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Description of a measurement campaign for the development and validation of a non-exhaust PM traffic emission model

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Contents

Summary

This document describes a measurement campaign intended to provide data for the further development and assessment of non-exhaust emissions and the models used to describe them.

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1 Motivation for the measurement campaign

Emission from non-exhaust traffic sources (road wear, break and tire wear, salting, sanding) is one of the major contributors to poor air quality in a number of Norwegian cities and towns and other Nordic countries as well as in Europe. Predicting these emissions, through the use of models, is a major challenge and has only been addressed to a limited extent. The application of models is necessary to provide complete territorial coverage of the emissions and to develop and assess air quality management plans. Recently, a generalized mass balance model for non-exhaust PM traffic emissions has been developed at NILU. This model is a representation of the various physical processes that lead to traffic induced non-exhaust emissions, in particular those related to road wear. As such, the model also represents the pool of available knowledge on these processes. To date, development and validation of the model has been based on existing monitoring data but this has been found to be insufficient to describe a number of the necessary processes.

To improve the model description of traffic induced suspension of road dust and salt, and to better understand the processes contributing to this, a focused measurement campaign is required. To this end a measurement campaign has been designed to address this issue. In order to fully realise the potential of such a campaign it is necessary to involve a number of stakeholders and institutes. Diverse expertise and instrumentation is required that NILU alone does not possess. This document outlines such a measurement campaign. It is hoped and intended that other institutes and authorities with an interest in this subject can contribute and enhance the campaign either with instrumentation, expertise or financing.

The results of the campaign will be used to establish the generalised mass balance model and its application in Norway and further in Scandinavia and Europe. The campaign will provide direct information on particle sources and processes, which is central to the good air quality management. Apart from the direct application of the results in Norway, the results will also be used and further disseminated through the EU project TRANSPHORM and the Nordic council of ministers project NORTRIP, both of which are due to start in 2010 and which deal in part or in whole with exactly this topic. Through these two projects NILU (and NIPH) will have access to expertise from other European institutes dealing with the same issue and it is intended that this timely interaction will generate even more knowledge on this topic.

2 Summary of the model

Before providing a description of the measurement campaign it is worth discussing the model itself as this also provides insight into the processes that are to be addressed. Previous modelling studies have generally relied on ambient air measurements to provide emissions factors for non-exhaust PM. The major problem with these models is that they lacked process descriptions, thus they not are used in management applications, and that they only provided emission factors for the local road conditions. Such models generally gave unsatisfactory results when applied under other conditions or for different road surfaces. To improve on this a more general model, providing a parameterised level of process description, is needed. The basis for such a more model concept is as follows:

1. It separates the PM emissions into direct and re-suspended emissions
2. It separates the road and road-shoulder into two different source areas
3. It uses road wear as the basis for the direct emissions
4. It includes both mechanical ejection and vehicle turbulence in the re-suspended emission description
5. Wear is dependent on surface conditions, vehicle speed, tire type and vehicle category
6. It includes the 'sand paper' effect where road wear is enhanced by mass on the road surface
7. It uses mass balance concept to accumulate mass on the road and shoulder surfaces including the addition of salt and traction sand and the removal by resuspension, drainage and cleaning.
8. It uses meteorological data and road and shoulder surface conditions (snow cover, temperature, wetness) to inhibit emissions
9. It uses parameterised forms for snow melt, drainage and drying of the road surface

Given the above characteristics of the model, a significant amount of new monitoring data is required to both develop and validate the model. Though some of these types of data have been gathered in the past, the generalized model makes use of new types of data that have previously not been used. In addition, the measurement of many of these variables has not been carried out simultaneously, making them unusable for model development or validation purposes.

As an example of how the model is formulated we provide a number of equations reflecting the model description.

To start with, we write the sum of the different PM emissions (from all sources, tire types and vehicle categories) for a given PM size category x as:

$$E(PM_x) = E_{direct}(PM_x) + \{E_{mech-road}(PM_x) + E_{turb-road}(PM_x) + E_{turb-shoulder}(PM_x)\}$$

For the case of direct emissions we write this as:

$$E_{direct}(PM_x) = \sum_{i}^{Source}\sum_{j}^{Tire}\sum_{k}^{Category}\sum_{m}^{Size} N_{i,j,k} \cdot W_{i,j,k}(V,T_s,w) \cdot f_{direct,i,j}(T_s,w) \cdot h_{m,i}$$

$$E_{direct} = Number\ of\ vehicles\ .Wear\ per\ vehicle\ .\ Fraction\ \ airborne\ .\ Size\ \ fraction$$

Where N is the number of vehicles, W the wear for the different sources (road, tire, break) and for tire and vehicle category types (studded, winter, summer and LDV, HDV), f is the fraction of the wear that is airborne (TSP) and h the fraction of the airborne particles in the size bin m.
For the case of resuspension due to turbulence this source can be written as:

$$E_{turb-road}(PM_x) = \sum_{k=1}^{Category}\sum_{m=1}^{Size} g_{turb-road,k}(V,T_s,w) \cdot M_{road} \cdot N_k \cdot h_{m,turb-road}$$

Where g is the fraction of road mass M that is resuspended per vehicle N. Similar formulas can be written for the other terms.
The road and shoulder mass is determined by the mass balance equations

$$\frac{\partial M_{road}}{\partial t} = Production_{road} - Sink_{road}$$

$$\frac{\partial M_{shoulder}}{\partial t} = Production_{shoulder} - Sink_{shoulder}$$

Where the *Production* and *Sink* terms for the road can be written as:

$$P_{road} = Road\ wear\ not\ emitted\ \{W - E(PM_{TSP})\} + \ Road\ wear\{sand\ paper\}$$
$$+ Deposition + Salting + Sanding$$

$$S_{road} = Road\ mass\ airborne\{E(PM_{TSP})\} + \ Road\ mass\ emitted\ not\ airborne\{E(PM_{>TSP})\}$$
$$+ Drainage + Cleaning + Ploughing$$

Similar production and sink terms can be provided for the road shoulder. The above description provides some indication of how the model is formulated and the needs of the model are reflected in the measurement campaign to be carried out.

