TRUCKS DRIVING AT NIGHT AND THEIR EFFECT ON LOCAL AIR POLLUTION

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1. INTRODUCTION

In January 2007 the Flemish transport minister proposed to improve the opportunities for loading/unloading goods in the port of Antwerp (Belgium) by extending the working hours at container terminals. The main intention of this set of measures is to increase the capacity for moving goods from the harbour out to the hinterland. This implies that the capacity of both the terminals and the motorway system is increased because it would enable trucks to avoid day-time congestion by driving at night.

Avoiding congestion is seen as beneficial for the haulage sector and also for the general economy because of the reduction of time losses from private cars queuing during the day. In addition congestion dramatically increases the amount exhaust emissions. Avoiding congestion is therefore seen as an environmental benefit by most policy makers. On the other hand it is evident that when more trucks drive at night, that would obviously have negative impacts related to night time noise exposure and possibly accidents.

In this paper we use a simple modelling scheme to demonstrate that changing the timing of the transport activity also has effects on the dispersion of the exhaust gases. Shifting the emission of pollutants to the late evening or early morning, when the atmosphere is relatively more stable can cause an unwanted increase in air pollution even when emissions are constant. Such an effect is easy to demonstrate, but has been overlooked by researchers because the focus of most studies has been either on episodes of severe air pollution or on estimating the annual average concentrations for exposure and analysis of health effects.

At the time of the political discussion, information on this effect was unavailable. We provide this analysis to demonstrate the important contribution that analysis of transport problems from an activity-based perspective can offer to policy makers.

2. METHODOLOGY

2.1 The dispersion model

Using a simple 1-dimensional Gaussian plume model, we studied the effect of shifting the timing of the emissions from day to night. The following equation was applied (Vlarem II, 2005):

$$C(x,y,z) = \frac{10^6}{3600.2\pi}.\frac{Q}{u_h \sigma_y \sigma_z}.\exp\left[\frac{-y^2}{2\sigma_y^2}\right]\left[\exp\left[\frac{-(z-h)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+h)^2}{2\sigma_z^2}\right]\right]$$

With

x,y,z (in m): Cartesian coordinates indicating the location of the immission, in the direction of dispersion (x), horizontal (y) and vertical (z) to the dispersion direction

$C_{x,y,z}$ (in mg/m^3): mass concentration of the air pollutant at the immission location with the coordinates x, y, z

Q (in kg/h): emission mass stream from the emission source

z (in m): height of the point of immission occurrence

h (in m): actual exhaust height

σ_y, σ_z (in m): horizontal and vertical dispersion parameter

u_h (in m/s): wind speed

This model is valid for the calculation of concentrations of gaseous pollutants when chemical transformation can be ignored as well as for fine particles when local deposition velocities are small. Both conditions are met for the generalized local conditions presented in this paper.

2.2. High resolution meteorological data

In this study we have used high resolution meteorological data on a 10 minute basis for an entire year. Information about wind speed, wind direction and temperature was provided for different measuring heights at a measuring point in the city of Mol. Every 10 minute the stability of the meteorological situation was determined based on wind speed and temperature information and a stability class was determined for every 10-minute record, ranging from 1 (= very stable situation) to 7 (= very unstable situation). Based on this information, the dispersion parameters (see equation above) could be calculated as:

$\sigma_y = A.x^a$

$\sigma_z = B.x^b$

with x: distance from the source (in m)

The coefficients A and B and the exponents a and b in these equations are subject to the stability class and derived from the following Table 1:

Table 1. Coefficients and exponents to calculate dispersion parameters (Vlarem II, 2005)

Stability class	Description	A	a	B	b
E1	Very stable	0.235	0.796	0.311	0.711
E2	Stable	0.297	0.796	0.382	0.711
E3	Neutral	0.418	0.796	0.520	0.711
E4	Slightly unstable	0.586	0.796	0.700	0.711
E5	Unstable	0.826	0.796	0.950	0.711
E6	Very unstable	0.946	0.796	1.321	0.711
E7	High wind speed	1.043	0.698	0.819	0.669

3. RESULTS

3.1. General

Wind speed and atmospheric stability classes at 10 minute time resolution were used to calculate the effect of truck emissions on pollutant concentrations at different distances from the road. A line source with an emission strength of 1 kg/hour was used to derive resulting concentrations for receptor points at a distance of 10 meters, 100 meters and 1 km from the emission source. The general result is presented in Figure 1.

