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Documentation of RoadAir 2.0

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PREFACE

This document aims at describing all the modules and assumptions made in RoadAir and describing the way the model works.

The original RoadAir 1.0 model for computation of emissions and pollutant concentrations along a road network was programmed by Frederick Gram at NILU from 1989 to 1990. Steinar Larssen has been a main contributor to the development of the technical contents of the model. The first version was written in FORTRAN for use on the NORD computer system.

RoadAir 1.0 was made available for use on PC by Jan Sørlie. The version 1.5 was completed by him in April 1991 (Microsoft FORTRAN Optimizing Compiler Version 5.00). This work was a major revision of the 1.0-model, concerning the way the model worked and the structure of the programming code. RoadAir 1.5 was specially adapted for use in air pollution assessment done in connection with the transport planning programme of the 10 major urban areas of Norway (TP10). It contained the possibility of presenting the calculated concentrations along road links as color coded plots.

RoadAir 2.0 was completed in June 1991. In addition to emissions and concentrations, this version calculated exposure to CO and NO_2, based on a building register. In version 2.0 the plotting possibility was removed. Also, road dust and "nuicance" modules were included.

There exists programmes called VREG, VADM and VPLOT that are used for registration of input data and plotting of the calculation results. Together with RoadAir these comprise a total system for registration of input data, calculation of emissions and concentrations and presentation of the results. However, only the programme RoadAir 2.0 has been translated to English so far.

CONTENTS

DOCUMENTATION OF ROADAIR
VERSION 2.0

1 INTRODUCTION

RoadAir is a PC based model which calculates air pollution from a road network. The following parameters are calculated:

- Total emissions of CO, CO_2 and NO_x
- Concentration of CO and NO_2 at a fixed distance from the road side of each link in the road network.
- Exposure of the population to CO and NO_2 outside the facades of their homes

The calculations are based on two input files; one with data on roads and traffic, and one with data on residential buildings.

This documentation aims at giving the information needed to be able to evaluate the calculations being done by RoadAir 2.0. A user's manual has been published (NILU TR 14/92), which should be seen in connection with this documentation.

RoadAir 2.0 is to a large extent based on the Nordic Method for Calculation of Vehicle Exhaust Gases (Nordisk Ministerråd (Nordic Ministerial Council), 1984), which will be referred to as "NBB".

2 GENERAL OVERVIEW OF ROADAIR

RoadAir has been designed to give indicator values of CO and NO_2 concentration near each separate link of a defined road network, to give a basis for classification of the air pollution problems associated with the network. However, it is important to note that RoadAir considers, as a separate contribution to the concentration, only the larger road closest to the receptor point. The contributions from all other roads and sources is considered as a sum, termed "city background". Concentration data for the city background has to be given separately as input to the model:

$$C_{total} = C_{link} + C_{background}$$

Figure 1 shows a simplified overview of the model, with input registers and output tables. The overview gives the main modules, characteristics and results, but is not complete in terms of details.

RoadAir is definitely a "road neighbourhood" model. Concentrations are calculated within a 20-meter band from the curb.

RoadAir calculates first the emissions of CO, CO_2 and NO_x, and classifies them according to vehicle, road and city area class. Then the program proceeds to calculate indicator concentration values of CO and NO_2 for each defined road link, and classifies the links according to the calculated values relative to present limits. The indicator value is the estimated maximum concentration of CO and NO_2. The term "maximum concentration" is exactly what it reads, the maximum concentration (1 hour average) that is expected to occur at all near each link. The receptor point (point of calculation) on each link is in principle at the middle of the link, at a pre-chosen distance from the curb. Thus, the values represent the part of the links which is not affected by the special emission and dispersion conditions near intersections.

