Elemental carbon as an indicator to monitor the effectiveness of traffic related measures on local air quality

M. H. Voogt, A. R. A. Eijk, M. P. Keuken & P. Zandveld
TNO, Netherlands Applied Research Organisation, The Netherlands

Abstract

Even when European standards on air quality are met, health effects occur near busy roads because of the increased exposure to tailpipe emissions. For a proper assessment of these effects, an additional indicator is available: elemental carbon (EC). This is a sensitive indicator for particulate matter from combustion emissions by road traffic. Currently, the concentrations of EC along busy roads are still significantly increased relative to the background, in contrast to PM_{10} and $PM_{2.5}$. Therefore, the effectiveness of traffic measures on local air quality and associated health effects can be better assessed with EC than with PM mass. This paper discusses the relevance of EC as an indicator in the assessment of air quality and health. This is illustrated with two pilot studies in the Dutch cities of Arnhem and Helmond where traffic measures were evaluated with EC measurements. Also model calculations of the effect of 80 km/h speed limit zones on Dutch motorways on the health risks of local residents are presented. It is concluded that the assessment of EC through monitoring and/or modelling is a powerful policy instrument to analyse the impact of local traffic measures on air quality and health. Typically, people living close to busy road transport may live 1 to 6 months longer when measures like enhancing traffic flow, speed limiting and environmental zoning are implemented.
Keywords: EC, traffic measures, health, measuring, modelling.

1 Introduction

Authorities implement traffic measures in order to improve the accessibility and quality of the urban environment. Examples of such actions are: volume measures to reduce inner city traffic e.g. by parking policy and encouraging cycling and

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public transport; environmental zoning; speed-limiting measures on urban highways; and traffic flow measures such as “green waves” on urban roads. Model calculations can provide insight into the effectiveness of most of such measures on air quality based on emission factors by vehicle category and speed regime. Regarding PM_{10} or $PM_{2.5}$ the effects of traffic measures are relatively small, since traffic emissions contribute only to a small extent to the total concentration. For EC on the other hand, traffic is the major contributor along urban roads. Therefore, effects of traffic measures are more pronounced for EC.

EC emission factors can be derived from the emission factors for $PM_{2.5}$ [1]. In combination with population data, the exposure to EC concentration can then be determined. Also, an assessment can be made of health effects by expressing the concentration differences in gain (or loss) of life years.

For local measures aimed at improving the traffic flow, it is quite difficult to calculate the effects on EC concentrations. The actual effect of a "green wave" on the traffic flow at a given location is difficult to predict. Also, since the effects on driving dynamics are not well known, the impact on local exhaust emissions can not be modelled accurately. To gain insight into the effectiveness of local traffic flow measures on air quality, measurement campaigns can be of help.

This paper describes two pilot studies where traffic measures were evaluated with EC measurements. In section 2, the study approach is discussed. Section 3 describes the results from two pilot studies based on monitoring in the city of Helmond and Arnhem. In section 4 a modelling exercise regarding the effects of an 80 km/h speed zone at the motorway around Rotterdam is presented. This paper is concluded (section 5) with some insight into the health effects of traffic measures that can be derived from the EC assessment.

2 Study approach of measurement campaigns

During the measurement campaigns hourly average concentrations of EC (actually its surrogate black carbon) were measured with MAAP monitors (Multi Angle Absorption Photometer model 5012). Measurements took place both near the road or crossing of interest and at a background location. In addition, real time data on wind direction and speed and traffic intensities by vehicle category were collected. On the basis of the prevailing wind hours were selected during which the monitoring location near the road was actually influenced by traffic emissions. For these hours the contribution of the traffic to the concentration of EC ("traffic contribution") was derived from the difference between the measured concentration at the traffic location and the background location.

During part of the measurement campaign the traffic flow measure was in force. This is referred to as the “implementation situation”. The other part is characterized as the “reference situation”. When the average traffic contribution during the implementation situation is less than that during the reference situation, there is a positive effect on air quality on the monitoring location. However, in addition to the measure, there are also other factors that account for changes in the traffic contribution. This concerns the variation in traffic volume and composition and the meteorological conditions. A simple modelling approach (linear scaling) was used to correct for these variations. In that way, misinterpretation of the effectiveness of the traffic flow measure on the local air quality is prevented.

