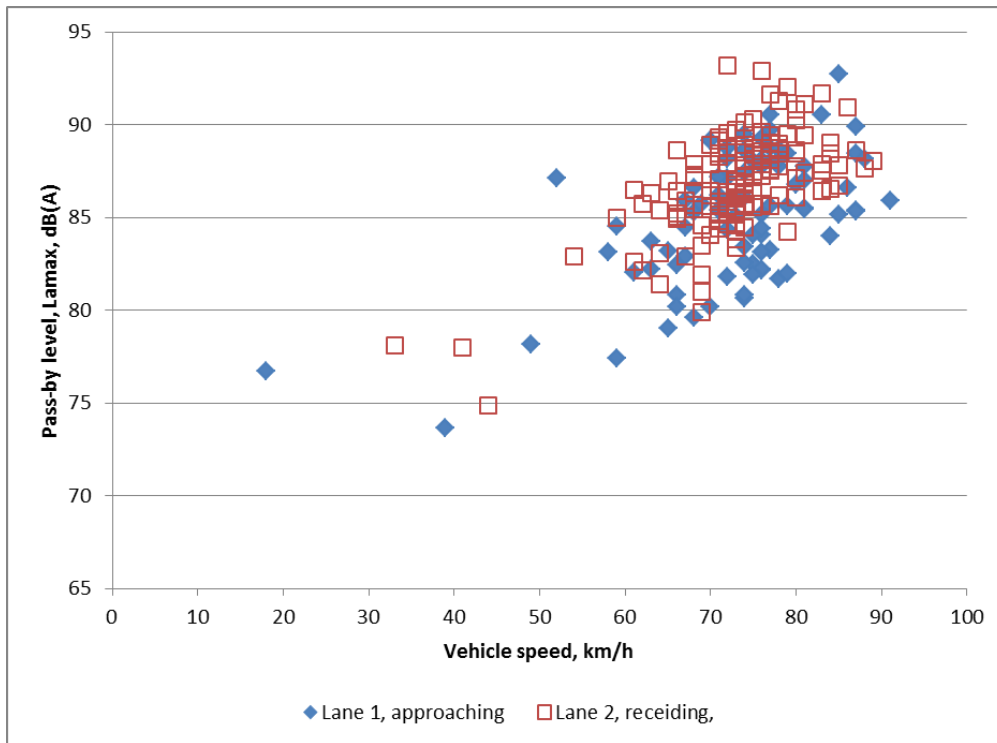




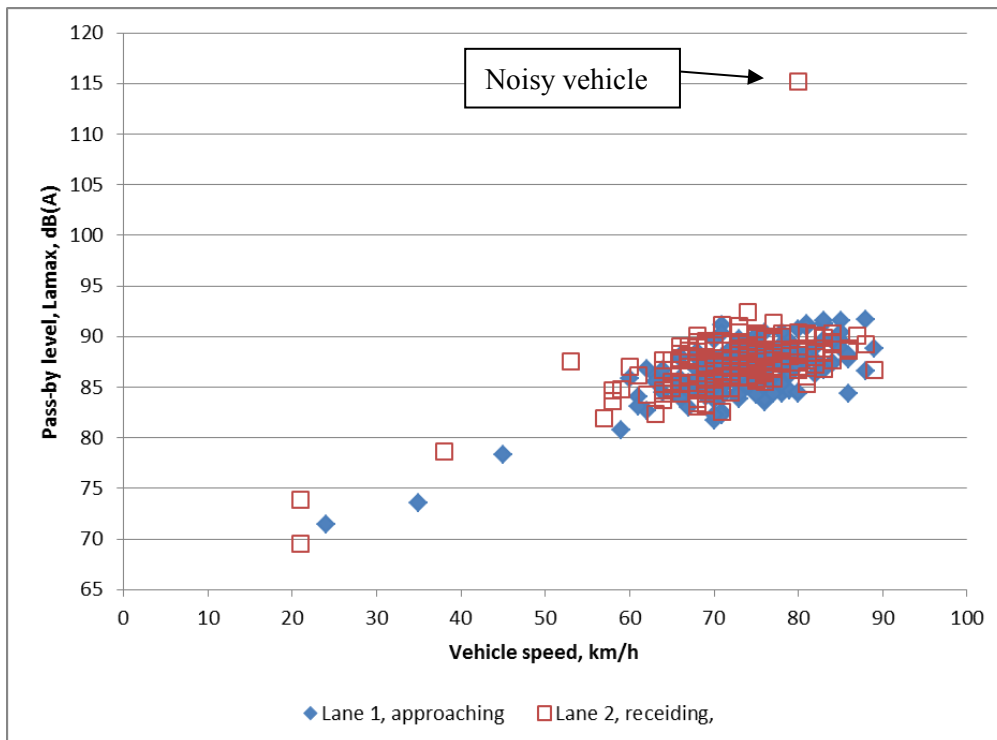
**Figure 27: Measured A-weighted noise levels of buses (class 5) as a function of vehicle speed.  
No of vehicles = 66**



**Figure 28: Measured A-weighted noise levels of trucks (class 3) as a function of vehicle speed.  
No of vehicles = 288**

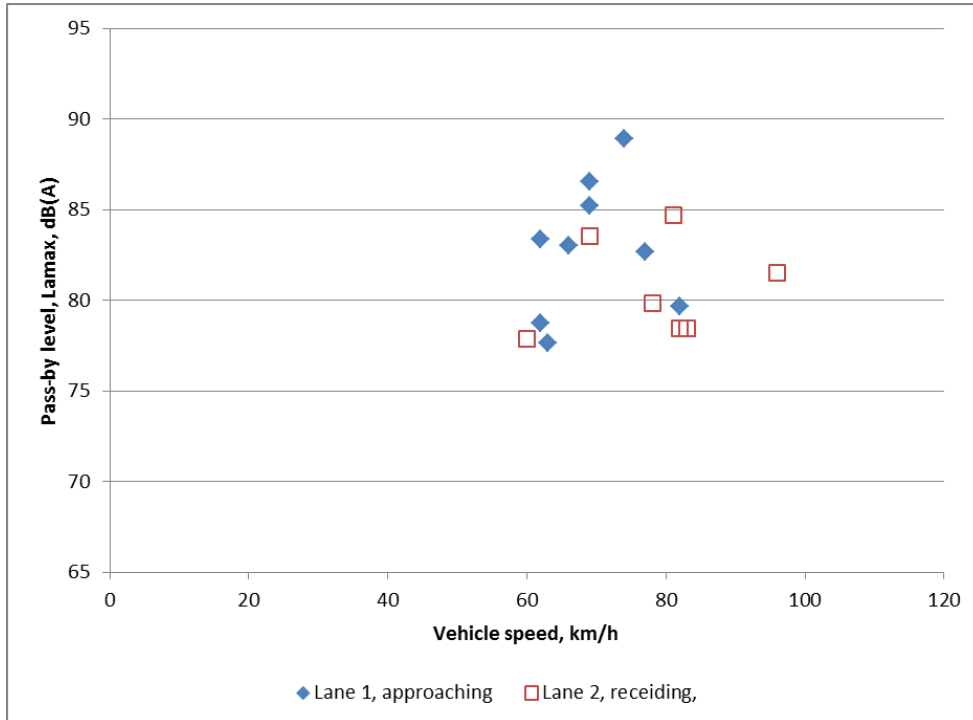


**Figure 29: Measured A-weighted noise levels of trucks with a trailer (class 8) as a function of vehicle speed. No of vehicles = 227**



**Figure 30: Measured A-weighted noise levels of road tractors (semitrailer) with a trailer (class 9) as a function of vehicle speed. No of vehicles = 354**

In this class, there is one vehicle with a noise level of more than 25 dB than the average. It is obvious that such vehicles has an un-legal noise level and should be repaired or modified.