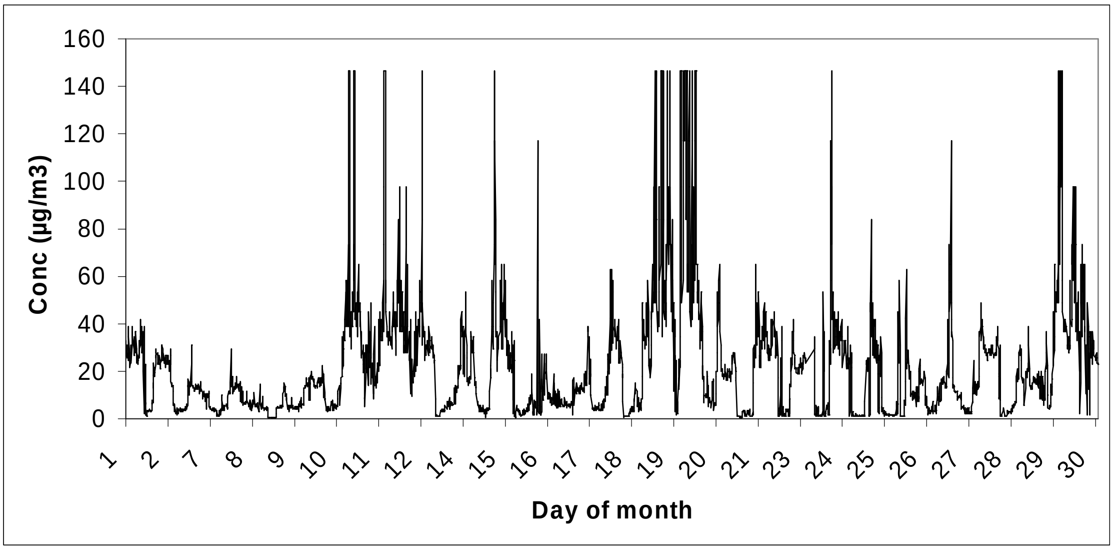

Figure 1 : Predicted concentrations for a receptor at a distance of 100 meters from the source (based on a continuous emission source strength and 1 month of high resolution meteo data, April 2005).

3.2. Effect of time of day

We have averaged the time-series discussed in the previous paragraph to obtain a mean concentration for each 10 minute interval of a twenty-four hours' period (based on 30 results, 1 for each day of the month). The results are shown in Figure 2 using meteo data for the month of April.

It is clear that that a constant source of emission causes concentrations that are higher at night than during the day for the same receptor. The effect is most pronounced at short distances from the road. At a distance of 10 meters, local concentrations will be up to four times higher during the night than during the day although the emissions are the same (assuming equal speed and traffic dynamics). A distance of 10 meters is a typical distance between the center of major roads and the facades of buildings.

At a distance of 100 meter from the road average night time concentrations equaled 30 µg/m^3 (21:00h-8:30h). Concentrations resulting from the same emissions source (constant strength of 1 kg per hour) are only about 10 µg/m^3 during the afternoon (12:00h – 18:00h).

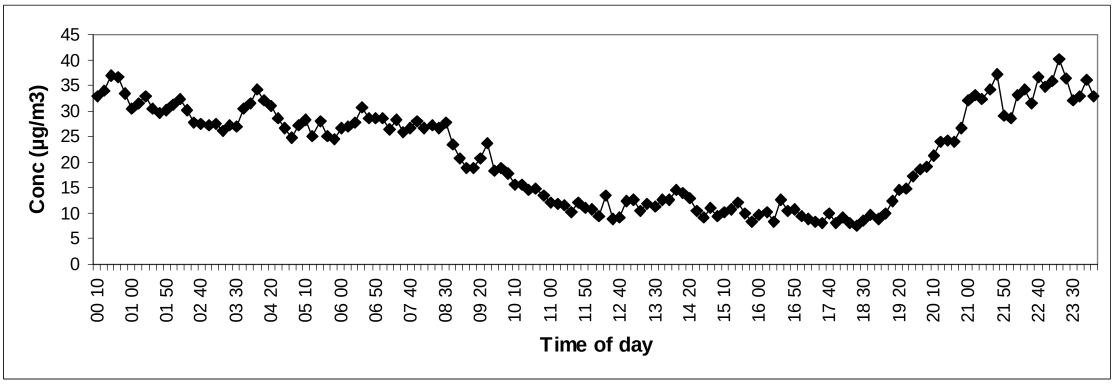

Figure 2: Average concentration for all 10-minute intervals (meteo data for April 2005, constant emission source at a distance of 100 meter).

The resulting concentrations at a distance of 1000 meters are an order of magnitude smaller. Hence any relative difference in concentration will be negligible in absolute concentrations (Figure 3).

