DEVELOPMENT AND VALIDATION OF THE NEW TNO MODEL FOR THE DISPERSION OF TRAFFIC EMISSIONS

J. Wesseling, J. den Boeft, G.A.C. Boersen, K. Hollander, K.D. van den Hout, M.P. Keuken, H. Spoelstra, S.D. Teeuwisse, O. Weinhold, P.Y.J. Zandveld
TNO-MEP, P.O. Box 342, 7300 AH Apeldoorn, The Netherlands

INTRODUCTION

TNO has a long history of dispersion modeling, both for traffic emissions as well as emissions from industrial sources. The TNO model for dispersion from mobile sources, VKM, (Hout, 1988) has been used extensively over the last decades in the Netherlands. However, the model still uses the Pasquill stability classes (Pasquill, 1983) instead of calculating the atmospheric turbulence from hourly meteorological data. Therefore the TNO Gaussian dispersion model has recently been extended with additional modules for traffic emissions, the Traffic Dispersion Model, TDM. The new model has been tested using detailed measurements of NO_x, NO_2, PM_{10}, BTX and CO in and in the vicinity of the city of Rotterdam. The measurements were performed as part of the European 5th framework program “HEAVEN” (Healthier Environment through the Abatement of Vehicle Emissions and Noise). The main results of the validation are presented. Emphasis is on measurements performed just outside the city as these served best to determine the basic performance of the model.

MODEL

Dispersion model

The TDM uses a box model to define the initial shape of the emission source for traffic, in this way creating an effective source. All emissions are assumed to mix homogeneously inside the volume of the box. The pollution is subsequently assumed to originate from the side of the box. The initial mixing of the emissions due to traffic-induced turbulence is parameterized by the height of the box (Z). The road is divided into a large number of segments (boxes). The lengths of the segments (W_k) are determined by a segmentation algorithm. Next, each segment is rotated perpendicular to the hourly wind speed. A similar approach of rotating segments is used in the code CALINE for a line source (Benson, 1989) (Benson, 1992). In the Finnish CAR-FMI model (Härkönen, 1996) also a Gaussian line source is used but there an explicit correction for the angle between the wind and the road segment is employed. With the side of the box perpendicular to the wind speed a simple relation can be obtained for the contribution of emissions from the box to any location downwind of the box, see Figure 1.

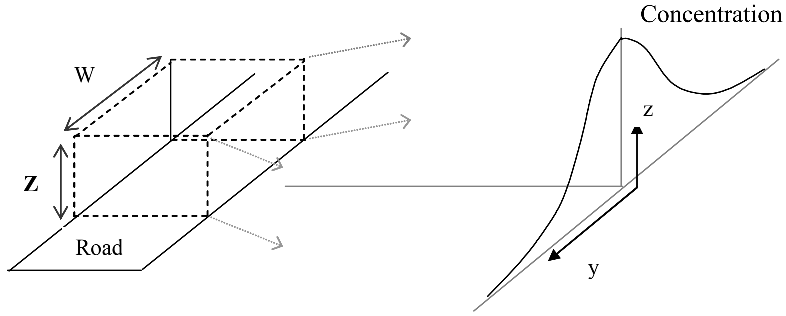

Figure 1. Schematic drawing of the road, the box and the concentration profile downwind in case of pure crosswind.

In the drawing it is assumed that the wind is perpendicular to the road segment. Integrating the standard Gaussian dispersion formula over the side of the box yields the following expression for the concentration contribution at a location downwind of the box, y meter from the projected center of the box, at a height of z meters:

$$C(z,y)=\frac{1}{4}Q\left[erf\left(\frac{1}{4}\frac{\sqrt{2}(2h+Z-2z)}{\sigma_z}\right)+erf\left(\frac{1}{4}\frac{\sqrt{2}(2h+Z+2z)}{\sigma_z}\right)-erf\left(\frac{1}{4}\frac{\sqrt{2}(2h-Z-2z)}{\sigma_z}\right)-erf\left(\frac{1}{4}\frac{\sqrt{2}(2h-Z+2z)}{\sigma_z}\right)\right]$$
$$\left[erf\left(\frac{1}{4}\frac{\sqrt{2}(W-2y)}{\sigma_y}\right)+erf\left(\frac{1}{4}\frac{\sqrt{2}(W+2y)}{\sigma_y}\right)\right]/(WZU) \qquad (1)$$

where Q is the total source strength, $\sigma_{y,z}$ are the horizontal and vertical dispersion parameters, W and Z are the dimensions of the box, h=Z/2 and U is the average wind speed at plume height.