**Figure 31: Measured A-weighted noise levels of motorcycles (class 10) as a function of vehicle speed. No of vehicles = 16**

In general, the results show that it is feasible to use such a monitoring equipment to identify noisy vehicles, for example in combination with an ANPR system linked to AUTOSYS (ANPR is not feasible for motorcycles).

### 5.3 CO measurements with LaserGas iQ<sup>2</sup>

, A field test was conducted on Fv885, Bratsbergveien to see if it was feasible to measure CO of passing vehicles. The radar (TOPO) and noise measurement system (without the met station) were included in the test, in order to measure the speed and noise of the passing vehicle. Figure 32 and 33 show the set up for the measurements.

The test was spilt into two parts:

- 1) Measurements of test vehicles
- 2) Measurements of random passing vehicles



**Figure 32: Set up with LaserGas iQ<sup>2</sup>, with reflector on the opposite side of Bratsbergveien**



**Figure 33: TOPO-bigbox and microphone set-up at Bratsbergveien**

### 5.3.1 Measurement with test vehicles

For the first part of the test, the following 3 cars were used:

**Table 7: Test of known vehicles**

Car no	Type/model, year of prod.	Engine	Transmission
1	VW Golf Variant, 2010	Diesel	5 speed manual
2	VW Caddy, 2014	Diesel	6 speed manual
3	Mazda CX-5, 2013	Diesel	Automatic

This test was in two parts:

- 1) Constant speed pass-by test from 30 to 60 km/h
- 2) Acceleration (moderate) with starting speed varying from 30 to 60 km/h

During the constant speed test, the oil temperature (indication on engine temperature) was monitored on the VW Golf, as this temperature is shown on the display on the dashboard with digits. For this car, the test at the low speeds then indicates a cold start condition, which normally gives higher energy consumption/CO level.

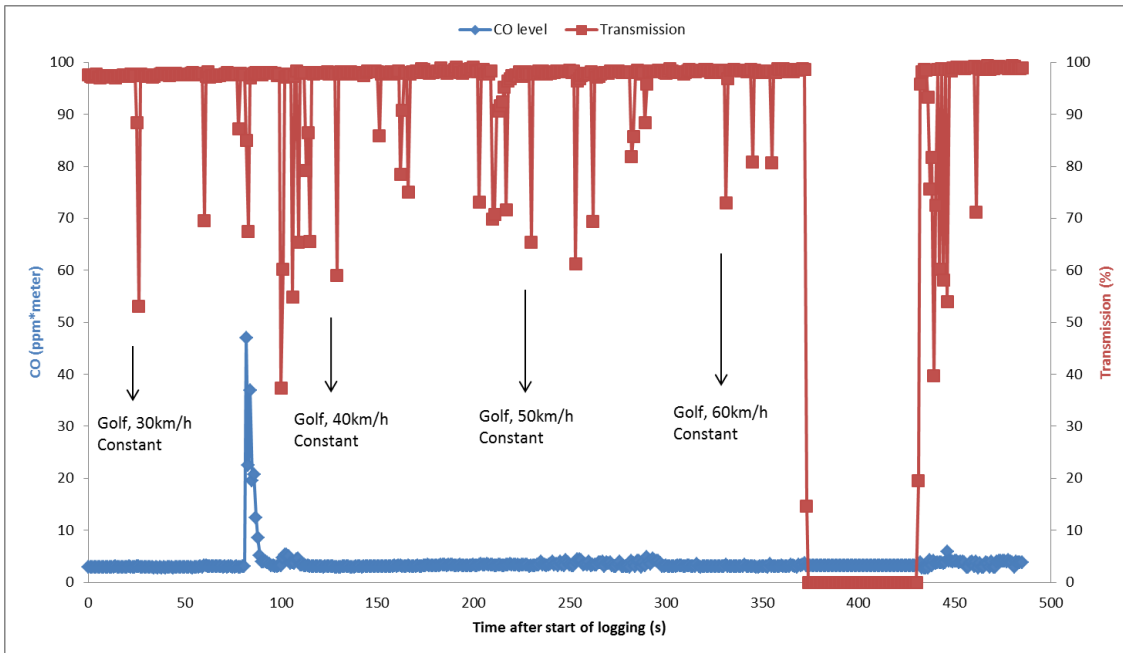
For the VW Caddy, only visual reading of the oil temperature level is possible (see figure 34)



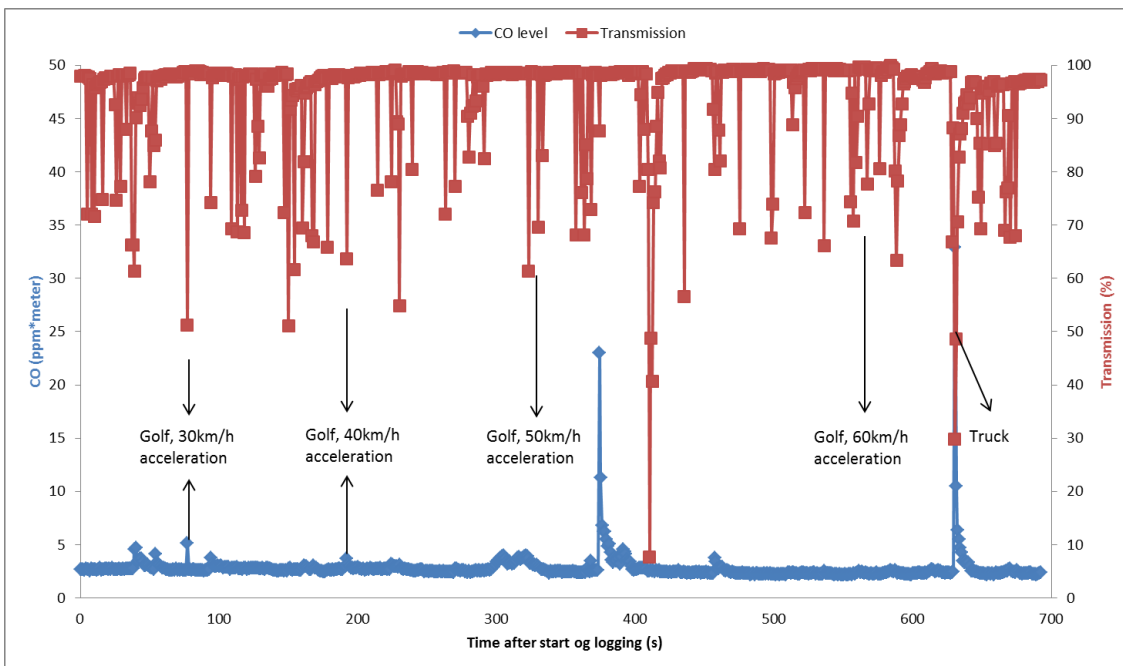
**Figure 34: Oil temperature of VW Caddy. Right: 70 °C (start of test), Left: 90 °C (normal temp.)**

The Mazda CX-5 had no visual indication of the oil temperature.