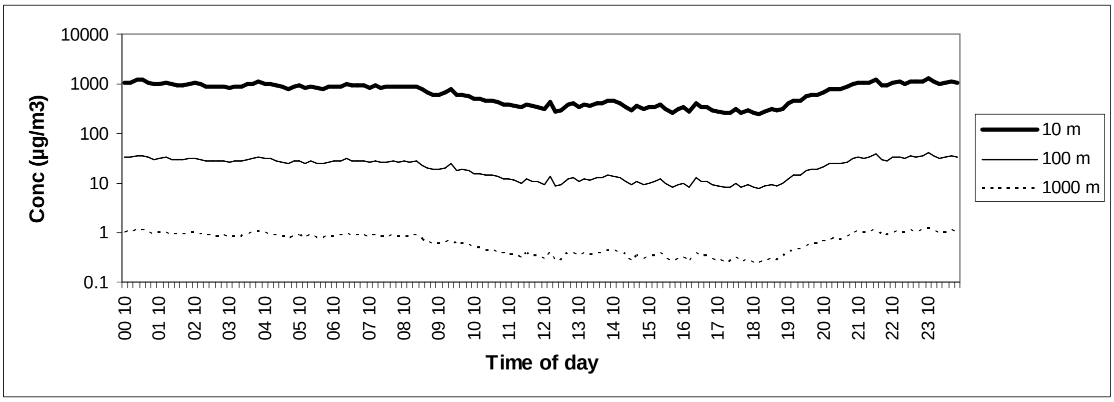

Figure 3: Comparative graphs for the concentration at receptors located at different distances from the emission source (logarithmic scale)

3.2. Effect of month of year

We repeated calculations for different months of the year, as far as high resolution meteo data was available. Because of the importance of average wind speed and atmospheric stability on the results, we show the results for the months of January and April, for receptor points at a distance of 10 meters (Figure 4). Differences between daytime and nighttime concentrations are more distinct in April than in January.

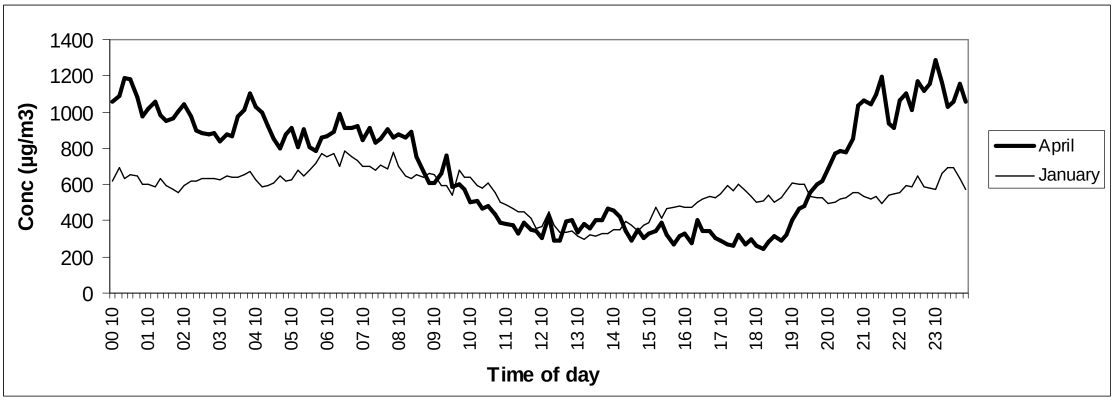

Figure 4: Average concentration for all 10-minute intervals (meteo data for January 2006 and April 2005, constant emission source at a distance of 10 meter).

4. DISCUSSION

In this paper we have demonstrated that identical emissions will cause local impacts that are higher at night than during the day. The magnitude of the difference is a factor of about three.

At first glance this result seems strange and it certainly needs an explanation. Everyone familiar with air quality measurements and time series knows that concentrations of primary pollutants are far lower at night than during the day. Peaks are usually seen during peak hours and concentration time-series follow the general daily pattern of the traffic flows, especially when measuring near busy roads.

In this study we have deliberately discarded the effect of changing traffic volumes to focus on the local dispersion. We have taken this approach because we are interested in the marginal effect of one unit of pollutant emitted at different times during the day.

Our results can be explained by differences in average wind speed and atmospheric stability at different times of the day. Meteorological conditions certainly appear quite random, but on average, there are important differences. Figure 5 shows the average wind speed data during 10 minute time intervals, corresponding to the concentrations that were calculated in Figure 4. Setting both figures side by side clearly shows the impact of wind speed on pollutant concentration. Lower wind speeds result in higher concentrations whereas higher wind speeds will dilute these concentrations. In January variations in wind speed are rather small compared to the wind speed variability in April, resulting in more concentration variability in April.