3 Existing data sources and further model requirements

In regard to development and validation of the model there already exist a number of data sources. These include:

1. Road wear models (VTI) and literature to provide information on road wear (e.g. Jacobson and Wågberg, 2007; Carlsson et al., 1992: Lindgren, 1996; Muschack, 1990)

2. Measurement campaigns on road dust carried out by SINTEF and NILU in the 1990's (Hedalen, 1994; Larssen, 1987) that have investigated the effect of road cleaning on road mass and particle concentrations

3. Air quality, meteorological and traffic data available from previous campaigns. These include the Nordbysletta campaign (Hagen et al., 2003) and the RV4 campaign (Hagen et al., 2005)

4. Information concerning road surface conditions from a road surface monitor measuring at Kirkeveien (Aldrin et al., 2010)

5. A range of information in the scientific literature regarding the fractional size distribution of PM emissions and depositions (e.g. Snilsberg et al., 2007; Snilsberg et al., 2008; Hedalen, 1994)

6. Scientific literature regarding the functional dependencies of PM emissions (e.g. vehicle speed) (e.g. Hussein et al., 2008; Gustafsson et al., 2008;)

7. Scientific literature concerning the parameterisations used for drying, drainage and melting (Aldrin and Haff, 2005; Omstedt et al., 2005).

Currently the model is being compared to available data from the previous campaigns in Oslo and with the current resuspension model from NILU (Tønnesen, 2000). However, it is clear from these campaigns that there is insufficient information on a number of aspects to which the model is sensitive. These include:

1. Surface road conditions and the parameterisations for determining these

2. The actual wear of the road surface

3. The functional dependencies of the wear, e.g. on vehicle speed and vehicle category

4. The fractional size distribution of directly emitted and resuspended particles

5. The road and shoulder surface mass concentrations, distribution and balance

6. The contribution of salt, and other sources, to the total non-exhaust emissions

The campaign is intended to address these, and other, aspects in order to provide suitable data for model validation and further model development.

4 Outline and justification of the campaign

The campaign will be conducted at one major site, with intensive and concurrent measurements, and at two other minor sites where air quality measurements are already conducted but additional measurements and data collection will take place. The campaign at the major site will cover both summer and winter periods for a total measurement period of 6 - 12 months, dependent on the type of monitoring to be carried out.

4.1 Priorities

The campaign is divided into three levels of priorities as follows:

- **Priority 1:** Those measurements that will provide the basic and essential information needed for the model development

- **Priority 2:** Those measurements that will provide necessary additional information for the further development of the model or provide other information required for interpretation of the measurements. These extra measurements will provide more certainty than the P1 measurements alone

- **Priority 3:** Those measurements that provide added 'opportunistic' information that can be gained with minor additional costs, either for improved understanding of the traffic contribution or for other source contributions, e.g. wood burning

These priorities reflect the different levels or depth of the monitoring campaign. It is important to note that all measurements are intended to be made coincidentally irrespective of their priority. i.e. Priority 2 and 3 measurements are not intended to made a later stage but at the same time as the priority 1 measurements.

4.2 Needs

The choice of measurement data reflects the following major needs:

1. To relate road wear to the direct emission of airborne particles from the road surface

2. To relate road and shoulder mass concentrations 'dust loading' to the re-suspension of airborne particles

3. To provide information on the size distribution of these particles

4. To provide information on the effect of road surface conditions and meteorological conditions on the emissions of particles

5. To provide information on the sources of the particles

6. To provide information on the road mass balance of the particles, e.g. drainage, ploughing, salting, cleaning, deposition

The measurement campaign and instruments used will address these needs.

4.3 Paired air quality and turbulence measurements

The major monitoring site will consist of two identical air quality stations, placed opposite each other on either side (10 – 15 m) of a selected major road. Pairing of the sites is used to provide information on the road contribution, subtracting upwind measurements from downwind measurements. Experience from previous measurement campaigns carried out by NILU as well as from other intensive road traffic campaigns (e.g. BAB-2), has shown that it is essential to measure both upwind (background) and the downwind (additional road traffic contribution) with respect to airborne particulate matter. If this is not done then there will always be ambiguity in the measurements. In this regard street canyons sites can not be used as the recirculation and complex wind fields mean that both stations may be simultaneously sampling the road traffic contribution.
At each of these stations the following measurements will be made:

1. Size resolved particle number counting: for identification of sources and size distribution

2. Filter collection of PM samples: for calibration of the particle counters and for chemical analysis

3. NOx measurements: for calibration of emissions

4. Turbulence measurements: for dispersion modelling and for relating re-suspension to turbulence

4.4 Single measurements and sampling

In addition to the paired air quality measurements the following single measurements will be made at the major campaign site:

1. 10 m meteorological tower measuring wind, temperature, radiation and humidity will be erected in the near vicinity of the road.

2. Precipitation

3. Road surface conditions such as temperature, wetness and snow cover.

4. Road surface and shoulder particle sampling for mass, size distribution and chemical analysis

5. Deposition measurements of particles on a transect perpendicular to the road

6. Snow depth measurements

7. Drainage samples for particle concentrations

8. Traffic data including studded tire fraction
9. Measurements of road wear
10. Web based camera monitoring of the site

4.5 Additional minor site measurements

The minor sites will be based at existing measurement stations. Additional traffic and other related road surface measurements will be carried out at these. The additional measurements will include:

1. Traffic and road activity data
2. Road surface condition data
3. Road dust loading
4. Road wear measurements
5. Web based camera monitoring

4.6 Additional information

In additional to the in situ monitoring data, other data will also be acquired including:

1. Salt samples for chemical analysis
2. Information on salting activities including quantity and occurrence
3. Information on other road activities including cleaning, ploughing, sanding
4. Meteorological data from Blindern and Valle Hovin

4.7 Chemical analysis of samples

Ambient aerosol filter samples from air quality measurements, as well as samples from the road surface, snow, deposition and other collected samples, will be chemically analysed to provide information concerning their chemical profiles, enabling sources to be identified through receptor modelling.