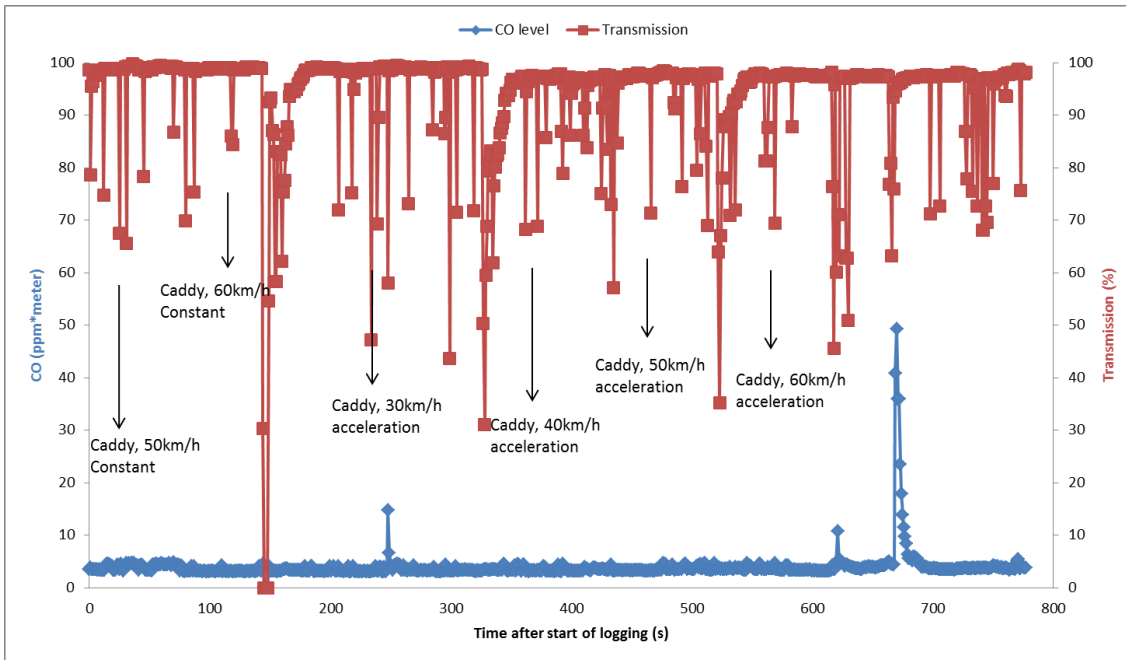
Figures 35 to 38 show the detection level of CO from the laser during the test of the 3 cars, together with the transmission. 100 % transmission level is when there is no passing vehicle. Note that the speeds indicated in the figures are target speeds and not necessarily the measured speed (see table 8).



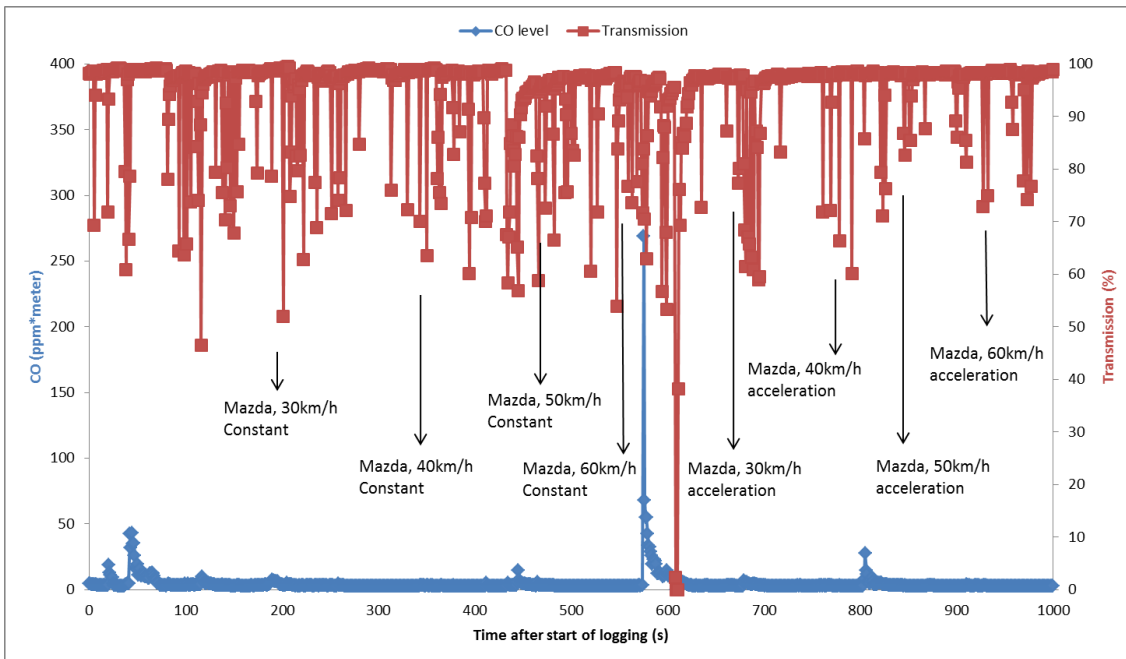
**Figure 35: Measurements of CO level during test of VW Golf, constant speed**



**Figure 36: Measurements of CO level during test of VW Golf, acceleration**



**Figure 37: Measurements of CO level during test of VW Caddy, constant speed and acceleration**



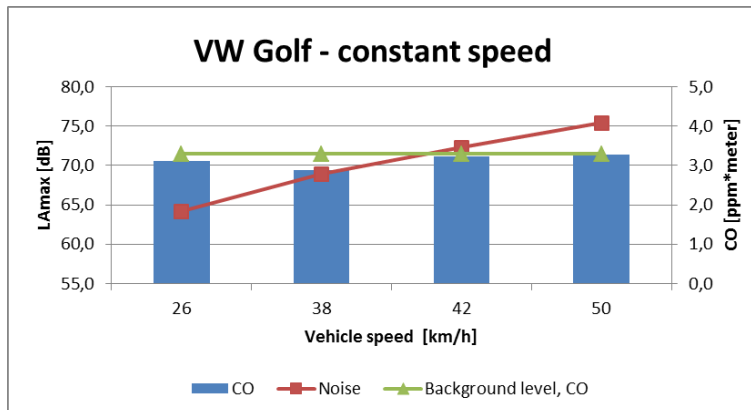
**Figure 38: Measurements of CO level during test of Mazda CX-5, constant speed and acceleration**

Table 8 summarises the measured level of CO and noise level for the 3 test cars during the two driving conditions. The speed is the actual speed as measured by the TOPO. During the acceleration mode, this is the speed measured during the passing of the radar, and not necessarily the maximum speed achieved during the test. Unfortunately, there was no option available to measure the value of acceleration (in  $m/s^2$ ).