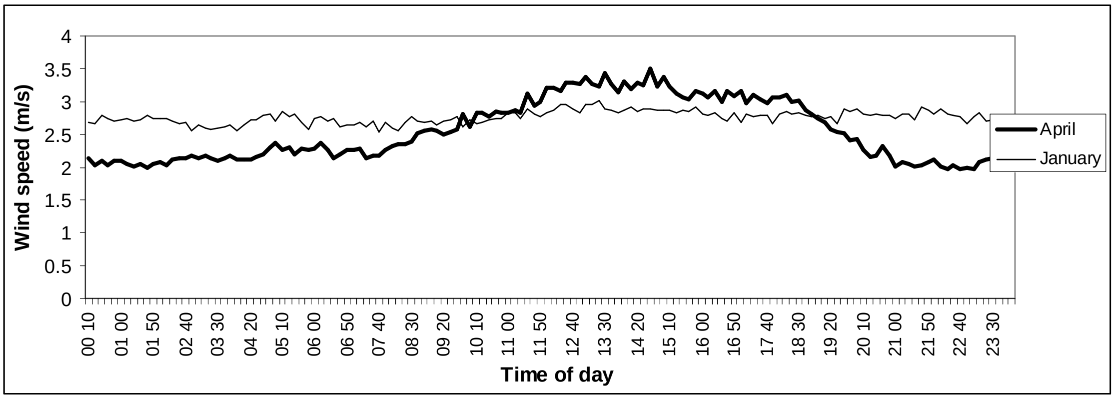

Figure 5: Average wind speed data for all 10-minute intervals (meteo data for April 2005 and January 2006).

It is clear that we cannot possibly capture the whole phenomenon in one simple model and some comments or objections can be made. Emissions (even from the same truck) may well be different because of different speeds or different driving behaviour (no congestion) during the night. We have also neglected the possible effects of lower temperature on the engine and differences in the use of headlights and comfort systems (heating and airco), but keeping the emission strength constant allowed us to focus on the diurnal changes in local dispersion.

On the other hand we may even have underestimated the effect because the highest concentrations are likely to occur during calm episodes with no wind at all. Unfortunately the dispersion under such conditions cannot be modeled with a Gaussian dispersion model.

The result presented in this paper have serious implications for air quality and transport policy. PM air quality targets prove very hard to comply with in areas affected by residential ribbon development. It has been shown that PM concentrations in 2010 will not meet air quality standards in the vicinity of many important roads. Partly changing the timing of the emissions on these roads from day to night will likely offset whatever benefits are gained from improved traffic flows. The unexpected magnitude of this difference in dispersion dwarfs recent improvements in European PM emissions standards for heavy duty. This effect is also large enough to offset remaining differences in PM emissions between advanced diesel cars and petrol fueled cars (Int Panis et al., 2001).

In addition our results also highlight the fact that annual average impacts (e.g. annual exposure of urban populations routinely used for health impact assessment) may hide important seasonal differences between summer months when days are long and winter time when rush hours occur either before sunrise or after sunset. Such aspects need to be studied in much more detail before the environmental consequences of specific transport policy measures can be assessed.

At this point we can only speculate what the impact of this effect is for the exposure of people living near busy roads. In many countries a significant fraction of the population lives next to a busy road and distances of 10 meter between the central axis of the road and the facades of the houses are common. One option to prevent negative environmental effects is to allow truck to load/unload at night but restrict driving to motorways. This would reduce emissions resulting from motorway congestion while preventing a disproportionate increase in urban concentrations.

Since traditional travel demand models mainly focus on peak hour information, only peak emissions and concentrations can be modeled. To overcome this problem and obtain hourly trip information, new travel demand models have been developed. The activity-based model treats travel demand as derived from the activities that individuals and households need or wish to perform (Ettema and Timmermans, 1997). The model aims at predicting *which* activities are conducted, *where*, *when*, for *how long*, *with whom* and the *transport mode* involved. This travel demand model predicts activity-travel patterns of individuals in a population based on activity diary information and provides very detailed information on the personal travel behaviour including very detailed trip departure data. This information is very useful when focusing at differences in travel behaviour, emissions or concentrations per time of day.

5. CONCLUSIONS

The time of day at which a specific emission takes place is very important for its impact on local air quality and exposure.

Activity-based models are capable of accurately predicting trip departure times and therefore they provide the necessary data to achieve greatly improved assessments of personal exposure.

The intention to increase night-time traffic (emissions) should be weighed against the negative effect on air quality that was demonstrated in this paper.

Bibliography

Ettema, K., and H. Timmermans (1997) Theories and models of activity patterns, in Ettema, K. and H. Timmermans (eds), *Activity-based approaches to travel analysis*, Pergamon, Oxford.

Luc Int Panis, Leo De Nocker, Ina De Vlieger and Rudi Torfs (2001) Trends and uncertainty in air pollution impacts and external costs of Belgian passenger car traffic. **International Journal of Vehicle Design**, **27** (1-4), 183-194.

Vlarem II (2005) Bijlagen bij het besluit van de Vlaamse regering van 1 juni 1995 houdende algemene en sectorale bepalingen inzake milieuhygiëne. Gecoördineerde versie 31 augustus 2005, 75-80.