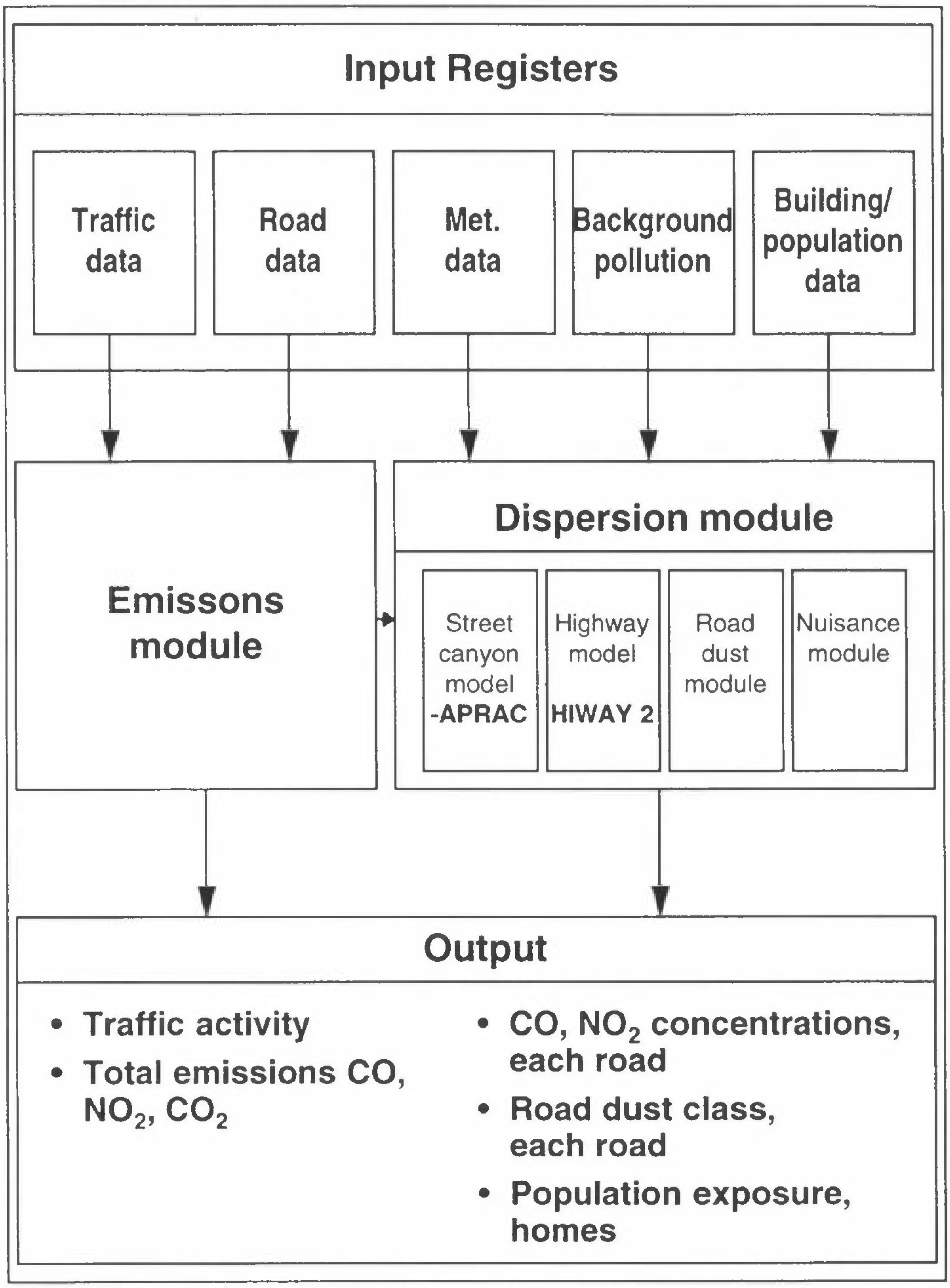

Figure 1: Flow diagram showing the interaction of the different modules in RoadAir.

RoadAir then proceeds to calculate "population exposure", by calculating the concentrations at all the buildings which are included in the building register input file. The building, and thus number of residents, are then located in classes of concentration intervals corresponding to air quality guidelines and other limit values.

The dispersion models utilized are the APRAC street canyon model (the leeward algorithm), modified through a data base of curbside CO and NO_2, measurements from Scandinavian countries (leading to a Nordic Calculation Model for Road Side Pollution), and the US EPA HIWAY model, modified at NILU to reduce initial dispersion and eliminate the initial dispersions dependency of the angle between the road and the wind. The model is employed to calculate maximum impact independent of wind-direction.

3 DEFINITIONS AND CLASSIFICATIONS

3.1 CLASSIFICATION OF VEHICLES

The vehicles are classified in the following way:

1. Light duty petrol vehicles
2. Light duty diesel vehicles
3. Heavy duty diesel vehicles, GVW* < 10 tonnes
4. " " " " , GVW 10-20 tonnes
5. " " " " , GVW > 20 tonnes

Buses are included in class 4.

Total number of vehicles, and fraction of heavy duty traffic on each link are input parameters to the model. Buses are classified as heavy duty traffic. The distribution of heavy duty

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* Gross Vehicle Weight.

traffic among the 3 classes dependent on the street class, is shown in Table 1. Light duty diesel vehicles, as a fraction the of the total number of light duty vehicles, is shown in Table 2.

Table 1: Distribution of the heavy duty vehicles between the three weight classes and five road classes (see paragraph 2.2). The values and are taken from NBB (1984).

Vehicle class	Road class				
	1	2	3	4	5
3	30%	50%	50%	25%	50%
4	30%	33%	50%	25%	33%
5	40%	17%	0%	50%	17%

Table 2: Light duty diesel vehicles as fraction of light duty vehicles in total (LDD), taken from NBB (1984).

Street class	1	2	3	4	5
LDD	6%	8%	4%	6%	4%

3.2 CLASSIFICATION OF THE ROAD NETWORK

The five road classes are described in more detail on p 7 in the User's Manual. The road class describes the function of the street or road:

1. Thoroughfare road, or main road for transport to and from urban centres.
2. Main road in urban area.
3. Main road in residential area.
4. Main road in industrial area.
5. Local road in residential area.

Classes 1-4 are taken from NBB. There was a need for adding the class "local road in residential area", because such roads are not covered by the four categories in NBB.

The classification in NBB was constructed with the urban situation in mind. Experience has shown that air pollution calculations will often be required for highways/motorways passing through rural areas. Such roads belong to class 1.

In addition to the road class parameter, an <u>area type</u> parameter for each road link is needed. Values determined by the <u>area type</u> parameter are

a) the value of city background pollution (see paragraph 4.2) that is assumed in the calculation of concentrations, and

b) the fraction of vehicles with "cold" engines on local roads (street class 5).

By "cold" engines is meant the state of the engine during the first few minutes of driving after a cold start ("cold start fraction").

Emissions are higher from a cold engines than from hot engines, with a few exceptions.

The area types used in RoadAir are:

1. Rural area/city outskirts
2. Intermediate area (urban)
3. Central area (urban).

3.3 DEFAULTS VALUES FOR TRAFFIC PARAMETERS FOR RUSH HOUR TRAFFIC

One of the parameters in the input file is Mmax, the hourly traffic in the rush hour, as % of AADT (Annual Average Daily Traffic). If no value is assigned to this parameter, the default values of Table 3 are used as a function of road class.

Table 3: Maximum hourly traffic, in % of AADT, as a function of road class. Standard values for morning and afternoon rushhour, as well as 24-hour mean. The values are taken from NBB.

Time of calculation	Road Class				
	1	2	3	4	5
morning	10	8	10	10	8
afternoon	10	8	10	10	8
24-hour mean	4,17	4,17	4,17	4,17	4,17

3.4 CLASSIFICATION OF POLLUTION LEVEL

RoadAir calculates maximum 1-hour average concentrations of CO and NO_2, the maximum values which will occur when rush-hour traffic and poor dispersion conditions coincide. Poor dispersion conditions occur on calm, cold and clear days when the atmosphere is stable. The following classification is used, based on the air quality guidelines that were recommended by the Norwegian authorities at the time of completing RoadAir 2.0, corresponding to WHO Guidelines:

CO - maximum 1-hour average:

- severe : > 25 mg/m^3
- high : 15 - 25 "
- medium : 8 - 15 "
- low : < 8 "

NO_2 - maximum 1-hour average:

- severe : > 350 $\mu g/m^3$
- high : 200 - 350 "
- medium : 100 - 200 "
- low : < 100 "

4 EMISSION MODUL

4.1 CO_2 EMISSIONS

CO_2 emissions are calculated on the basis of fuel consumption.