**Table 8: Measurement of CO and noise level from 3 test cars**

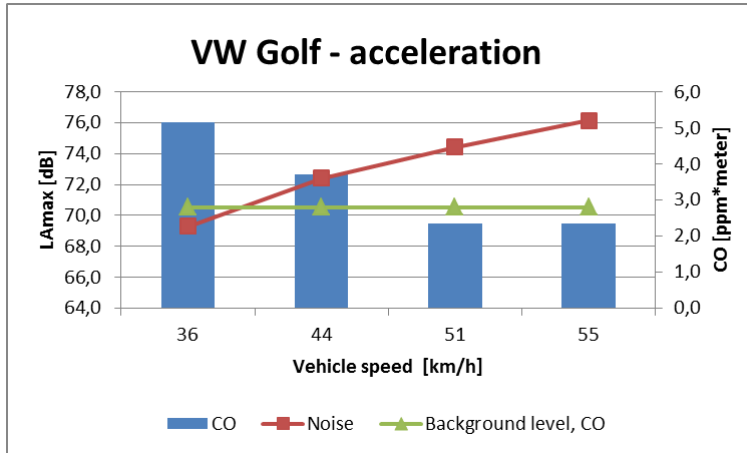
Car	Driving mode	Meas. speed, km/h	Gear	Oil temp °C	L <sub>A</sub> max, dB(A)	CO, ppm*meter
VW Golf	Constant	26	2	62	64,2	3,1
	Constant	38	3	70	68,9	2,9
	Constant	42	3	77	72,3	3,2
	Constant	50	4	86	75,4	3,3
	Acceleration	36	2	97	69,3	5,2
	Acceleration	44	3	97	72,4	3,7
	Acceleration	51	3	97	74,4	2,3
	Acceleration	55	3	97	76,1	2,3
VW Caddy	Constant	26	2	75	70,6	-
	Constant	41	3	90	73,5	-
	Constant	42	3	97	75,3	4,7
	Constant	50	4	97	75,5	3,2
	Acceleration	40	2	97	73,9	3,2
	Acceleration	52	3	97	75,5	3,2
	Acceleration	54	3	97	76,4	3,3
	Acceleration	56	4	97	77,2	3,2
Mazda CX-5	Constant	29	Auto	-	64,9	3,4
	Constant	38	Auto	-	68,9	3,3
	Constant	49	Auto	-	73,3	3,3
	Constant	59	Auto	-	76,6	2,9
	Acceleration	41	Auto	-	69,6	3,0
	Acceleration	48	Auto	-	72,9	3,3
	Acceleration	55	Auto	-	74,6	3,2
	Acceleration	62	Auto	-	76,3	3,1

Figures 39-44 show the measured maximum A-weighted noise level and CO as a function of vehicle speed for the two modes of operation. The general measured average background level of CO at the time of measurement of the car is included in the figures.

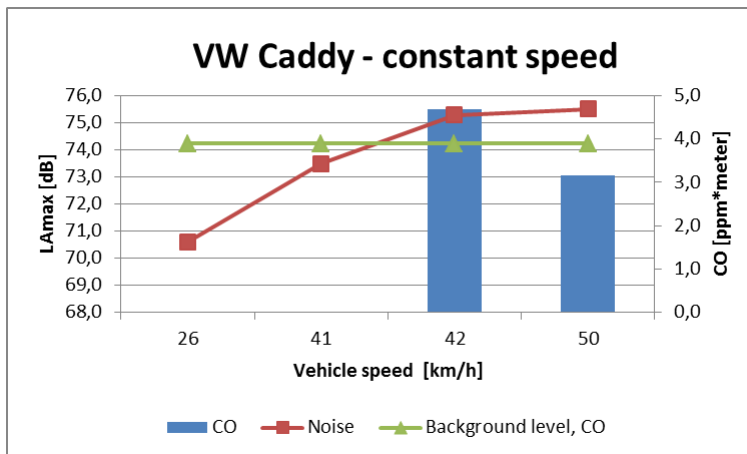


**Figure 39: VW Golf, constant speed test, CO and noise level**

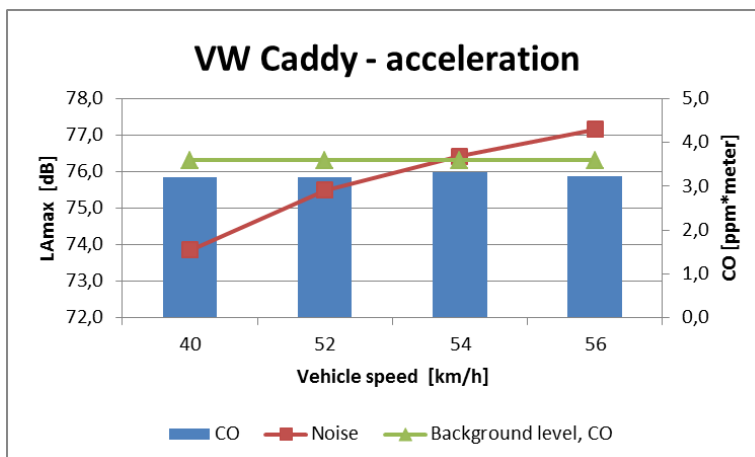




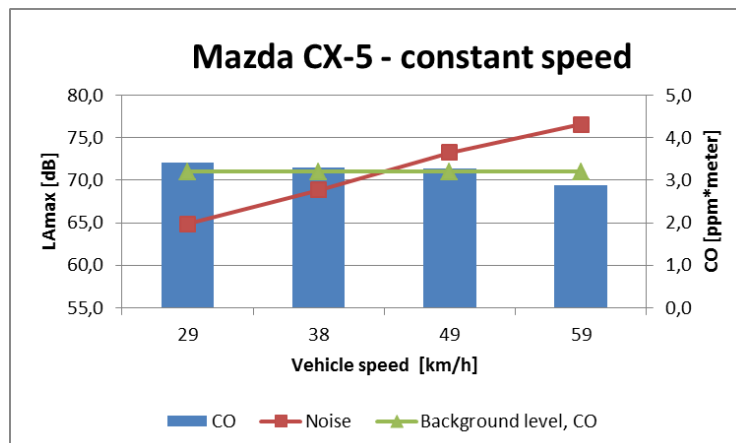
**Figure 40: VW Golf, acceleration test, CO and noise level**



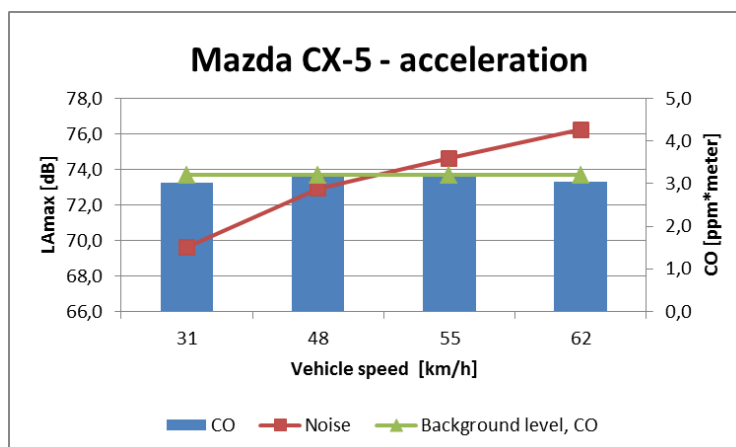
**Figure 41: VW Caddy, constant speed test, CO and noise level**



**Figure 43: VW Caddy, acceleration test, CO and noise level**



**Figure 43: Mazda CX-5, constant speed test, CO and noise level**



**Figure 44: Mazda CX-5, acceleration test, CO and noise level**

In general, these results show that it is only one case, where the measured CO level is above the background level:

- During acceleration of the VW Golf from a low speed, even if the oil temperature had reached a normal level.