3 Monitoring pilot studies

3.1 Helmond: different traffic control schemes at an inner urban junction

Commissioned by the SRE, a cooperation of municipalities in the city region of Eindhoven, TNO conducted a measurement campaign to study the impact of two different traffic control schemes at a T-junction in the city of Helmond on the local air quality. The campaign lasted for 2 months and was carried out in the autumn of 2010. During the campaign, both schemes were alternated on a daily basis. One scheme aims at optimizing the traffic flow on a local level: stop times of traffic on all three directions are minimized. The other scheme aims at optimizing the traffic flow on the two directions that are part of the main road through the area: on the specific T-junction local traffic may be delayed. The object of the experiment was to investigate whether differences in traffic contribution to the local air quality between the schemes would occur at all and not to qualify the "best" scheme. The latter can not be assessed by measurements on a single location only.

In the vicinity of the T-junction a suitable monitoring location was found (see photo in Figure 1). The location is influenced by traffic at southern wind directions. In the area south of the junction, the background monitoring location was set up.

Figure 1: Monitoring location at the T-junction in Helmond (map: Google, photo: TNO).

After analysis of the measurement data including the correction for variation in traffic and meteorology, the following was concluded for weekdays between 7 a.m. and 21 p.m.: the differences in the traffic contribution to the concentration of EC at the monitoring location between the traffic control schemes are in the order of 20%. A first (limited) analysis of queues during peak periods gives confidence that the EC differences are indeed related to differences in the traffic flow (or "non-flow") at the junction. A supplementary analysis of differences in the traffic flow needs to be carried out.

3.2 Arnhem: measures to enhance traffic flow at a busy provincial road

In 2010 measures to enhance the traffic flow on the provincial road N325 near Arnhem were implemented. The measures include widening of the road and connecting traffic control installations at the N325. Also, the traffic control installations at the connection of the N325 with the highway A12 were introduced to the network.

Commissioned by the province of Gelderland TNO conducted a measurement campaign to study the impact of these measures. At the provincial monitoring location along the N325 (see Figure 2) and in the neighbourhood to the north (background location) EC concentrations were measured.

Figure 2: Monitoring location at the N325 in Arnhem (map: Google, photo: TNO).

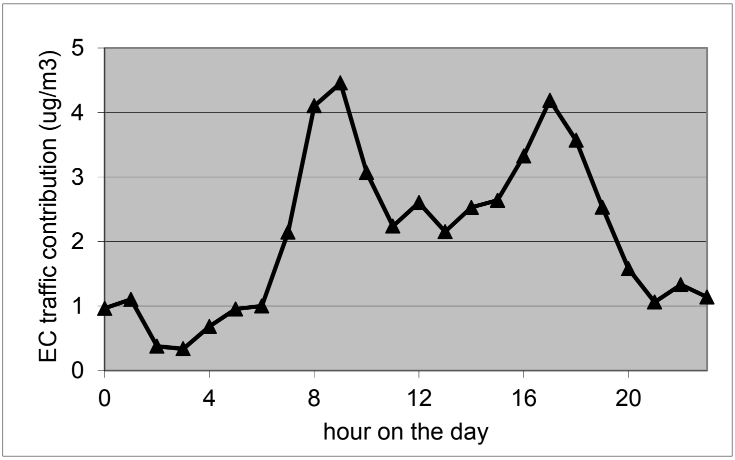

Figure 3: Average diurnal traffic contribution to the EC concentration ($\mu g/m^3$) at the provincial road N325 in Arnhem during the reference period (February-March 2010).

In February and March 2010 reference measurements were carried out. They are representative of the former situation. The average diurnal concentration of the traffic contribution to the EC concentration is given in Figure 3. This shows the strong relationship between traffic emissions and EC: morning and evening rush hour traffic peaks coincide with peaks in the EC concentration.

From January until April/May 2011 EC measurements in the new situation were carried out. A preliminary analysis of the EC measurements yields a decrease of the traffic contribution to the EC concentration in the order of 20 to 30%.

In this case, the correction for variation in meteorology (wind speed) plays an important role in the (preliminary) outcome. Actually, measurements of just the traffic contribution to the EC concentration during the reference and implementation period were not that much different. However, the wind speed during the implementation period was significantly lower. The traffic contribution to the EC concentration is inversely proportional to the wind speed. Therefore, had the wind speed been similar to the reference period, the EC concentration contribution during the implementation period would have been significantly lower.