Fuel consumption = N * S * D * R

N - number of vehicles
S - specific fuel consumption
D - distance driven
R - reduction factor as function of year of calculation

The 1989 specific fuel consumption figures, for six vehicle classes and nine velocity classes are shown in Table 4. The specific fuel consumption is expected to be reduced in the future. The reduction factors used are as follows:

Delta = 2005 - year of calculation

1) Light duty vehicles (class 1 and 2 in Table 4):
R = 0.70 + ((0.3*Delta)/16)

2) Trucks (classes 3, 4 and 5 in Table 4):
$R = (0.83) + ((0.5 * Delta) / 48)$

3) Buses
$R = 0.75 + ((0.25 * Delta) / 16)$

Table 4: Specific 1989 fuel consumption (l/km) as a function of vehicle speed and vehicle class. (See p. 4).

Vehicle class	Vehicle speed (km/h)								
	10	20	30	40	50	60	70	80	90
1	0.185	.150	.120	.100	.085	.075	.070	.070	.090
2	0.185	.150	.120	.100	.085	.075	.070	.070	.090
3	.300	.300	.300	.300	.280	.270	.260	.250	.250
4	.370	.370	.370	.370	.360	.360	.350	.340	.330
5	.450	.450	.450	.450	.450	.450	.450	.425	.400
buses	.450	.450	.420	.380	.360	.350	.350	.350	.350

The fuel comsumption is converted to CO_2 emissions in the following way:

$$m(CO_2, diesel) = V(diesel) * D(diesel) * 3.18$$
$$m(CO_2, petrol) = V(petrol) * D(petrol) * 3.11$$

m = mass emitted (kg)
V = fuel volume consumed (dm^3)
D = specific mass (kg/dm^3)
D(diesel) = 0.83
D(petrol) = 0.75

Diesel: 3.18 kg CO_2/kg fuel
Petrol: 3.11 kg CO_2/kg fuel

This is based on the assumption of complete combustion. Depending on the engine characteristics, some of the carbon in the fuel will be emitted as CO, VOC and particles. Nearly all the carbon will eventually be converted into CO_2 in the atmosphere.

4.2 EMISSIONS OF CO AND NO_x

4.2.1 Present emissions, general

The emission factors in RoadAir 2.0 for CO and NO_x are taken from the model NOXCO (Tønnesen, 1990). The basic factors for the five vehicle classes (paragraph 3.2.2) as a function of driving speed are taken from NBB. These are valid for driving on horisontal roads, and the driving pattern represents urban driving. It does not cover the zones around road intersections, with increased occurance of acceleration, deceleration, and idle.

The emission factors of NBB 1984 were only given for velocites up to 60 km/h, as the model was constructed for the urban situation. Based on a literature study, the emission matrix was extended up to 90 km/h.

A further extension was made to include the effect of road gradient. This was based on measurements made by the Swedish laboratory for vehicle road exhaust, in Studsvik.

In RoadAir, the emission factors in NOXCO are assumed to be valid for the car fleet of 1989. A certain rate of renewal of the vehicle fleet is assumed (paragraph 3.2.6). The emissions from the cars introduced in a certain year will depend on the current emission regulations. The emission regulations (in g/km or g/kWh) are referred to a specified driving cycle. In addition the regulation may also include a limitation to the increase in emissions over a certain length of driving, e.g. the first 80 000 km. In order to know the emission factors from vehicles satisfying a certain emission standard, laboratory tests must be carried out. In these tests, emissions are found as a function of velocity and acceleration ("emission matrix"). When these test results are combined with a specific driving pattern, emission factors such as those in Table 6 and 7 are obtained.

4.2.2 Future emissions, general

In order to find the effect of renewal of the vehicle fleet on the current emission matrix representing today's fleet, two methods are possible:

- One assumes that the emissions from future vehicles can be reduced by a factor, uniform for all velocities, based on the ratio between emission standards:

$$\begin{array}{c}\text{New}\\ \text{emission}\\ \text{factor}\end{array} = \begin{array}{c}\text{Old}\\ \text{emission}\\ \text{factor}\end{array} * \frac{\text{New emission standard}}{\text{Old emission standard}}$$

- Introduction of new emission standards often implies introduction of a new technology such as the three way catalyst. When the effect of this technology is know, the emission factors are reduced accordingly.

In the first method, the assumption is made that the car manufacturers will meet the emission standards. How the standards are met is not considered. This may cause an overestimation of the emissions, as new technology may reduse the emissions below the standard.

The second method is probably the one that introduces the least error. It is, however, only possible to use when all car manufacturers use the same technology to reach a certain emission standard. In RoadAir, the second method is used for the introduction of three way catalyst on petrol cars. For the so called "California"-emission regulations, and stricter NO_x-emission regulations for heavy duty vehicles from 1994, the first method is applied.

In the model, there is no coupling between the emission factors for CO and NO_x, and the fuel consumption, i.e. CO and NO_x emissions are not reduced proportional to reduced fuel consumption.

4.2.3 Emission factors for CO and NO_x

Emissions of CO in g/km are calculated by the subroutine CO_PROD and NO_x emissions by NOX_PROD. Assumptions:

- Car fleet of 1988 (no catalysts)
- Cold start fraction = 0

NOX_PROD and CO_PROD contains the emission factors for five vehicle classes, nine velocity classes and six classes of road profile. The emission values are given in Table 6 and 7. Velocity <10 km/h is set equal to 10 km/h. Velocity >90 km/h is set equal to 90 km/h.

The emission factors are given for six gradients (-12%, -6%,-2%, 0,6%, 12%). Emission factor for a particular gradient is found by interpolation.

Table 5: Value of interpolation factor Z in various gradient ranges.

Gradient of the road, G	Interpolation factor Z
< -12	-
[-12, -6>	G/6 + 2.0
[-6, -2>	G/4 + 1.5
[-2, 0>	G/2 + 1.0
[0,6>	G/6
[6, 12>	G/6 - 1.0
≥ 12	-

Table 6: Emissions of CO (g/km) as a function of road class, driving velocity and gradient of the road. Vehicles in hot engine mode without a catalyst. $v \leq 10$ in fact means $v \leq 10.05$ etc.