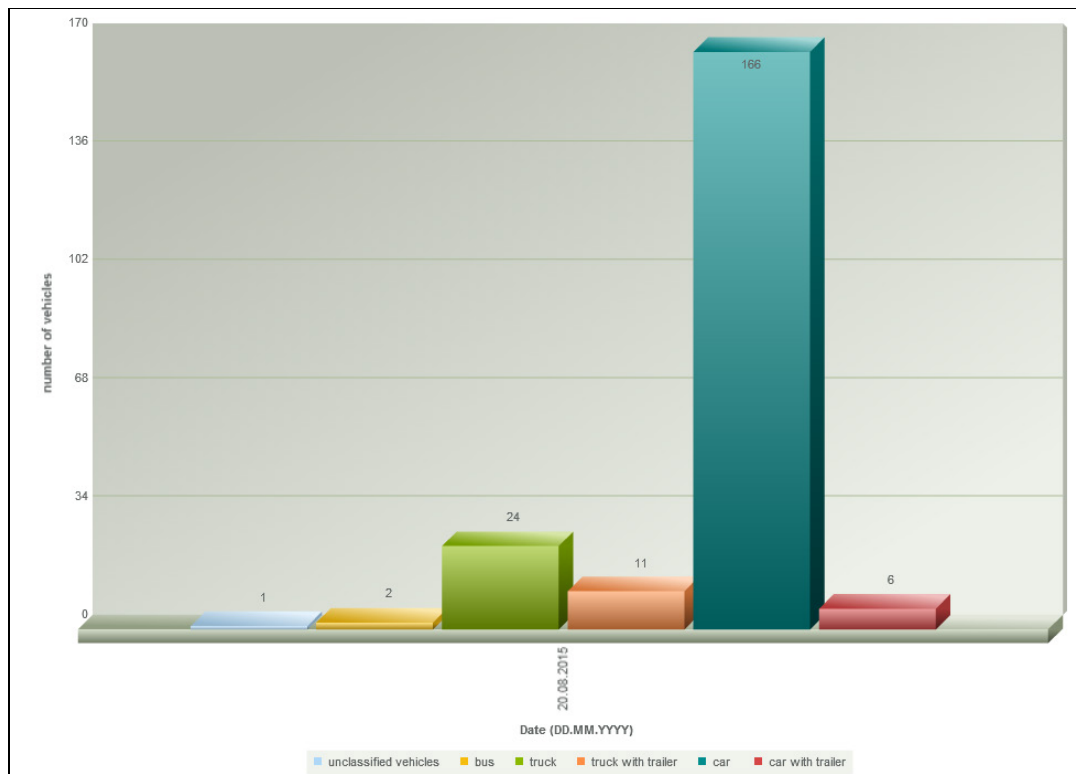
For the other tests, the levels are close to the background level of CO.

The first test of the VW Golf, constant speed at 26 km/h, the engine was cold, and one could expect a higher level of CO. This was not found for this car. A higher level was found when the car was accelerating from a low speed, as shown in figure 40. An acceleration test with cold engine would probably have shown higher levels of CO.

As expected, the measured noise levels are speed dependent. During acceleration, the engine has a higher load than at constant speed and normally this increase the noise.

### 5.3.2 Measurements of random passing vehicles

In figure 45, the total number of passing traffic (554 vehicles) registered by the TOPO.bigbox is shown. The measurement time was approximately 1 hour and 45 minutes.



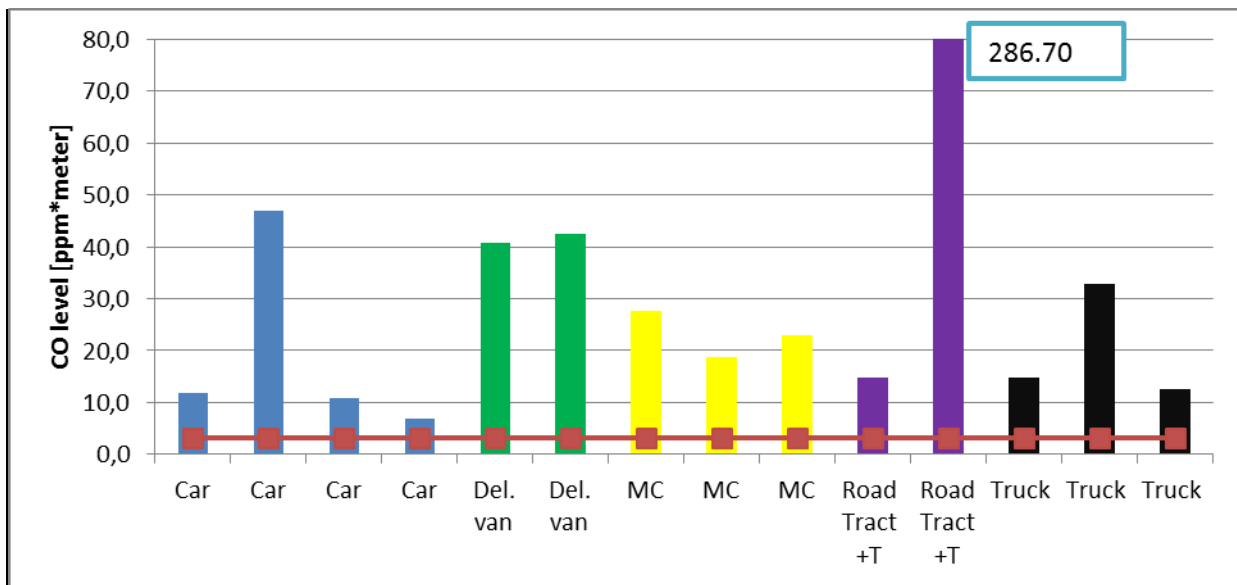
**Figure 45: Number of passing vehicles in 5+1 classes at Bratsbergveien**

As can be seen in figure 32, the reflector for the laser was placed at a low height, primarily to detect CO from vehicles with the exhaust tail pipe position at the rear of the vehicles below the bumper. For heavy vehicles, the exhaust tail pipe may be located at a higher position. Thus, it is not realistic to measure CO from such vehicles. It should also be noted, that this was only the first test on real traffic for this system. It may be possible to find an optimal height and position to improve the detection of CO (or other gases).

Even if the system position was not optimised, it proved successful to be able to detect vehicles with abnormal high CO levels. The measured CO level from the laser was correlated with the classification of vehicles from the TOPO system and time of passing.

In figure 46, all the vehicles with a CO level higher than the background level are shown. Note that for one of the vehicles, the measured level was very high (268,70 ppm\*meter), so the bar for this vehicle is not shown in full length.

Of the total of 554 vehicles measured, 14 vehicles (2,5 %) were registered with a CO level above the "background" level.



**Figure 46: Measurement of CO level of passing vehicles**  
*Red curve is average background level*

## 6 Automatic number plate recognition (ANPR)

### 6.1 General considerations

By using an automatic number plate recognition system (ANPR), it is possible to link the number to the national AUTOSYS database. In this database it is possible to identify some important parameters which may be relevant for the pass-by noise level (except for the influence of the driving conditions). Such parameters can be:

- vehicle type/model
- type of engine/power train (diesel/petrol/electric/hybrid)
- transmission type (manual/automatic)
- year of production – related to type approval level (noise, CO<sub>2</sub>, NO<sub>x</sub>)
- vehicle dimensions, including net weight/maximum allowed weight
- standard tyre dimensions

As more stringent noise limits for vehicles and tyres are introduced, it would be desirable to know which type approval level the measured vehicle has been approved for. A new noise system for vehicles has recently been approved within EU/EEA and UN/ECE. Both more stringent noise limits will be introduced in the coming years and a new measuring method (ISO 362-1/2) has been adopted. This method is designed to simulate normal driving conditions of vehicles in traffic.