Atmospheric boundary-layer treatment

The treatment of meteorological conditions and atmospheric turbulence are compliant with the Dutch National Model and scientific standards. They are extensively described in (Ham, 1998) and (Erbrink, 1995). Meteorological data were obtained from the nearby (5 km) Rotterdam airport. From the above models and the available hourly data the horizontal and vertical dispersion parameters are calculated.

Emission model

For the HEAVEN experiments hourly averaged traffic intensities were available. These were combined with emission factors for traffic obtained from TNO-Automotive (Gense, 2001). These emission factors seem to provide the best description of emissions due to traffic on Dutch highways during weekdays. Emissions seemed to change substantially between weekdays and weekends. This indicates significant changes in fleet composition and/or driving pattern mix. A recent study (Kühlwijn, 2000) estimates the statistical uncertainties in emission factors to be 16-22% for NO_x. Systematic deviations are estimated at 22%. In the present study hourly averaged traffic composition and driving speeds for all lanes were available. Consequently the net uncertainty in the emissions will be somewhat less than reported above. Driving pattern mix and effective emission factors remain the largest uncertainties.

Chemistry model

The treatment of the NO_x, O_3 and NO_2 chemistry in the TDM is according to a simple empirical method proposed by TNO (Hout, 1988). In this semi-empirical relationship the NO_2 concentration is related to the NO_x transported to the receptor point and the ambient NO_x, NO_2 and O_3 concentrations as follows:

$$[NO_2] = fNO_2 \cdot [NO_x] + \beta([Ox]_{background} - [NO_2]_{background})\frac{[NO_x]}{[NO_x]+K} \qquad (2)$$

where *Ox* stands for oxidant (O_3+ NO_2), fNO_2 is the fraction of NO_x emitted as NO_2 and β and K are empirical parameters. In a recent study (Dosio, 2002) the TNO method was compared to a number of other models, including the Canyon Plume Box Model (Yamartino, 1986), the Discrete Parcel Method (Benson, 1989) and the Operational Street Pollution Model (Hertel, 1989). The TNO method was shown to be both very robust as well as comparable in accuracy to the more complex models. The TNO method is currently also being used in other Dutch air quality models (Teeuwisse, 2002).

MEASUREMENT SITES AND EXPERIMENTAL SET-UP

Measurements performed by the DCMR Environmental Protection Agency Rijnmond took place during two periods. From October 2000 to December 2000 measurements were performed just outside the city of Rotterdam, on a stretch of road with very few obstructions to the airflow around the road (open field measurements). Subsequently the whole set-up was moved to locations inside the city, to the "Overschie" part of Rotterdam where measurements were performed from April 2001 until present.

At the “open field” location, three measuring stations were located around the A13 highway from the city of Rotterdam to the city of Delft. One station (A3) was located wind upward of the A13 highway and served as a background station. The other two stations (A1 and A2) were located 50 and 200 meters down wind of the A13 highway, respectively. On all three measuring stations hourly values of NO_x, NO_2, O_3, PM_{10}, BTX and CO concentrations were measured and stored. The NO_x/NO_2 measurements were performed using NO_x chemiluminescence analyzers (Thermo Electron model 42). During some months small corrections were necessary to correct for relative drift of the apparatus. The uncertainties in the measured concentrations are estimated at several $\mu g/m^3$ for each station.

RESULTS

The measured NO_x and NO_2 concentrations have been compared to calculated values for those hours where the wind direction allowed a reasonable estimate of the relevant background concentrations. A full statistical analysis of the match between calculated and experimental concentrations is currently being performed. A comparison between the current TNO model for dispersion of traffic emissions (VKM) and the new TDM for the NO_x contribution of the traffic during November 2000 is presented in Figure 2. It is clear that there are no large differences between the two models. This is somewhat surprising as the models differ significantly in underlying assumptions as well as in numerical approach. The correlations between calculated and measured NO_x concentrations are very satisfactory, see Figures 3 and 4. There is some variation between correlations obtained for different months but overall the calculations give a good description of the data. With the available measured values for the O_3 and NO_2 backgrounds it was possible to calculate the total NO_2 due to traffic and background. Correlations between calculated and experimental NO_2 are presented in Figures 5 and 6. There is a relative large scatter in the O_3 measurements and therefore also in the calculated total NO_2 values. A comparison between calculated and measured NO_2 values in the city of Rotterdam is shown in Figure 7. These data are for a measuring station (E1) some 20 meters from the side of the highway. At higher concentrations (NO_2 >60 $\mu g/m^3$) the calculations seem to systematically exceed the measured concentrations. Further away from the road (200 m) the calculated total NO_2 concentration seem some 10-20% too low. However, the data suggest a systematic offsets between the measured NO_2 concentrations obtained at the station E2 and at the background station E3. This is presently being investigated. Although we have not yet fully analyzed all data the quality of the TDM calculations seems comparable to that reported for CAR-FMI (Kukkonen, 2001).