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
v≤10 km/h	1	40.0	45.0	50.0	51.4	97.7	156.0
	2	5.04	6.50	8.4	9.36	10.8	12.2
	3	5.0	5.0	4.5	5.1	7.6	8.6
	4	5.0	5.0	7.05	9.11	12.4	16.0
	5	5.0	5.0	9.5	14.4	16.0	30.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
v≤20 km/h	1	20.0	25.0	29.5	30.8	59.6	92.7
	2	2.52	3.0	4.15	4.72	9.18	6.82
	3	2.50	2.50	2.50	3.90	4.40	5.40
	4	2.50	2.50	4.02	5.54	12.0	16.1
	5	2.50	2.50	7.0	11.52	16.0	30.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
v≤30 km/h	1	12.0	16.0	20.9	23.3	50.4	80.9
	2	1.68	2.0	3.06	3.6	5.15	6.7
	3	1.20	1.20	1.70	3.30	4.00	5.10
	4	1.20	1.20	1.70	3.96	11.50	17.50
	5	1.20	1.20	1.70	9.00	16.00	30.00

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
v≤40 km/h	1	7.5	10.0	13.1	14.7	24.9	69.7
	2	1.26	1.50	2.00	2.23	4.52	6.80
	3	0.90	0.90	1.30	2.14	4.00	7.50
	4	0.90	0.90	1.30	3.88	11.20	18.0
	5	0.90	0.90	1.30	7.02	16.20	30.0

Table 6: Cont.

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 50$ km/h	1	6.8	8.0	10.8	12.2	20.9	58.5
	2	1.01	1.??	1.61	1.76	4.3	7.0
	3	0.70	0.70	1.0	1.51	3.90	9.80
	4	0.70	0.70	1.00	3.68	13.3	18.5
	5	0.70	0.70	1.00	5.67	16.5	30.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 60$ km/h	1	5.5	6.0	9.3	11.0	19.1	53.5
	2	0.84	1.00	1.34	1.51	4.25	7.10
	3	0.60	0.60	0.90	1.40	7.40	10.10
	4	0.60	0.60	0.90	3.25	13.3	18.5
	5	0.60	0.60	0.90	5.40	16.9	30.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 70$ km/h	1	4.9	5.3	8.3	9.8	16.7	46.6
	2	0.72	0.72	1.17	1.4	4.2	7.2
	3	0.60	0.60	0.90	1.38	7.50	10.50
	4	0.60	0.60	0.90	3.13	13.30	19.00
	5	0.60	0.60	1.20	5.31	16.90	30.00

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 80$ km/h	1	4.6	5.0	7.8	9.2	15.6	43.7
	2	0.63	0.63	1.11	1.35	4.15	7.25
	3	0.80	0.90	1.10	1.37	7.50	10.8
	4	0.80	0.90	1.20	3.05	13.3	19.0
	5	0.80	0.90	1.50	5.20	16.90	30.00

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 90$ km/h	1	4.3	4.7	7.5	8.9	15.1	42.3
	2	0.56	0.56	1.07	1.32	4.1	7.1
	3	0.90	1.10	1.30	1.37	7.50	11.00
	4	0.90	1.10	1.50	3.00	13.30	19.00
	5	0.90	1.10	2.00	5.10	16.90	30.00

Table 7: Emission factors for NO_x (g/km) as a function of vehicle class, vehicle speed and "gradients". Vehicles in hot engine mode without a catalyst are assumed.

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 10$ km/h	1	1.5	2.0	2.3	2.38	4.0	7.5
	2	0.50	0.6	0.7	0.78	1.10	1.73
	3	8.64	8.64	8.64	11.34	18.0	24.1
	4	8.64	8.64	15.39	22.14	30.8	50.0
	5	8.64	8.64	26.73	44.82	50.0	76.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 20$ km/h	1	1.3	1.8	2.3	2.62	4.2	8.0
	2	0.45	0.5	0.6	0.74	1.15	1.85
	3	4.32	4.32	4.32	8.32	18.	26.5
	4	4.32	4.32	11.02	17.71	30.8	50.0
	5	4.32	4.32	21.37	39.14	49.5	78.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 30$ km/h	1	0.8	1.0	1.92	2.38	4.2	8.0
	2	0.30	0.4	0.6	0.72	1.18	1.90
	3	2.02	2.02	2.88	7.56	18.0	27.0
	4	2.02	2.88	8.82	14.76	30.7	50.0
	5	2.02	2.88	16.38	29.88	49.0	78.5

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \leq 40$ km/h	1	0.3	0.3	1.80	2.55	5.1	9.0
	2	0.15	0.15	0.55	0.7	1.35	1.95
	3	1.51	1.51	2.16	7.41	18.5	27.4
	4	1.51	2.16	7.21	12.25	30.7	50.0
	5	1.51	2.16	11.39	20.62	47.5	80.0

Table 7: Cont.

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \le 50$ km/h	1	0.3	0.3	1.89	2.69	5.9	9.3
	2	0.15	0.15	0.55	0.72	1.35	1.95
	3	1.21	1.21	2.00	6.12	18.7	27.4
	4	1.21	1.73	5.88	10.04	30.7	51.0
	5	1.21	1.73	8.34	14.94	46.5	82.5

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \le 60$ km/h	1	0.2	0.2	2.03	2.88	6.5	9.5
	2	0.1	0.1	0.6	0.76	1.40	1.98
	3	1.01	1.01	2.44	5.29	17.2	28.0
	4	1.01	1.44	5.35	7.82	30.6	51.5
	5	1.01	1.44	6.70	11.95	46.75	85.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \le 70$ km/h	1	0.3	0.4	2.19	3.09	7.0	9.7
	2	0.15	0.2	0.6	0.80	1.45	2.00
	3	1.10	1.10	2.88	4.53	17.2	28.0
	4	1.10	1.23	4.31	7.38	30.6	51.5
	5	1.10	1.23	6.59	11.95	46.8	85.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \le 80$ km/h	1	0.4	0.6	2.40	3.30	7.4	9.9
	2	0.2	0.3	00.7	0.85	1.50	2.00
	3	1.30	1.50	2.88	4.55	17.3	28.0
	4	1.30	1.50	4.50	8.00	30.7	51.5
	5	1.3	1.5	6.25	12.50	47.0	85.0

	Vehicle class	Gradient					
		-12%	-6%	-2%	0	6%	12%
$v \le 90$ km/h	1	0.5	0.8	2.64	3.56	8.0	10.0
	2	0.25	0.4	0.75	0.90	1.55	2.00
	3	1.80	2.00	3.23	5.50	17.4	28.0
	4	1.80	2.00	5.70	9.50	30.8	51.5
	5	1.80	2.00	8.40	14.0	47.0	85.0

4.2.4 NO_2 fraction of tailpipe NO_x

The emitted amount of NO_2 is calculated as a certain fraction of NO_x (Table 8), depending on the vehicle class and gradient of the road. Due to lack of data otherwise, the NO_2 fraction of NO_x is assumed constant as a function of driving speed.