4.8 Temporal resolution of the measurements

For a number of air quality and meteorological measurements a high temporal resolution is required for the following reasons:

1. To ensure that up-and downwind measurements are resolved
2. To ensure that the traffic variability and the associated turbulence and road dust emissions are resolved

Temporal resolutions of between 5 – 15 minutes are envisaged. This will be dictated to some extent by the techniques applied. We will use 5 minutes as a basis temporal resolution as this can always be aggregated as required. Other measurements, such as filter samples, cannot be made more frequently than every 12 hours and other sampling, e.g. road and deposition, may, have a lower frequency of sampling, from days to months.

4.9 Duration of the campaign

The duration of the campaign is an important parameter in regard to both cost and coverage of the various seasons. Ideally, the campaign should cover an entire year, but it may also be argued that the winter period is so important that two winters should be covered. In any case it is necessary for the campaign to cover as broad a range of conditions as possible including:

1. The autumn season before studded tires are introduced
2. The winter season with sub-zero temperatures
3. The spring season when melting and drying lead to high resuspension episodes
4. The transitional periods at the start and the end of the studded tire season
5. The summer season

If costs are to be reduced then the campaign can be carried out intermittently, where some automatic measurements are allowed to continue but other sampling, e.g. filter sampling, is stopped.

5 Detailed description of the major site measurements

The following section provides a more detailed description of the intended monitoring and data collection to be carried out at the major campaign site. Note that all air quality and turbulence measurements will be carried out at two sites situated on either side of the road. This is intended to provide background concentrations to assess the road contribution, whilst making the maximum use of all the available measurement data. To make this most effective, air quality, meteorological and turbulence measurements will be carried out at high temporal resolutions (5 minutes) where possible to guarantee up- and downwind contributions to the concentrations. These will be averaged over longer periods dependent on wind direction.
Within the following description each measurement activity is labelled depending on its priority as P1, P2 and P3. These priorities are described in the previous section.

5.1 Air quality measurements

The following air quality measurements are to be made. Their relevance and justification is indicated:

1. Size distributed number concentrations in the 0.3 – 25 μm range using optical particle counters (P1)

It is essential to provide size distributed information on the particles at high temporal resolution. The OPC instruments can provide high temporal resolution measurements of size specific particle numbers but do not by themselves provide mass information. These monitors must be calibrated to the filter measurements. Temporal resolution of 5 minutes.

2. Size distributed number concentrations in the 10 – 700 nm range using scanning mobility particle sizers (P1)

   In order to account for the contribution of exhaust and other fine particles the full range of particle size measurements are required. This will enable source apportionment and account for the sub-micron mass contribution. These results will also be useful for further health studies relating combustion sources to health effects. Temporal resolution of 5 minutes.

3. Daily filter measurements (manual) of PM_{10} and $PM_{2.5}$ (P1)

   Filter measurements are essential for two reasons. The first is to provide samples of PM for chemical analysis and subsequent source apportionment and the second is to calibrate the particle counters. Temporal resolution of 24 hours.

4. NOx measurements (P1)

   In order to convert from PM concentrations to PM emissions it is essential to have some form of emission tracer that can be used. Emissions of NOx have the lowest uncertainty of any emission source from traffic and these can be used to infer PM emissions form measured concentrations. The alternative is to use dispersion models but these models themselves are usually validated against NOx emissions. The temporal resolution of these measurements should correspond to the particle counting resolution of 5 minutes.

5. Daily filter measurements (manual) of PM1 mass (P2)

   PM_1 measurements wil improve the calibration of the particle counters and provide important information on the mass contribution from sub-micron particles, allowing a clear delineation between road dust and combustion sources. Chemical analysis of the PM_1 filter samples is intended as a third priority (P3). Temporal resolution 24 hours.

5.2 Meteorological measurements

The following meteorological data will be collected.

1. 10 m tower measurements of standard meteorological data such as wind speed, direction, temperature, global radiation and humidity (P1).

   Meteorological data will be gathered from a 10 m mast within close proximity to the air quality measurements but only on one side of the road. Temporal resolution of the logged data will be 5 minutes.

2. Precipitation data (P1).

   Precipitation data will be measured locally at an hourly resolution using tipping bucket measurements

3. Turbulent fluxes (P1)

   Sonic anemometers will be placed close to each of the air quality monitoring sites. These sonics will provide turbulent flux and turbulent kinetic energy measurements necessary for an accurate application of dispersion models and most importantly to provide data to relate re-suspension of materials to turbulent kinetic energy generated by traffic. Raw data at 20 Hz and 5 minute averages, corresponding to the air quality data averaging period, will be logged.

5.3 Sampling measurements

A number of in situ samples will be made during the campaign. Most important of these is the sampling of road and shoulder dust loading (mass available on the road and shoulder surface). The dust loading is a prognostic variable of the model and these measurements will provide important information for validation and process studies. The following measurements are envisaged.

1. Road and shoulder dust loading (P1)

   Measurements of the road dust loading will be carried out. These measurements will provide estimates of the amount of mass on the road surface. The measurements will be carried out regularly but mostly under dry conditions using wet vacuum sampling techniques. Samples will be collected, dried and weighed to determine dust loading. Chemical analysis of selected samples will be carried out to identify chemical profiles for use in receptor modelling (P2). Measurements will take place outside of peak traffic conditions, requiring the closure of single lanes or temporary cessation of traffic flow.

2. Particle deposition measurements (P1)

   To provide information on the road dust mass balance horizontal profiles, perpendicular to the road, of particle deposition will be carried out using deposition instruments and also snow sampling (when appropriate). 5 deposition samplers will be placed on either side of the road out to a distance of 50 m and samples will be collected on a weekly basis

3. Salt samples (P1)

   Samples of salt used for road salting will be taken from the depot from which they are distributed. Several samples will be taken during the winter period to assess any variations. These samples will be chemically analysed to provide chemical profiles for salt source apportionment.