AIR QUALITY MANAGEMENT

Easy use of the TDM for air quality management within the framework of the EU directives was an important aspect during the development of the model. The possibility to provide the general public with information on air quality with the (TDM) model was a key issue. Consequently, model development took place in close contact with regulatory bodies and end-users. The TDM is presently being used as part of the Decision Support System to provide real-time short-term predictions of the air quality around busy roads running through the city of Rotterdam on an hourly basis. The results are available from the Internet at www.dcmr.nl/HEAVEN to inform the Dutch public.

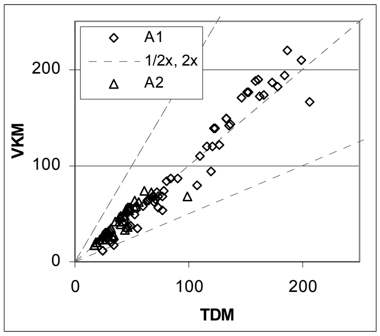

Figure 2. Comparison of the TDM and the existing TNO dispersion model.

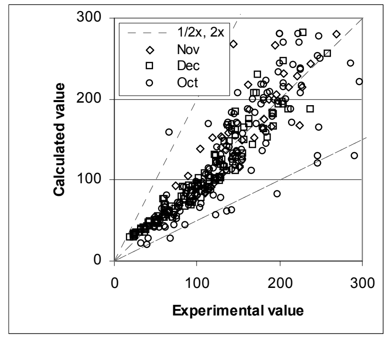

Figure 3. NO_x <u>total</u> at station A.1.

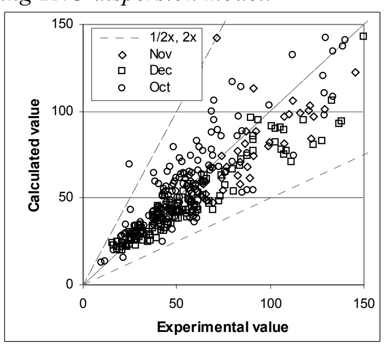

Figure 4. NO_x <u>total</u> at station A2.

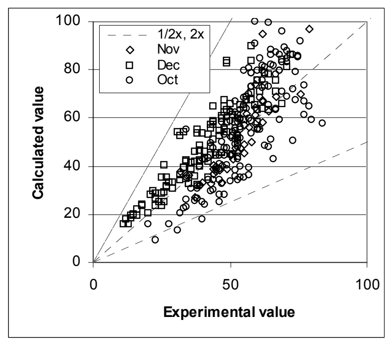

Figure 5. NO_2 <u>total</u> at station A1.

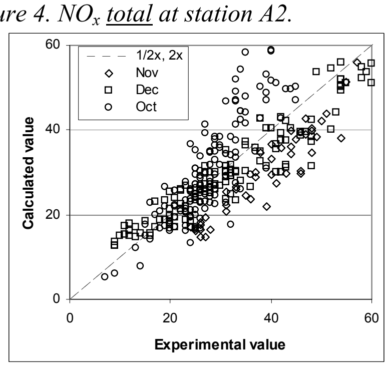

Figure 6. NO_2 <u>total</u> at station A2.

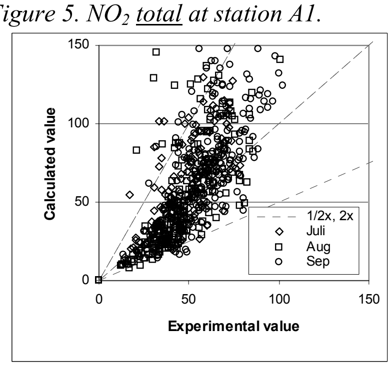

Figure 7. NO_2 <u>total</u> at station E1.

CONCLUSIONS

Concentrations calculated using the new TNO model for dispersion of emissions from mobile sources have been compared to an extensive experimental data set. Overall there is a satisfactory match between calculated and measured NO_x and NO_2 values. A further and more detailed analysis of the quality of the model will be published in the near future.

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