The method for linear interpolation between the gradient classes, in shown in Table 9.

Table 8: $\frac{NO_2}{NO_x}$ as a function of vehicle class, for roads with gradient -4%, 0% and 4%.

	Road gradient class		
Vehicle class	downhill (-4%)	flat (0%)	uphill (+4%)
1	20	3	4
2	20	15	4
3	20	15	4
4	20	15	4
5	20	15	4

Table 9: Interpolation to find $N = \frac{NO_2}{NO_x}$ as function of road gradient g.

g	N
$\leq -4\%$	N(down)
$-4\% < g < 0\%$	$N(flat) + \frac{g}{4}\,[N(flat) - N(down)]$
$0 = g \leq 4\%$	$N(flat) + \frac{g}{4}\,[N(up) - N(flat)]$
$g > 4\%$	N(up)

4.2.5 Emissions from cars in cold start mode

The cold start mode is defined as the first 6 minutes of driving, corresponding to 2 km in urban areas. It corresponds to the first part of the ECE R15 driving cycle.

The emission factors for CO from light duty petrol cars are corrected according to the cold start fraction.

For non-catalyst cars, the cold start emission correction factor for CO is set to 2.67, and is taken from NBB (1984), valid for 0° C. For non-catalyst cars, cold start is assumed to have no effect on NO_x-emission.

The cold start fractions used in RoadAir are shown in Table 10 below.

Table 10: Cold start fraction as a function of road class and time of calculation. Average for morning and afternoon rush-hours, as well as 24-hour average. Values taken from NBB.

Street Class		Morning	After-noon	24 hrs.
1: Main road/through fare road		25%	25%	25%
2: Main road, urban area		15%	40%	25%
3: Main road, residential area		40%	15%	25%
4: Main road, industrial area		15%	25%	25%
5: Local road	OTY* = 1	5%	5%	5%
	OTY = 2	25%	25%	25%
	OTY = 3	40%	15%	25%

*) OTY = area type

At present, the differentiation of cold start fraction is the only use of the morning/afternoon parameter in RoadAir. The cold start fraction on roads not included in the defined network ("low traffic roads") is set equal to 25%.

Catalyst cars in cold start mode are considered to have CO- and NO_x-emissions equal to non-catalyst cars in cold start mode.

This leads to the following correction factors due to cold start fraction:

$$\mathrm{FAKCO} = \mathrm{BPB}\ (1 + 1.67\ \mathrm{CLSTART} + 0.9\ \mathrm{CLSTART} + \mathrm{RAN} - 0.9\ \mathrm{RAN})$$
$$\mathrm{FAKNO} = \mathrm{BPB}\ (1 - 0.9\ \mathrm{RAN} + 0.9\ \mathrm{CLSTART} * \mathrm{RAN})$$

BPB = fraction of petrol driven vehicles
RAN = fraction of catalyst cars
CLSTART = cold start fraction

4.2.6 Rate of renewal of the vehicle fleet

Class 1, light duty petrol vehicles: The renewal rate is set to 7% per year. All new cars after 1.1.89 are equipped with a three-way catalyst. The resulting fraction of catalyst cars is shown in Table 11 below. In catalyst cars with hot engines, the emissions are reduced to 10% compared to non-catalyst.

Table 11: Fraction of petrol driven cars equipped with 3 way catalyst, from 1990 until 2002.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Fraction	.06	.12	.20	.28	.36	.44	.51	.58	.65	.72	.79	.86	.93

A further reduction in NO_x-emissions is achieved if the so called California-restrictions are chosen during programme execution. See Table 12 for the fraction of "California"-cars. The

"California" cars emit 65% of the NO_x from a warm catalyst car, according to the reduction of the emission standard, from 0.62 g/km to 0.40 g/km.

Table 12: Percentage of light duty petrol driven vehicles satisfying the California standard for NO_x emission, from 1996 to 2009.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Fraction California cars, F	.06	.12	.20	.28	.36	.44	.51	.58	.65	.72	.79	.86	.93	.100

<u>Class 2, light duty diesel vehicles</u>: The renewal rate is approximately 10% per year.

CO : Pre 1989-emission : 24,6 g/km
Emission after 1989[1] : 4,09 g/km
NO_x : Pre 1989-emission : 2,65 g/km
Emission after 1989 : 0,34 g/km

<u>Classes 3-5, Heavy duty vehicles</u>: The renewal rate is approximately 7% per year.

CO : Present emissions : 4 g/km
Emissions after 1994 : 3 g/km

NO_x : Present emissions : 18 g/km
Emissions after 1994 : 9 g/km*
*Used if "stricter emission regulations for heavy duty vehicles" is chosen from 1994.

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[1] The regulations are valid for all cars bought after 1.1.89.

Class 4, including buses: The renewal rate is approximately 8% per year.

CO : Present emissions : 4 g/km
Emissions after 1994: 3 g/km

NO_x: Present emissions : 18 g/km
Emissions after 1994: 9 g/km

4.2.7 Emissions from road intersections

In the basic emission calculations, account is not taken of the extra emissions connected to deceleration, standstill and acceleration near intersections. These extra emissions are covered by subroutine "Kryssutslipp" ("Intersection emission"). A road link may have 0, 1 or 2 intersections connected with it. In RoadAir 2.0 two types of intersection are considered:

- intersection with traffic signals
- intersection with no traffic signals
- roundabouts

The fraction of vehicles forced to stop before crossing the intersection, k, is set to

- no traffic light k= 0
- traffic light k = 0,5
- roundabout k = 0,25

Intersection emissions of CO are calculated assuming only class 1 vehicles. Intersection emissions of NO_x are calculated considering the actual fractions of light- and heavy duty vehicles on the links adjacent to the intersection.