Several investigations, e.g. in the Netherlands<sup>11</sup> have demonstrated that previous regulations of the maximum permissible noise levels during type approval has not had any positive effect on the general traffic noise levels, except for heavy vehicles, to some extent. The main reason for this is believed to be an increase of tyre/road noise (wider and low profile tyres).

By identifying a vehicle in a traffic flow by ANPR, and using a general vehicle database, one can find the type approval valid for that specific vehicle. This establishes a link between the measured noise level in a traffic flow and the type approval level. However, it is important to take into account all other parameters relevant for the measured noise level, such as speed, meteorological conditions etc.

The main issue is to look for larger amount of data from different vehicle categories, to study if new vehicles type approved according to new limits and test procedures in fact are more silent in a normal traffic situation.

As the test of the monitor in this project shows (figures 24 and 30), there is obvious some vehicles with abnormally high noise levels, which are not related to driving conditions. It would be a major contribution to reduce the impact of road traffic noise to remove such vehicles from the traffic flow. They may represent a major nuisance to the public, and may cause health risks and sleep disturbance.

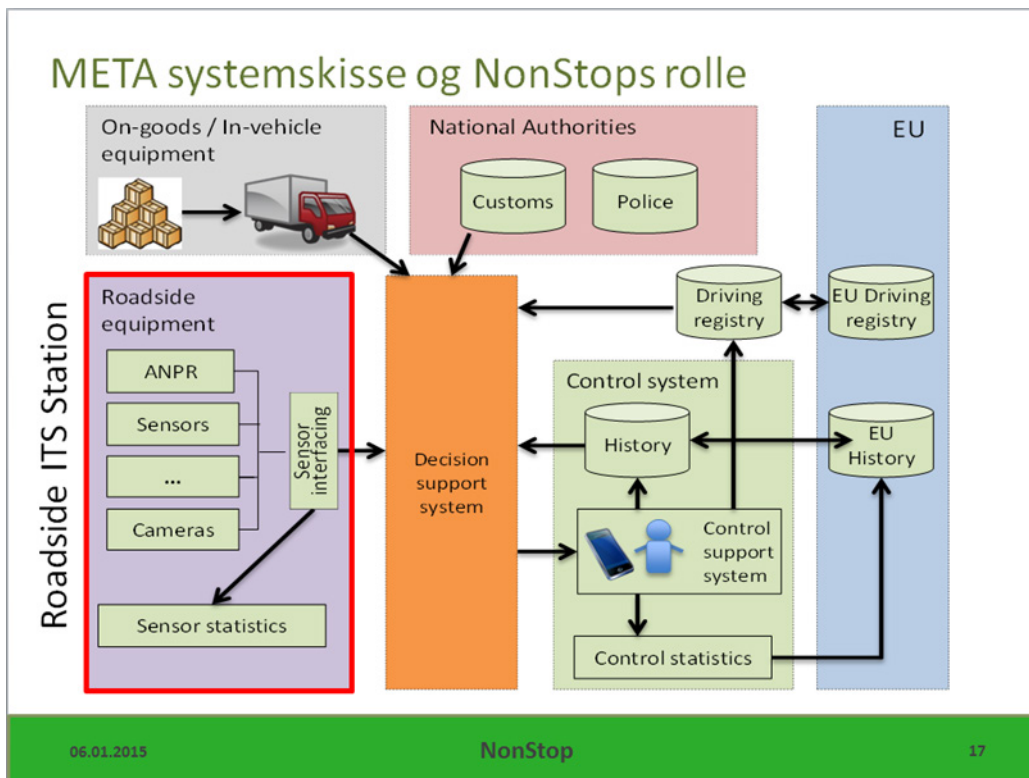
By identifying such noisy vehicles, one can follow-up a measurement by a technical inspection. This can be done either by a letter calling to present the vehicle for inspection or by a road side inspection immediately after the monitoring station.

## **6.2 Procedure to implement ANPR**

By identifying the number plate of a passing vehicle and linking this information to a general vehicle database (like AUTOSYS) the owner of the vehicle is also identified (not the driver). Such data is in most countries sensible information and can violate privacy. The use of ANPR must comply with national regulations.

In Norway, SINTEF has worked with the ANPR technology in the project NONSTOP. In this project the weight of heavy vehicles is registered when the vehicle is passing over sensors in the road ("weight-in-motion"). At the same time, the number plate is read by a camera and the weight is automatically checked with the maximum allowed weight for this particular vehicle in the AUTOSYS database. If the weight is close to or above this limit, the system gives a warning to a road side control station, to stop and check this vehicle manually. By this technology, only the vehicles that may be violating the weight limit will be checked and all other trucks may pass. All information about the registration number is deleted immediately after passing the ANPR system. The NONSTOP system was partly sponsored by the Norwegian Public Roads Administration and the Research Council of Norway.

The NONSTOP system is proposed to be integrated in a larger ITS system, both nationally and within EU. All communication between sensors and database is based on common standards and protocols (transparent system). Figure 47 show a META system sketch of such a system, where NONSTOP is integrated. A monitoring system like developed in the MOVE project may easily be implemented in a general ITS system.



**Figure 47: A META ITS system and integration of NONSTOP**

Implementation of ANPR in a monitoring system for noise levels will require permission from the authorities (in Norway: Datatilsynet).

In discussions with the Norwegian Public Roads Administration, it was clarified that by using the same approach as for the NONSTOP system, it should be feasible to implement ANPR in a system as developed in the MOVE project. The Norwegian company Ciber as, did the programming of the communication between the camera and the database in NONSTOP, and this company has offered to do the same type of work, to make a selection of data from AUTOSYS as described above.

The use of ANPR in a noise monitoring system would give the authorities a tool to remove noisy vehicles from the roads. However, not motorcycles, as the system only reads number plates in the front of the vehicle.

Noisy motorcycles can however, be checked in the same way as in the NONSTOP project. If the noise of the motorcycle is above a chosen level, it may be stopped at a control station after the monitor for further control of the noise level (stationary noise level).

## 7 Example of a web-solution for a monitoring system

There are many examples of environmental monitoring system that gives the general public access to such data via internet. This is the case for both monitoring of air pollution<sup>14</sup> and noise levels (<http://rumeur.bruitpari.fr>)<sup>15</sup>. In the MOVE project, an example of how such a system may work has been made, based on simulated data from the tests made by SINTEF at E6 Klett. For this example, noise data and CO data are presented.