4. Road cleaning samples (P2)

   As part of the normal road salting and cleaning activities carried out by the traffic authorities many road surfaces are regularly cleaned and/ or salted in Oslo (2 – 3 times per week/month). Such cleaning will also occur at and in the vicinity of the campaign site. The dust and salt collected from this cleaning can be weighed, by weighing the contents or the entire cleaning truck before and after the cleaning, to provide information on the mass deposited on the surface. These samples may also be analysed to *determine the proportion of salt, road dust and other constituents in the samples, as with the road and shoulder dust sampling.*

5. Drainage water samples (P2)

   The degree to which particles are drained from the road surface will vary dependent on the drainage capacity of the road. In order to provide estimates of the mass of dust drained from the vicinity of the road, samples will be taken when appropriate of runoff from the site. The samples will be analysed for dust mass and salt content.

5.4 Chemical analysis of filter samples

An essential part of the monitoring campaign is to determine the sources contributing to the ambient particulate matter loading at the measurement site. The number of sources can be substantial, including traffic related sources such as road surface, tires, breaks, exhaust, salt, sand and gravel, as well as PM from long range transport, wood burning, industry, and various natural sources, which all can be deposited on the road surface through dry or wet deposition processes. Though some of these sources can be separated to some degree by size distribution alone (e.g. direct exhaust and road dust emissions), receptor modelling techniques are needed to identify and apportion the various contributing sources. Thus, a broad chemical and physical characterisation of the collected filter samples is needed to provide the necessary input to the receptor model. Notably, source receptor modelling provides source categories rather than individual emitters.

Some elements and chemical species are associated with PM from various sources, although in various quantities, while others are more specific with respect to which source they originate from. By including highly source specific samples a better separation of the sources can be obtained. Unfortunately, such tracers are not available for all sources. Further, there is a limitation with respect to how many elements and chemical species can be obtained from one filter sample, as not all can be obtained by one method and since the various methods have different requirements with respect filter quality and so forth. In addition, the uncertainty of the data will increase if the available filter material is distributed amongst too high a number of different analytical methods. Thus, a careful selection of which analyses to be performed would have to be made. Alternatively, additional filter samplers could be recruited.

In the present study we will use Inductive Coupled Plasma Mass-Spectrometry (ICP-MS) for element analyses. While several elements will be quantified in the filter samples, aluminium (Al), calcium (Ca), iron (Fe), Manganese (Mn), and titanium (Ti) will be particularly important with respect to apportioning the mineral dust content of road dust. Copper (Cu), zink (Zn), cadmium (Cd), antimony (Sb), barium (Ba), and lead (Pb) are all associated with wearing of brake lining, but not exclusively; e.g. Zn constitutes a substantial fraction of car tires as well as being entitled by wood burning. Molybdenum (Mo), Strontium (Sr), Chromium (Cr), and Nickel (Ni) are all present in vehicle exhaust.

The most important element in the Earth's crust Silicon (Si), and thus an important element to allocate road dust, cannot easily be analysed using ICP-MS. For this purpose PIXE appears to be the most likely choice, but such samples would have to be analyzed in another country than Norway and in addition, different filter quality most be applied. Thus, if Si were to be included, an additional sampler loaded with nucleopore filters would have to be added to the monitoring program. For these reasons Si will not be included in the analysis.

Thermal-Optical Analysis (TOA) will be used to quantify the particles content of elemental carbon (EC) (soot) and organic carbon (OC). EC is exclusively associated with incomplete combustion of fossil fuel and biomass, while OC additionally originates from various natural sources.

The major inorganic anions, SO_4^{2-}, NO_3^-, Cl^-, and cations Ca^{2+}, Mg^{2+} , NH_4^+, Na^+, K^+ will be analyzed using ion chromatography (IC). Na^+, Cl^- and Mg^{2+} are rather specific with respect to sea salt, which both have a natural origin (sea spray) and which is added on the road surface in winter. SO_4^{2-}, NO_3^-, and NH_4^+ are the hallmark of long range transported PM.

The highly source specific tracer of biomass burning PM emissions levoglucosan will be analyzed using High Performance Liquid Chromatography in combination with High Resolution Mass Spectrometry (HPLC/HRMS).

The Presence of N-cyclohexyl-2-benzothiazolamin (NCBA) in PM has been suggested as a specific tracer associated with tire wear, while hopanes and steranes have been linked to exhaust from diesel and gasoline vehicles; these species will be considered for analysis given sufficient PM loading on the filter samples but they are not currently included in the overall budget.

In additional to gravimetric measurements of the filters, the following filter samples will be analyzed by ICP/MG. IC,TOA and HPLC/HRCMS.

1. PM_{10} filter samples (P1)

   All samples to be measured gravimetrically for mass. To reduce costs only half of the samples, to be selected, to be analyzed chemically. Levoglucosan to be measured as P2.

2. $PM_{2.5}$ filter samples (P1/P2)

   All samples to be measured gravimetrically (P1) for mass. To reduce costs only half of the samples, to be selected, to be analyzed chemically (P2). Levoglucosan to be measured as P2.

3. PM1 filter samples (P2/P3)

   All samples to be measured gravimetrically (P2). To reduce costs only half of the samples, to be selected, to be analyzed chemically (P3).

5.5 Chemical analysis and size distribution of other samples

A number of in situ and other samples will be made during the campaign. These include:

1. Road samples, ground samples taken from the road surface itself (P1)
2. Road and shoulder dust loading (P1)
3. Particle deposition measurements (P1)
4. Salt samples from the depo (P1)
5. Drainage water samples (P1)

These samples will also require chemical analysis to establish the chemical composition of the road surface itself, the road dust that can potentially be resuspended, including its salt and EC/OC content to establish the level of bound salt and exhaust particles on the road dust loading (P1).

The aim of this is to identify the chemical profiles of these sources, improving and enabling the source apportionment studies to be carried out on the ambient air concentrations. This will potentially enable us to differentiate between direct emissions of road dust and resuspended road dust.