The emission equations used are:

$$\Delta q_{CO} = 45\ k\ AADT\ \ q_V\ \frac{V}{50}\ (\frac{48}{q_V} - 1)\ \text{[mg/s per (road link)]} \qquad (1)$$

$$\Delta q_{NO_x} = 45\ k\ AADT\ \frac{V}{50}\ [q_{V,light}\ (1 - TA)\ (\frac{5,4}{q_{V,light}}) + q_{V,heavy}\ TA\ (\frac{26}{q_{V,heavy}} - 1)] \qquad (2)$$

Nomenclature:

t - time (s)
q - emission factor (mg/s*vehicle)
AADT - annual average daily traffic (vehicles/s)
s - distance (m)
q_V - emission factor (mg/m*vehicle)
Δq - increase in emission from a link due to the intersection
k - fraction of vehicles forced to stop

Subscript:

r - deceleration
a - acceleration
t - standstill
l - "light" vehicles
h - "heavy" vehicles

It is assumed a time interval of 1 minute between each green signal, and the average duration of vehicle standstill is assumed to be 15 sec. Δq is not very sensitive to the length of this time interval. Increasing signal intermittance from 1 min. to 2 min:

Δ_{CO} increases 30%
Δq_{NO_x} almost unaffected.

In deciding the value of k for traffic lights, we have assumed that 50% of the vehicles will be stopping, and that the time intervals for red and green signals are equal. A further development would be to let k be a function of the way the traffic lights are programmed (e.g. green waves), or possibly of the differences in AADT for the two intersecting roads.

For roundabouts, k is set to 0.25. In other words, we assume that 25% of the vehicles have a behaviour corresponding to stop at traffic lights. This fraction might seem too high, but most vehicles will go through some degree of retardation/acceleration when passing the roundabouts.

4.2.8 Emission from low traffic roads

When the road network of the calculation area is defined, often only roads with a certain traffic activity are included. In other cases only a certain category of roads will be included, e.g. the public main roads. The model gives the possibility of estimating the emissions of CO, CO_2 and NO_x from roads not included in the define network.

There are no general rules governing how large fractions of the traffic activity on the defined road network is in comparison with the remaining roads, so data on this must be given. This may be done either by giving the absolute traffic activity on these roads, or by giving traffic activity in percentage of that on the defined road network.

5 DISPERSION MODULE

5.1 CONCENTRATION CALCULATIONS

Street canyons

For calculation of concentrations in street canyons, RoadAir 2.0 uses Nordic method of calculation of vehicle exhaust gases (NBB, 1984). The concentrations are calculated at the facades, 3 m above ground level.

The concentration are calculated as follows:

$$\text{Concentration } [g/m^3] = \text{Emission } [g/m \cdot s] * C$$

The function C has the dimension $[s/m^2]$.

The C algorithm in the model is as follows:

$$C = F \cdot 8.95/(AL + X + 2.75)$$

X : n * road width (between sidewalks) [m]
AL: width of the sidewalk [m]
F :
- For calculation of annual 99th percentile values, which is calculated in the NBB model, F = 1.0
- For calculation of maximum and 99th percentile values, F = 1.5, based on the ratios between maximum and 99th percentile values (hourly averages) from the data base from Scandinavian streets mentioned below.

The function C is derived from the street canyon dispersion algorithm for the leeward side of the street in the APRAC dispersion model (ref.).

This APRAC algorithm was slightly modified during the development of the NBB model, based on comparison with a data base from curb-side measurements of CO and NO_2 in several streets in Scandinavian countries during the period 11975-1980 (ref.).

The value of n in the expression for X above, depends on whether there is traffic in one or two directions:

CASE 1:
Traffic in each direction of the road link is given separately in the input file, and traffic in direction 1 is larger than traffic in direction 2:

Concentration = Emission 1 * C1 + Emission 2 * C2

C1 = C(AL, X1)   X1 = 0.75 * road width
C2 = C(AL, X2)   X2 = 0.25 * road width

CASE 2:
One way traffic or traffic in both directions added together as one road link:

Concentration = Emission * C, X = 0.5 * road width

Highways

Near urban roads which cannot be described as "street canyons", i.e. roads without continuous building facades along both or one side of the road link, dispersion is calculated by use of the model NEWAY, which is a modified version of the U.S. Environmental Protection Agency (EPA) HIWAY model (Petersen, 1980).

To better reflect the problems related to dense trafic at intermediate and low vehicle velocities, and to avoid odd features close to the roadside from the wind direction dependency of initial dispersion, the modification of initial dispersion due to the angle between the road and the wind-vector was removed.

The concentrations near such roads are calculated based on the following configuration:

A single straight road section is considered. The road is 10 m wide, 200 m in each direction from the point of calculation, and the directional split in the rush hour traffic flow is 60/40%. A wind of 0.4 m/s velocity and 15° angle to the road is used, and the atmospheric stability is "slightly stable".

The concentration profiles from NEWAY as a function of distance from the road center-line, for the given conditions, are shown in Figure 2, for a unit emission of 1 g/m·s. In RoadAir, the curve for 15° angle between road and wind directions is used, since this produces the highest concentrations in the 15-20 m section closest to the road, which is the area of interest for RoadAir calculations.