The test example is available at: <http://biamove.cloudapp.net/>

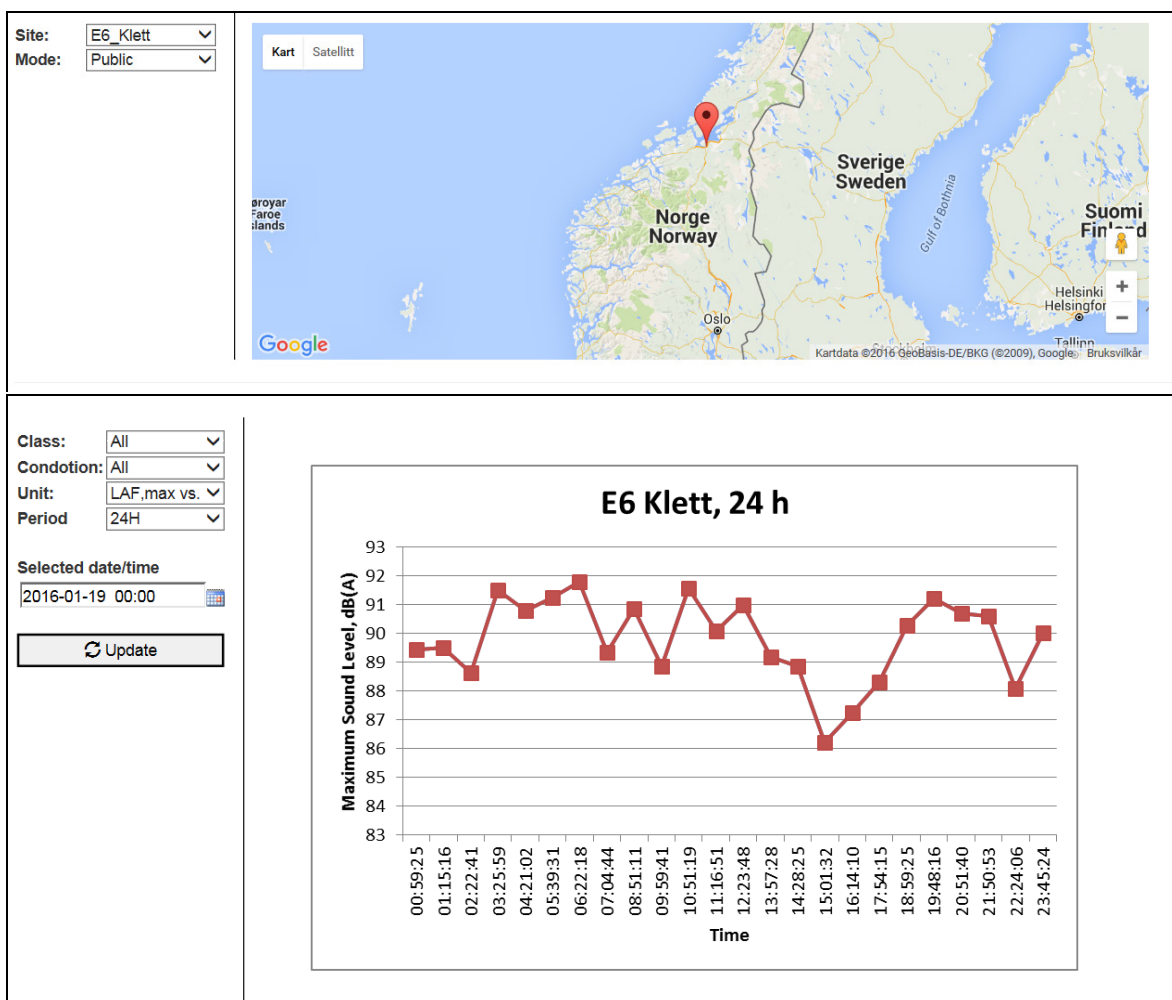
The demo web-site gives a status at the location of the monitor for two modes to be selected:

1. General public user
2. Expert user (will require a username and a password)

## 7.1 Public user

The information to the public should be simple and presented in such a way that the data is easy to understand. The present demo only gives some indication on the possible lay-out. On a "real" web-page for a noise monitor, some simple explanation on noise levels and the use of the decibel unit may be necessary and informative. Some links to external organizations such as the Norwegian Environment Agency may be useful.

In figure 48, the web-page for the "public user" is shown.

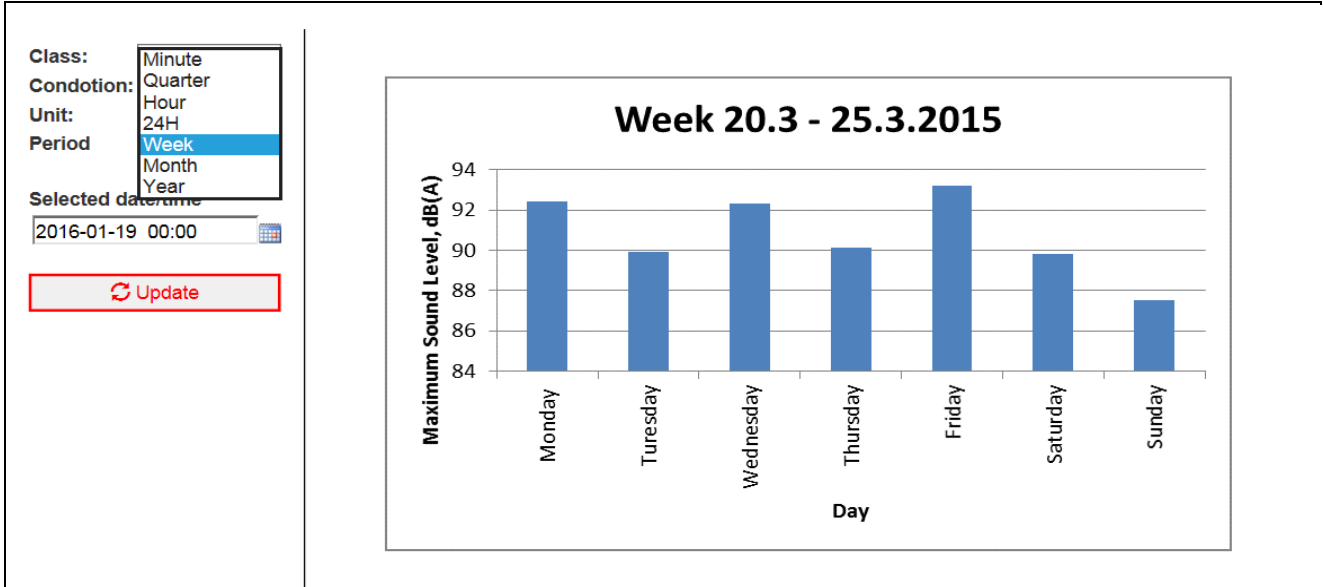


**Figure 48: Example of lay-out for a web-page for a public user**

The first part will always be a Google map, showing the locations of the different monitors.

The monitor location can either be accessed by clicking on the map itself, or choose site by the "Site" on the menu to the left. For the public user, only aggregated data for all classes will be shown. The maximum noise level (LAF, max vs time) has been chosen in this example. Other indicators such as  $L_{den}$  may also be

included in a real monitor. The public user shall also be able to choose period for the data, as shown in figure 49. In this figure, data for a week is presented.