4 Modelling exercise

On motorways through urban areas of the Hague, Utrecht, Amsterdam and Rotterdam 80 km/h speed limit zones with strict enforcement are implemented. These zones aim to protect residents along these highways against air pollution and noise. Recently questions about the usefulness and necessity of the 80 km/h zones have been raised. Therefore we investigated its significance for the health of the residents along the 80/h km zone in Rotterdam. With the URBIS model [2], we calculated the difference in EC concentrations with and without the 80 km/h speed limit for the existing 80 km/h zone in Rotterdam and for the whole ring road around Rotterdam. The result of this calculation for 2008 is shown in Figure 4.

Figure 4 shows that through the 80 km/h zone the EC concentrations decrease up to a maximum of 0.5 $\mu g/m^3$ depending on the distance to the highway and the traffic composition. For residents along the current 80 km/h zone in Rotterdam, the risk of premature death decreased by 1-3 months for 2,500 people and with 0-1 month for 6000 people. These health effect calculations are based on relationships between long term exposure to EC and premature mortality derived in epidemiological studies. For EC we used a relative risk of 1.06 expressed per 1 $\mu g/m^3$ [3].

If the zone would have been implemented over the entire ring road around Rotterdam, the risk of premature death would decrease with 1-3 months for 4000 people and with 0-1 month for 15,000 people. This exercise shows that an 80 km/h zone significantly reduces the health risk for a quarter of the Rotterdam population living less than 500 m from the ring road.

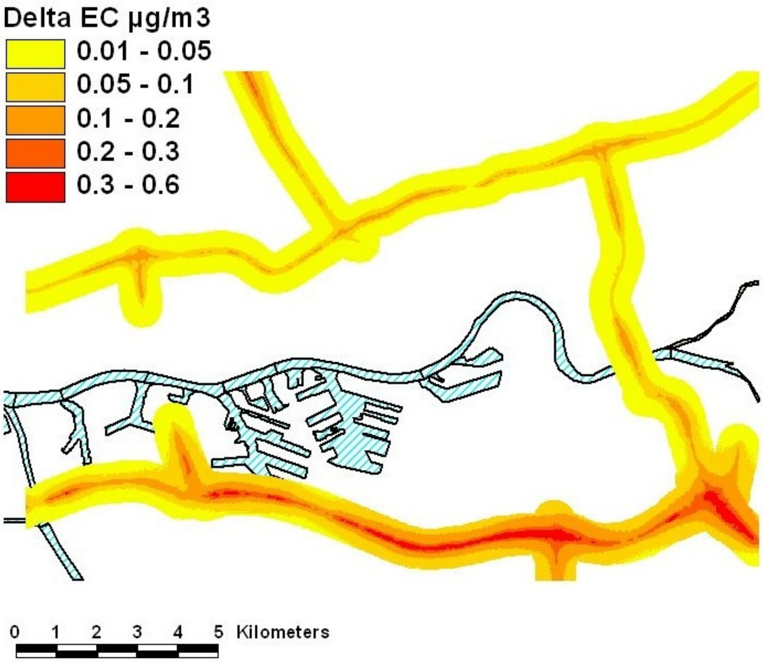

Figure 4: The difference in yearly averaged EC concentration (µg/m^3) with and without a speed limit of 80 km/h on highways around Rotterdam in 2008 (otherwise speed limits are 100 or 120 km/h).

5 Policy relevance

These exercise and pilot studies illustrate that road traffic emissions of EC can be reduced with tens of percents with local measures such as volume reduction, environmental zoning, speed limitation and improvement of the traffic flow. For air quality this means a reduction of EC concentrations in the order of 0.1-1 µg/m^3 depending on the effect of the measure and the distance of the location of interest to the traffic source. This decrease in EC yields a decrease in the risk of premature mortality by air pollution of approximately 1-6 months. This is a significant health gain for people living near busy road transport by relatively simple measures.

Modelling and/or measuring of changes in EC concentrations provide policy makers with an instrument to assess the impact of traffic measures on air quality and health. Whether or not limit values for particulate matter are met.

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