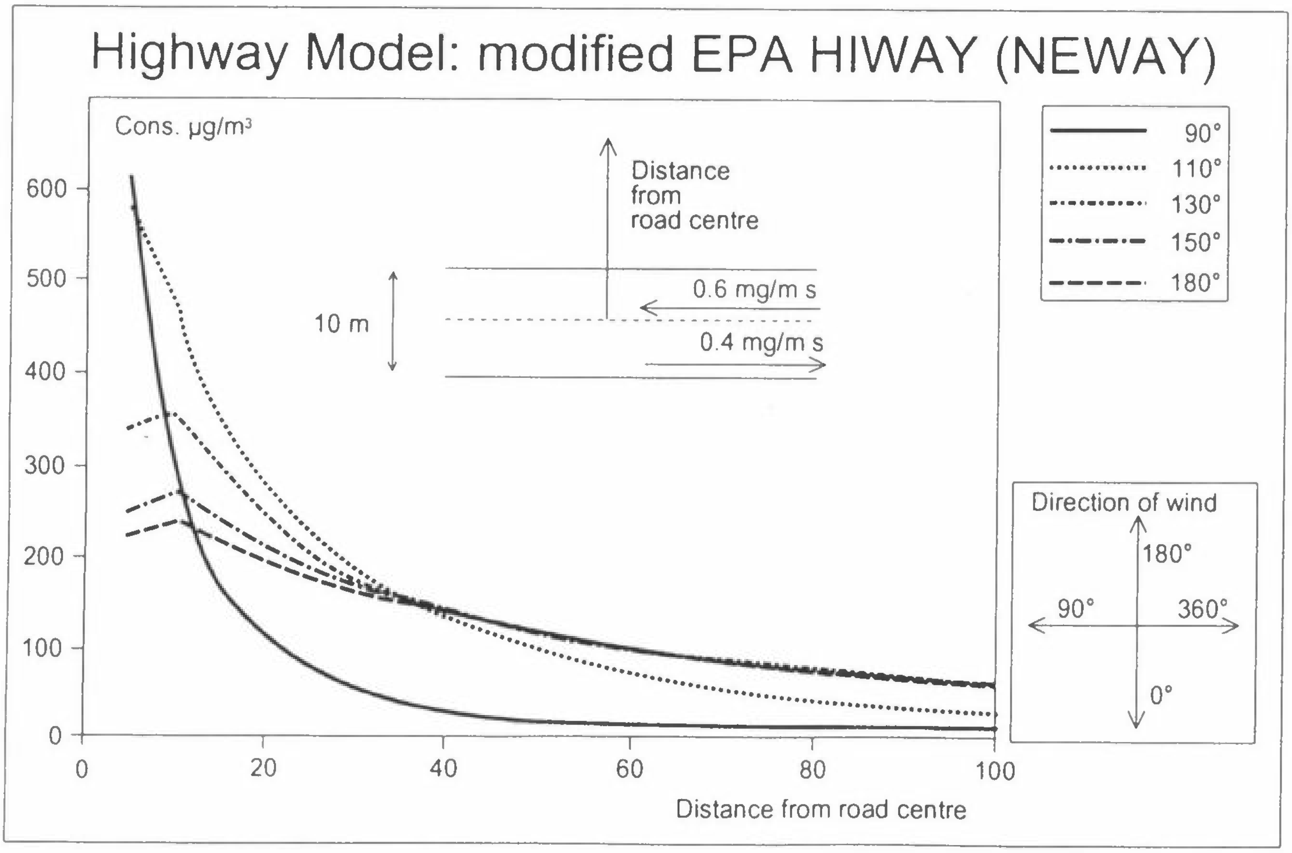

Figure 2: Concentration as a function of distance from curb, given by the modified HIWAY-model (NEWAY), for different angles between wind and road direction.

5.2 CITY BACKGROUND CONCENTRATIONS

The pollution concentration along a given road equals the sum of the city background concentration and the concentration due to emissions from the traffic on the road in question.

The city background level is due to local emissions from other sources (traffic, heating, industry) other then the street in question, and to long range transport.

The background level of CO and NO_2 will vary according to the location in the city (centre outskirts) as well as the dispersion conditions. For urban areas the background pollution tends to decrease from the centre towards the outskirts.

The city background NO_2 concentration is calculated as the sum of direct-emitted NO_2 background and the background due to secondary-formed NO_2 through the reaction of NO with O_3. For high pollution episodes in streets during winter conditions in Europe, this NO_2 formation is covered by the reaction:

$$NO + O_3 \longrightarrow NO_2 + O_2$$

The background level of ozone in the Nordic area is mainly due to long range transport. Based on regional background O_3 measurements, a value of 60 $\mu g/m^3$ is suggested to be used to account for the ozone contribution to NO_2 during high-pollution winter episodes.

To determine the city background concentration for CO and NO_2 in an area of interest, it is recommended that measurements are made in city background locations in the area. However, such a measurement program is time consuming and expensive, and thus prohibitive in many cases. For that purpose, we have recommended city background values for CO and NO_2 to be used in Scandinavian countries, to be added to the calculated maximum street/road concentration contribution. These values are given in Table 14, as a function of city population and location in the city (centre, intermediate, outskirts).

Table 14: Recommended city background pollution levels of CO, NO_2 and O_3 in Norway.
The values depend on area type and town population.
The values for NO_2 and O_3 are to be added, to give the total NO_2 background.

Population	CO (mg/m^3)		(NO$_2$ /µg/m^3)		O$_3$ (µg/m^3) (regionally)
	Central urban area (OTY = 3)	Intermediate area (OTY = 2)	Central urban area (OTY = 3)	Intermediate area (OTY = 2)	
< 50 000	4	3	27	17	60
50-200 000	6	4	39	25	60
>200 000	11	7	68	43	60

For area type 1 (outskirts), the background pollution values are fixed in the programme: 1 mg CO/m^3, 5 µg NO$_2$/m^3. The table 14 below gives values suggested for area type 2 and 3. These values are proposed for Nordic towns.

6 ROAD DUST DEPOSITION

Resuspension of road dust is the major cause of dust deposition near road. As for "nuisance", the road dust module is valid for the dry part of the winter season, in countries where studded tyres are in frequent use.

The following equation is used:

$$W = W_o \frac{AADT}{AADT_o} \cdot f_v \cdot f_{tt} \cdot f_d + W_b$$

W - maximum dust deposition ($g/m^2 \cdot month$)
W_b - dust deposition, background value
AADT - average 24 hr traffic
f_v - function of resuspension vs. vehicle driving velocity
f_{tt} - function of resuspension vs. fraction of heavy duty traffic
f_d - function of dust deposition vs. distance from the road side
the subscript "o" is used for the reference situation (see below).

Resuspension is assumed to be proportional to the square of the driving velocity ($f_v \alpha V^2$).

Resuspension is as a first estimate assumed to be proportional to the air resistance of the vehicles:

$$f_{tt} \quad \alpha \quad 1 + \frac{k_2}{k_1} TA$$

k_1 and k_2 - air resistance factors of light and heavy duty vehicles respectively.
TA - fraction of heavy duty traffic.