In addition to the chemical sampling of these samples the road and shoulder dust and deposition measurements may also be analysed to determine the size distribution of the measurements. This can be achieved using the Coulter LS 230 particle counters available at NTNU/SINTEF, range 0.04-2000 µm. Because it is not clear if the particle sizes measured remain representative of the in situ dust after collection and treatment these measurements have priority P2. However, the information obtained from these will be important for assessing the processes leading to re-suspension.

5.6 Traffic data and measurements

Essential to the campaign are data concerning traffic volume, traffic speed, vehicle category and vehicle tire type. All these data are required at time resolutions equivalent to the monitoring data. To achieve this, a traffic counting station will be established close to the campaign site. Data from this traffic counting will provide information on volume, speed and vehicle length in all possible lanes of the road at a temporal resolution of 5 minutes.

In addition to this, information on the fraction of studded and non-studded tires is required, as well as that of summer or winter tires. Though acoustic measurements can be applied under dry conditions to assess the number of vehicles with studied tires this method is not considered to be reliable under wet conditions. To determine the percentage of cars with studded tires passing the monitoring stations manual counts will be instigated for short periods (30 – 60 minutes) of passing cars at regular intervals. During the transition season from summer to winter and winter to summer tires, counts will be made every day. Outside of these periods counts once a week will occur.

All these measurements are of priority P1.

5.7 Road surface condition measurements

The Norwegian road traffic authorities currently possess a number of road surface and meteorological stations. These stations measure surface and sub-surface temperatures, wind speed, relative humidity, surface wetness and surface conductivity. Many of these measurements, however, duplicate the meteorological mast measurements. The two most important measurements that are needed from these road meteorological stations are the surface temperature and surface wetness (including snow or ice cover). Surface temperature may be measured directly using probes or by using long wave radiometers. These products are commercially available.

Past experience with the road surface stations indicates that the measurements of surface wetness are not sufficient for determining the cohesive nature of the road surface particles. An alternative measurement of road surface and dust loading wetness is therefore needed. This can be achieved through direct sampling of the road and shoulder dust loading that can easily be assessed for water content by weighing and drying in the laboratory. These samples will be taken once or twice a day during periods after rain to assess the rate of drying of the shoulder. These measurements have priority P1.

However, measurements of higher temporal resolution concerning road wetness are also needed. At the time of writing it is not clear how this can be done but a number of probe and optical systems are commercially available for measurement of soil humidity. These measurements have priority P2.

In addition a web cam will be installed for the continuous monitoring of the site to provide indicative information on road wetness and snow cover. See section 5.9.

5.8 Road wear and other road activities

Essential to the model are measurements of road wear since this is the initial source of most of the non-exhaust particulate matter. Though road profiles are regularly measured throughout Norway these measurements, made using a laser scanner, will contain both road wear (caused by heavy vehicle traffic and studded tires) and road deformation (caused chiefly by heavy vehicle and poor traffic flow). Though it is possible to minimise the impact of deformation on the road profile by siting the experiment in a non-congested and low heavy vehicle road, these aspects are required to obtain a range of traffic conditions and traffic fleet compositions for assessing their impact on particle emissions.

SINTEF has previously used, and also currently possesses, a horizontal beam ’rettholtbjelke’ instrument for measuring the road surface profile. In order to effectively use this instrument copper bolts are inserted in regular intervals across the road, into the road surface, and these are used as reference points, assuming they do not deform with the surface. The total mass lost can then be calculated by integration over the arm distance (4 m), which will not include deformation. Preliminary calculations show that over a month period roughly 1 mm of road will be worn from the surface in the tire track region. This loss of around 1 kg from the surface should be measurable with the instrumentation.

To effectively use this instrument 3 different lines of bolts will be set into the road surface in the summer prior to the campaign. Measurements will be carried out on a monthly basis during winter and every 2 -3 months in summer. Total number of measurements will be around 8.

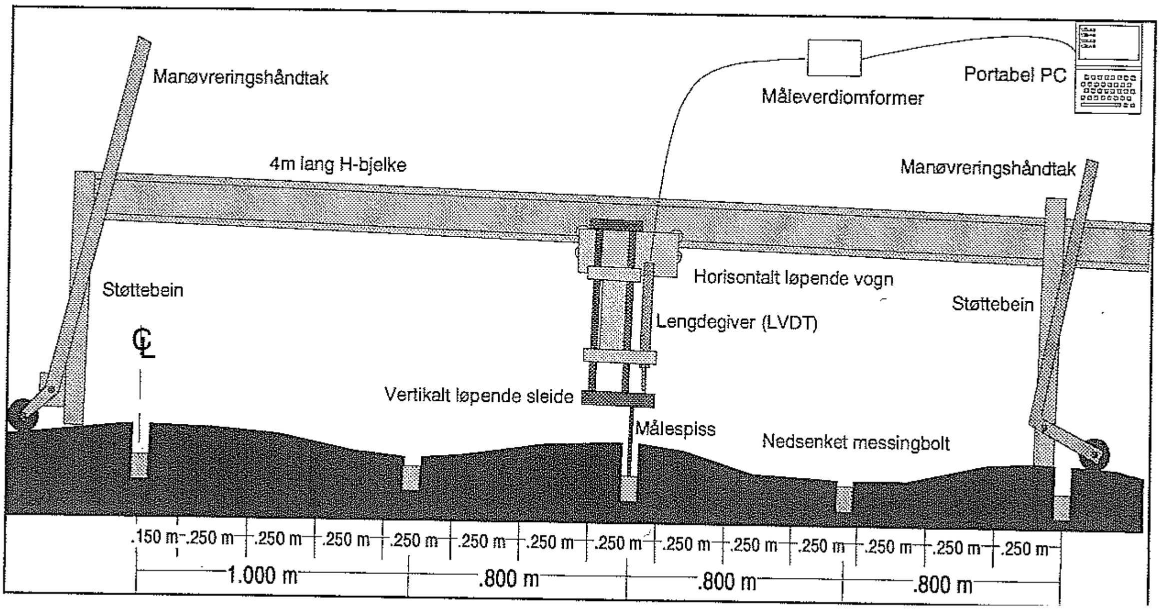

Figure 1: Illustration of the horizontal arm measurement instrument for measuring road wear.