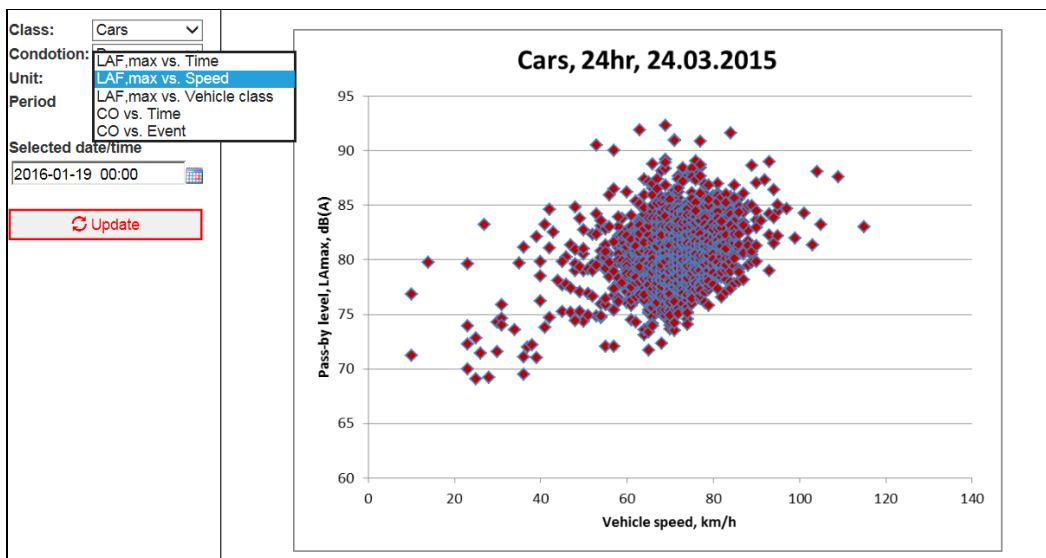


**Figure 49: Example of data for a week – public user**

## 7.2 Expert user

For the expert user, data should be presented in a way that is useful for different types of analysis. In the demo, some figures from excel-sheets are presented. However, in a real monitor, databases such as Access should be used as these are more flexible to gather and analyze large amount of data.

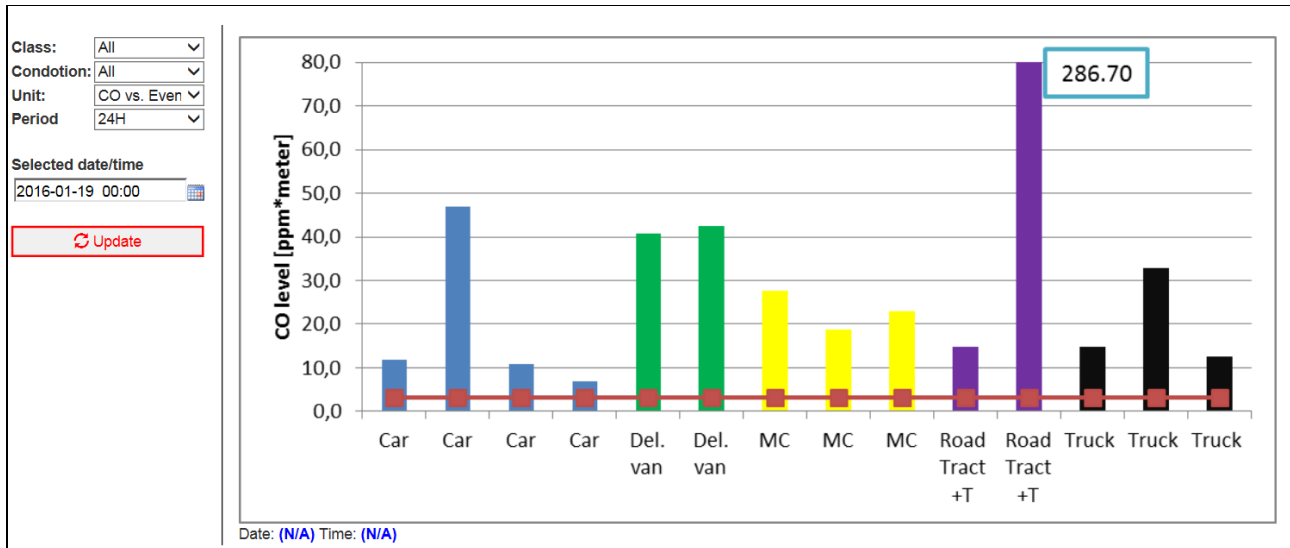
Figure 50 shows example of noise data presented for the expert user. In this example, noise levels vs. speed for cars on a dry surface for a chosen for a period of 24h have been selected.



**Figure 50: Expert user – example of noise data for cars**



In figure 51 data for single events of pass-by of vehicles with measured CO levels above the "background" level (red line/dots) are shown.



**Figure 51: Expert user – example of data from CO measurements**

## 8 Recommendations for further work

Within the time frame of the MOVE project, only a minor road side test of the system was possible. The test of the microphone array was also limited and further testing and development of the signal processing algorithm should be encouraged.

Implementation of ANPR was also not feasible within this project.

Since the main tests of the system were made during the last part of the project, presentations of results are planned for international conferences in 2016 (Internoise2016, BNAM2016, etc.)

The following recommendations for further work are given:

- Implementation of ANPR
- Tests of an integrated system with Nor150
- Further development of a public access system using internet
- Further development of the microphone array technology
- Develop procedures for processing and presentation of large amount of data ("big data")
- Further testing of the laser equipment from NEO, including measurements of NO<sub>x</sub>
- Investigations of the connection between measured noise emission levels and traffic noise calculation methods (e.g. reference values for different categories of vehicles)
- Include algorithm/system to detect studded tyres

## 9 References

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- [12] ISO 362-2(2009): "Acoustics – Measurements of noise emitted by accelerating vehicles – Engineering method - Part 2: L category". International Organization for Standardization (ISO), Geneva, Switzerland
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- [15] F. Mietlicke, C. Ribeiro, M. Sineau: Experiment of low-noise road surfaces on the Paris ring-road. Proceedings of Internoise2013, Innsbruck, Austria, 15-18. September 2013.

## 10 List of publications/media presentations

### Publications:

1. T. Berge: Status per november 2012. SINTEF Notat 90402.01, 2011-11-22.
2. T. Berge: BIA MOVE: Rapport fra avslutningsseminar i CITY HUSH. SINTEF Notat 102002420, 2013-01-28
3. T. Berge: BIA MOVE: Referat fra møte i ISOWG33 og møte hos BASt i Tyskland. SINTEF Notat 102002420, 2013-02-13.
4. T. Berge: BIA MOVE: Parameterstudie. Forslag til struktur for registrering av parametere for målestasjon. SINTEF Prosjektnotat 102002420, 2013-02-20.
5. T. Berge: BIA MOVE: Rapport fra en internasjonal konferanse hos RTB, Tyskland. SINTEF Notat 102002420, 2013-04-03.
6. T. Berge: BIA MOVE: Statusrapport og forslag til videre arbeid. SINTEF Notat 102002420, 2013-06-06.
7. T. Berge: BIA MOVE: Testing av utstyr og status for videre arbeid. SINTEF Notat 102002420, 2014-02-04.
8. A. Solvang: BIA MOVE: Mikrofonarray - evaluering ved simulering. SINTEF Prosjektnotat 102002420, 2014-03-15.
9. T. Berge: BIA MOVE: Status for arbeidet med automatisk nummeregjenkjenning og oppslag i AUTOSYS. SINTEF Notat 102002420, 2015-01-08

### Media presentations:

1. 2013: GEMINI: <http://gemini.no/2013/02/er-bilen-din-en-sto-yversting/>
2. 2014: Teknisk Ukeblad: <http://www.tu.no/it/2014/06/26/her-prover-forskere-a-male-stoy-og-utslipp-pa-kjoretoy-i-fart>
3. 2015: Blogg - Acoustics Research Centre: <http://acousticsresearchcentre.no/category/nyheter/milak/>



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