The ratio k_2/k_1 is set to 10.

f_d is based on a series of measurements of road dust deposition that have been carried out by NILU in Oslo.

Based on this, the following equation can be set up, describing the road dust deposition rate:

$$W = W_o \frac{AADT}{AADT_o} \left(\frac{V}{V_o}\right)^2 \frac{1 + \frac{k_2}{k_1} TA}{1 + \frac{k_2}{k_1} TA_o} \cdot f_d + W_b$$

The reference traffic situation is described by $AADT_o$, V_o and TA_o. W_o is the road dust deposition in the reference situation.

RoadAir 2.0 uses the model described above for calculating maximum monthly road dust deposition (in $g/m^2 \cdot month$) along each road link. The deposition may be calculated at 5, 10 or 20 m from the curb for roads without facades. Along roads with one- or two-sided facade coverage dust deposition is calculated 5 m from the curb. The classification of the dust deposition situation is shown in Table 11 below.

W_o is set to 175 $g/m^2 \cdot month$ at 5 m distance from the curb, for $AADT_o$ = 70 000 vehicles/24 hrs, V_o = 80 km/h and TA_o = 0.15. The distance function f_d is set to 1.0 at 5 m, 0.6 at 10 m and 0.35 at 20 m distance from the curb.

Table 11: Classification of road dust deposition.

Category	Little dust deposition	Medium dust deposition	High dust deposition	Severe dust deposition
Road dust class	1	2	3	4
Deposition rate [g/m^2 * month]	<5	5-10	10-20	>20

7 POPULATION EXPOSURE, AND "NUISANCE"

RoadAir 2.0 calculates the exposure of the residents along the roads to concentrations of CO and NO_2.

The basis is the "building register" input file, which should contain data on the distance to the nearest main road, and the number of residential units, for each of the buildings within about 100 m from the road system.

The exposure calculations are made by the NEWAY model, irrespective of the facade coverage. For each building in the register, the maximum concentration is calculated, using the wind direction which gives the highest concentration at each given distance (see Figure 3). The number of people is calculated from the number of residential units, and the average occupancy number of each residential unit in the area (to be taken from local population statistics).

The resulting population exposure is given as the number of people in each of four concentration intervals, based on the concentration calculated for the ground level at the facade facing the street/road.

The experience of nuisance from air pollution along roads is due to the following factors:

- odour
- particles from the vehicle exhaust
- road dust.

The relative importance of these three factors to the nuisance experienced by individuals cannot easily be described. Odour from exhaust will mainly be due to volatile organic compounds, coming from both diesel and gasoline combustion. Exhaust particle emissions come mainly from diesel vehicles. The generation and resuspension of road dust is mainly due to the heavy duty vehicle fraction of the traffic flow.

It should be noted that the nuisance calculations are valid for the dry winter situation in countries where studded tyres are used extensively. The model is based on NO_2 concentrations as an indicator of nuisance. The reason for this is that both odour, exhaust particles and road dust particles is to a large extent due to heavy duty vehicles, which are also the main contributors to the NO_2 emissions. The quantitative connection between NO_2 concentrations and the number of people "severely bothered" is shown in Table 10 below. The numbers are based on results from the Traffic and Environment Project which was carried out in an area of Oslo with heavy traffic (Samferdsel, 1991).

Table 10: Relationship between NO_2 concentrations and fraction of the population "severely bothered" by air pollution from traffic. The numbers are valid for the urban, winter situation of 1991 in Oslo.

Interval for maximum 1-hr average NO_2-concentration	Percentage of exposed people being severely bothered
<35	0
35- 75	15
75-125	30
125-175	40
175-225	50
225 275	65
275-325	75
>325	85

8 CHECKING OF THE INPUT DATA

Prior to the checking of input data in subroutine "Beregninger" ("calculations"), the following parameters are assigned a value in the cases where they have the value 0 in the input file (for nomenclature, see the User's manual):

TA = DTT (GKL), (p4)

Mmax = AADT * Trad (GKL, ITID)

$$\text{Bmax} = \text{AADTB} * \frac{\text{Mmax}}{\text{AADT}}$$

Vmax = V

Tmax = Tmax (GKL)

The following tests are made on the input data
(They should satisfy the following criteria):

- $1 \leq \text{GKL} \leq 5$
- $\text{KB} > 0$
- $0 \leq \text{RE} \leq 2$
- $1 \leq \text{OTY} \leq 3$
- $1 \leq \text{FD} \leq 6$
- $0 \leq \text{TA} \leq 100$
- AADT # 0 or AADTB # 0
- $\text{V} \geq 0$
- $\text{L} \geq 0$
- $\text{Mmaks} \geq 0$
- $\text{FA} \geq 0$
- $-\text{Vmaks} \leq 0$
- $0 \leq \text{Tmaks} \leq 100$
- $\text{Bmaks} \geq 0$
- $\text{FB} \geq 0$
- $\frac{\text{AADT-B}}{\text{AADT}} - \frac{\text{TA}}{100} \leq 0$

- Bmaks < AADT-B
- Mmaks $\leq$ AADT
- Bmaks $\leq$ Mmaks

9 OTHER POINTS OF INFORMATION

- The maximum number of links is 2000.

- There are certain lower limits for the values of Vmaks, Tmaks, Bmaks and Mmaks in the input data. Standard values are used below these limits:

  . Mmax must exceed 1, if not the values in table 15 are used.

  . Bmax (the number of buses per hour in the rush hours) must exceed 0.5. If not the following value is used:

  $$\frac{AADT_{bus}}{AADT} * M_{max}$$

  . Tmax must be greater than 0. If not, it is set equal to TA.

  . Vmax must be greater than 0.5. If not, it is set equal to V.

- Sorting is done by the "bubblesort" algorithm.

- The user is asked whether the calculation should be done for morning or afternoon rush hour. According to this, a value is assigned to the variable ITID, which affects the following variables.

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ABSTRACT

This is the documentation of the programme RoadAir 2.0, developed at the Norwegian Institute for Air Research. The programme calculates emissions CO, CO_2 and NO_2 and concentrations and exposure to CO and NO_2 in connection with road traffic.

* Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C