In addition to the wear data, information concerning the timing and quantity of salting activities is required as well as ploughing and cleaning. Such data will need to be made available through the traffic authorities who contract these out or must be derived from the webcam.

The following information concerning salting and cleaning was received from Vegvesen:

> *"Slik feiing foregår i Trondheim og Oslo skjer dette om natten før ny mengde med magnesiumkloridløsning (22 %) legges ut. Se bilde av støvet som er feid opp i Oslo. Det har jordaktig konsistens pga saltet. Detteretter legges det salt ut etter behov. Det skjer 2-4 ganger pr uke. Feiing skjer 2-4 ganger pr måned. Har det regnet mye sløyfes feiing. Saltet legges primært på vegkant. I Oslo brukes ca 30 % magnesiumkloridløsning (22 %) sammen med veisaltet som standard resept i vinterdriften. I tillegg kommer støvdempingen."*

Figure 2: Showing the stock pile resulting from road cleaning in the winter in Oslo.

5.9 Webcam placement

A digital camera will be installed to overview the site. The camera should be positioned so that:

1. all the road is visible
2. street lighting makes it possible to discern wet and dry periods
3. precipitation events can be identified
4. the meteorological and measurement stations are visible
5. it has a sampling frequency that makes it possible to identify specific activities on the road such as salting and ploughing.

The camera output should be accessible during the entire measurement period through the web and the data should be logged with the required frequency (approximately 1 - 0.5 Hz). The camera will be used to support the road surface condition measurements, to identify salting and ploughing activities, precipitation events and to identify problematic situations (e.g. congested roads, stoppages or vandalism).

5.10 Micro-siting of the stations

The micro-siting of the stations should be as follows:

1. Stations should be placed at a distance approximately 10 – 15 m from the kerbside directly opposite, or close to opposite, each other on the road.
2. Intake for air quality measurements at approximately 3 m.
3. Meteorological measurements at 10 m (wind, radiation) and at 2 - 4 m (temperature, humidity). These measurements should to be carried out on a separate tower several 10's of meters from the air quality measurements, if possible in open terrain.

4. Sonic anemometer measurements of turbulence to be made at a height of 3 – 5 m at the same distance, or closer, from the road as the measurement stations. These measurements, if possible, should be some distance (5 – 10 m minimum) from the air quality stations parallel to the road to avoid interference from the air quality stations.

5. Deposition measurements should be carried out at 2, 4, 10, 20 and 50 m from the kerbside if possible.

5.11 Site selection

Currently no specific site has been nominated. The following criteria should apply:

1. Flat and obstacle free on both sides of the road for several 10’s of meters

2. Have traffic of variable volume and speed

3. Have a sufficient volume to reduce stochastic uncertainties in the measurements and to have a significant share of HDV’s

4. Have available power sources on both sides of the road

5. Is expected that road salting , cleaning and snow ploughing will be carried out

6. Have a relatively new road surface with known asphalt type

7. Not be more than 2 lanes in either direction and no exists near measurement station

8. Be at a significant distance from other major road sources

9. Flat road shoulder area

Some suggested sites include:

- Kirkeveien where a large number of measurements have already taken place (Though this site is far from optimal in regard to an open terrain).

- RV22 in close proximately to NILU

6 Description of the minor site measurements

In addition to the major campaign site it is necessary to carry out a number of selected measurements at other sites in order to assess the representativeness of the major campaign site. This will be achieved by enhancing already existing air quality measurement sites with extra traffic and road monitoring capabilities. The aim is to provide the same level of traffic and road activity data as for the major site, to assess if the measured concentrations at these other sites also reflect the same characteristics.

Two traffic sites (to be selected) where PM_{10}, $PM_{2.5}$ and NO_X are already being measured as part of the regular activities will be used. In addition to these air quality measurements, the following sampling will take place:

1. Traffic data as for the major site
2. Monitoring of road surface condition data as for the major site
3. Data on salting, ploughing, cleaning as for the major site
4. Road wear measurements as for the major site
5. Road dust loading measurements as for the major site
6. Webcam as for the major site

In addition to these two selected traffic sites, air quality data will also be collected from the other sites in Oslo.

7 Calibration and inter-comparison of the instruments

Calibration of a number of the individual instruments against standards will be carried out in the laboratory both before and after the measurement campaign. Calibration of the NOx measurements will occur in the field at regular intervals as well as calibration of the filter flow.

In addition to these standard calibration procedures, the major measurement stations will be placed along side each other for 1 week in both a summer and a winter period for calibration and comparison. Sonic anemometers and wind and temperature measurements will be placed at concurrent heights for comparison over the same period. PM measurements using filter, OPC and DMPS will be inter-compared. This extra set of quality control measurements is essential to determine the inter-comparability of the measurements, particularly since they will be used as paired stations where it is necessary to know the uncertainty in the difference of the measurements.

8 Management, quality control and reporting

For such an extensive campaign, potentially involving a number of partners, good management is required. In this regard 4 person months are set aside to ensure that preparations, monitoring, logistics, quality controls are in place for an efficient and effective completion of the campaign.

The measurement campaign outlined above will also provide a large and extensive dataset. Quality control of these data is required. Some of these monitoring data, e.g. filter samples and NOx monitoring, are quality controlled within the monitoring price. However, other data relating to particle counting, to traffic counts, to road surface measurements require further quality control and calibration. In particular the, conversion of particle counts to particle mass using filter data requires significant attention. In addition to these controls, databases for the monitoring campaign are required if these data are to be efficiently and effectively retrieved for further analysis. 3 person months have been set aside for these activities with additional time if P2 and P3 activities are undertaken.

Due to the extent of the project, extended reporting will be expected. This will come in two phases. The first set of reports, delivered after the completion of the campaign, will contain an assessment of the general success and data retrieval of the campaign. Indicating where data was lost, where data may be of low quality and where interesting events or periods occur for further analysis. The second phase of reporting will come at the end of the project after a more in depth analysis of the data has taken place. 3 person months have been set aside for this reporting. This does not include the analysis itself.

9 Analysis and application of the results

The measurement campaign outlined above will provide a large and extensive dataset. Quality control, analysis and application of the dataset is then required. Data from a successful campaign will generate a significant body of data, which must be assessed and analysed to provide the best possible result for the project. The analysis will be divided into the following elements:

1. Overall assessment of the campaign, identifying data distribution and gaps and providing information for the first phase reporting.

2. Statistical analysis of the data providing a more in depth representation of the relationships between the data collected.

3. Source apportionment using receptor modelling. Based on the size distribution profiles, the filter sample chemical analysis and the in situ sampling chemical analysis, receptor modelling using UNMIX, PMF and COPREM will be carried out. The aim of this activity is to identify sources such as salt, tires, breaks, directly emitted road dust, resuspended road dust, exhaust and other urban and regional background contributions to the ambient PM concentrations. As P1, 3 person months is set aside for this activity with an increase of 50% for P2 and 25% for P3.

4. Assessment and interpretation for modelling. This last data analysis post is of the utmost importance since the campaign is intended for providing input for the further development of the models. The results will be used to provide information for model parameterisations and to enable the validation of the model on a number of aspects. The model can then be verified against other data retrieved from the minor stations. This activity is expected to take several months. 10 months are set aside for this work, divided between the priorities P1, P2 and P3.

5. Publication in scientific journals, conference proceedings and popular scientific articles is required if the information gathered is to be disseminated to a wider public. Currently 5 months are allocated to this activity in priorities P1, P2 and P3. Given a successful monitoring

campaign the number of publications resulting will be significantly more than the time indicated.

10 Work plan for the project

For the current work plan there are two different starting dates, depending on when funding can be made available for the measurement campaign. The two periods we envisage are:

1. the measurement campaign will start in the summer of 2011 and finish in the summer of 2012.

2. the measurement campaign will start in the autumn of 2011 and finish in the autumn of 2012.

The following work plan is based on the first of these two possibilities. The duration of the project will be 2 years.

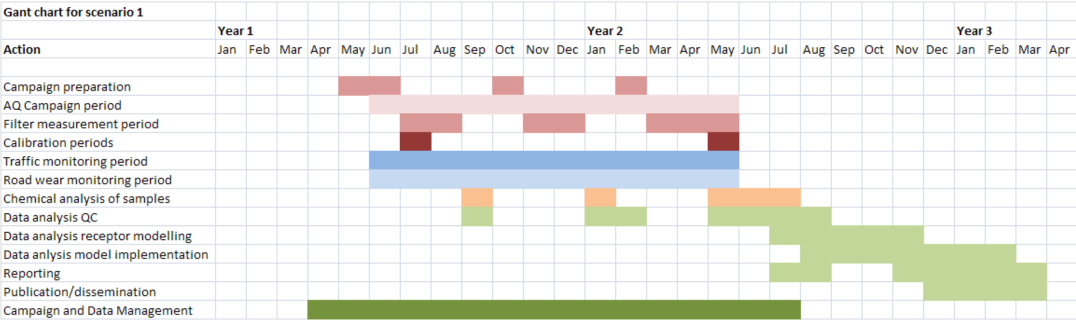

Figure 3: Work plan for the measurement campaign starting in April for two years.

11 Budget summary and scenarios

The complete budget breakdown is provided in the accompanying excel sheet but the summary of the budget is provided here. The budgets for the individual Priority measurements are divided and the major posts are also provided. All costs are in Norwegian Kroner.

Table 1: Budget breakdown for 12 month measurement campaign with 6 months of filter sampling. This is also contained in the accompanying excel worksheet.

Summary budget	P1 Total cost	P2 Total cost	P3 Total cost	P1 + P2 + P3 Total cost
Air quality measurements	886104	18876	0	904980
Meteorological measurements	252000	0	0	252000
Sampling measurements	393776	44352	0	438128
Chemical analysis	783840	1166400	433800	2384040
Traffic data	72000	48000	0	120000
Road and shoulder surface data	88800	48000	0	136800
Road wear and other activities data	628000	392000	0	1020000
Labour costs (measurements and QC)	1790920	83160	0	1874080
Total monitoring costs (including related labour)	**4895440**	**1800788**	**433800**	**7130028**
Labour costs (annalysis and reporting)	2419200	1783560	562224	4764984
Total costs	**7314640**	**3584348**	**996024**	**11895012**

The costs in Table 1 are shown graphically below:

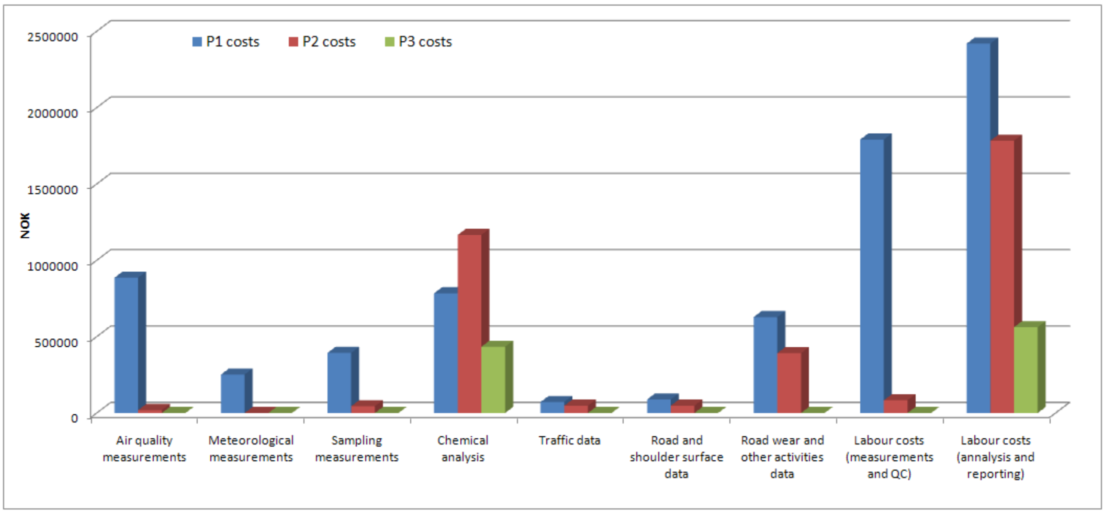

Figure 4: Graphical representation of budget breakdown (Table 1) for 12 month measurement campaign with 6 months of filter sampling and subagents reporting. This is also contained in the accompanying excel worksheet.

The breakdown of the individual costs are shown graphically below:

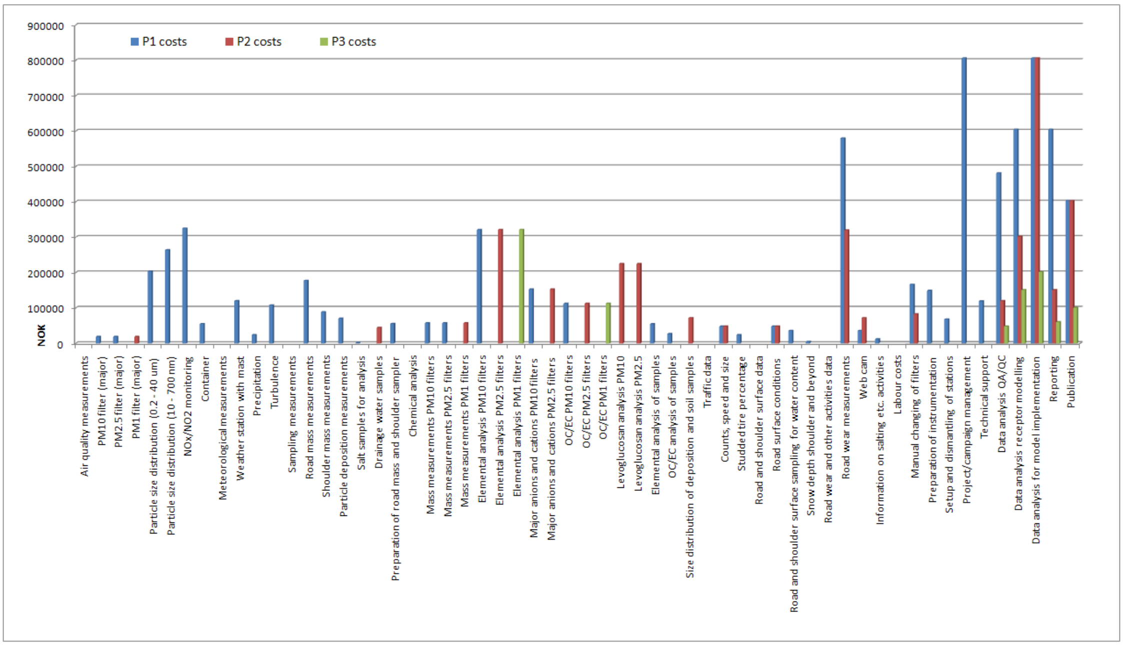

Figure 5: Graphical representation of the detailed budget breakdown contained in the accompanying excel sheet for 12 month measurement campaign with 6 months of filter sampling. This is also contained in the accompanying excel worksheet.

11.1 Uncertainties in the budget

There are currently a number of uncertainties in the budget. Those costs that are not well defined are labelled in the accompanying excel sheet as ‘Estimated’.
In addition to these uncertain costs there are always unknown foreseen or unknown costs associated such as damage to the instruments, logistic costs not included such as electrical power connections and costs related to instrumental failure.

11.2 Measurement period scenarios

The following table shows the ‘total monitoring costs (including related labour)’ for a selection of alternative measurement period scenarios using the priority P1. The costs presented in table 1 are indicated in grey.

Costs (NOK)	**Total measurement campaign period (months)**		
Filter campaign period (months)	6	12	18
3	3628060	4442404	
6	4081096	4895440	5709784
12		5801512	6615856

12 Financial support

The costs of the monitoring campaign and associated analysis and reporting of the results are significant. For this reason multiple funding sources are required to support the project. The following sources should be considered:

1. Klif (The Norwegian Climate and Pollution Agency)
2. Statens Vegvesen (The Norwegian Public Roads Administration)
3. Oslo kommune (City of Oslo)
4. NILU (The Norwegian Institute for Air Research)
5. NFR (The Research Council of Norway)
6. MD (The Norwegian Ministry of the Environment)
7. The car industry
8. The European Commission

Given the extent of the measurement campaign any applications or requests from funding sources or administering institutes cannot be realistically provided before 2011. i.e. request must come in 2010.

13 Concluding remarks

This report provides a description, justification and a budget for a measurement campaign to provide the required data for improved modelling and understanding of the processes leading to non-exhaust emissions from traffic. The campaign will provide a significant step forward in understanding non-exhaust PM and will provide leading edge scientific data on this phenomenon. Implementation of the results in a process based road dust emission model will provide the necessary information and tools for assessing the impact of these emissions in a much wider region and will provide the tools for developing realistic mitigation scenarios in regard to PM.

The campaign has been divided into 3 levels of priority. The first level of priority is considered to be the minimum ambition for the campaign. The total cost of the P1 campaign has been determined to be approximately 7.3 MNOK.

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AUTHOR(S) Bruce Denby, Karl Espen Yttri, Steinar Larssen, Markus Fiebig, Claudia Hak, Janne Berger, Kjersti Tørnkvist	CLASSIFICATION * A CONTRACT REF.

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ABSTRACT
This document describes a measurement campaign intended to provide data for the further development and assessment of non-exhaust emissions and the models used to describe them.

NORWEGIAN TITLE

Beskrivelse av en målekampagne for utvikling og validering av en utslippsmodell for trafikkforurensning av PM_{10} ikke relatert til eksos.

KEYWORDS		
Road dust emission	Measurement campaign	PM_{10}

ABSTRACT (in Norwegian)

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