Model Calculation of Environment-Friendly Traffic Flows in Urban Networks

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The environmental impact of traffic flows in urban networks is an increasingly serious problem. The possibilities are investigated of modifying route choice of traffic in urban networks to meet the standards for noise annoyance and the emission of pollutants. Therefore, for each link of the network an environmental capacity is defined, being the minimum capacity of a link resulting from the selected environmental standards. The maximum flow on a link is defined by the minimum of the environmental capacity and the free flow capacity. By assigning the traffic to the network using the equilibrium assignment technique, a desired pattern of flows is obtained that meets the environmental standards as far as possible. The model is applied to the network of the town of Ede-Bennekom, the Netherlands.

One of the drawbacks of increasing use of the automobile is its impact on the environment. The Dutch government has been giving this wide-ranging environmental issue a great deal of consideration, which has resulted in a set of policy measures. First, extensive regulations (e.g., the Noise Act) have been laid down as to the qualification and quantification of environmental annoyance. On the one hand, these regulations specify the limiting values, the standard values, and the preferred values within which particular environmental effects should be kept. On the other hand, standard methods are given by which these effects can be assessed and mapped, e.g., *Technical Aspects of Air Quality Regulations*, and the *Environmental Impact Map*. Second, research is being carried out on the kind of measures that will decrease undesirable and polluting side-effects of various activities (e.g., the introduction of petrol with low lead levels and the establishing of routes for the transport of noxious materials). From the mid-1980s, the Dutch government has adhered to the so-called "stand-still" principle. This principle implies that the levels of the various kinds of environmental pollution must (at least) not be increased.

The main subject is the environmental impact of road traffic. In order to illustrate its scale, in 65 percent of noise annoyance cases road traffic is the chief source; road traffic is responsible for more than half of the emission of carbon monoxide (70 percent), lead (80 percent), and nitrogen oxides (50 percent).

The predicted drastic increase in motor traffic (*1*) will lead to a more extensive use of the existing infrastructure, with all its consequences for the environs. Concern about the environment will result in the phased introduction of stricter standards with respect to environmental effects, making it obligatory for local authorities to issue reports and take particular measures, i.e., reorganizing town and transportation planning in existing situations or else adjusting it to new situations.

A model is especially well suited for determining an assignment (circulation) of traffic in an area in such a way that a favorable situation will arise with respect to meeting the various environmental standards. This approach merits considerable attention for the following reasons:

- The model indicates to what extent desired environmental standards can be met and on which road segments measures to this end will be required;
- By modifying traffic flow circulation, integral measures are taken at the source; by decreasing traffic at an environment-critical site, polluting factors will become less serious.
- Particularly in situations where the greatest problems may be expected to occur (urban agglomerations), alternative approaches are often scarce. Noise barriers cannot be built everywhere.
- By taking into account the future development of traffic, policymakers will be able to deal with the present situation and to anticipate expected developments.

Houtman and Immers (*2*,*3*) have recently developed a model by means of which an environment-friendly traffic assignment can be established on the basis of permissible noise levels, as specified in the Noise Act. This model was extended with a component for air quality requirements. The most important features on the previously developed model are briefly explained. Then the theoretical background and possibilities for integrating air quality requirements into the existing model are considered. The results of some sensitivity analyses and an application of the model are presented and analyzed, after which some conclusions and recommendations are drawn. An extensive report of the research project was provided by Oosterbaan (*4*).

NOISE ANNOYANCE

Traffic in residential areas may have considerable consequences for human well-being. Many local authorities are faced with the question of which measures to take to meet a desired environmental quality. In order to answer this question efficiently, a model has been developed at Delft University of Technology that optimizes noise annoyance in connection with accessibility.

Central to the model is the environmental capacity (X_a) for Road Segment a, defined as the capacity (veh/hr) resulting from the standards for the emission of noise [see Dutch legal

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standard, calculation method I (*5*)]. Equation 1 was derived by Houtman and Immers (*2*).

$$X_a = \left(\frac{d}{p_l \cdot 10^{Y_l} + p_m \cdot 10^{Y_m} + p_z \cdot 10^{Y_z}}\right) \cdot 10^{L_{max}/10} \quad \text{(veh/hr)} \tag{1}$$

where

Y = noise emission parameter;
$Y_l = 5.12 + 0.021u_l - \log_{10} u_l$;
$Y_m = 6.84 + 0.009u_m - \log_{10} u_m$;
$Y_z = 7.62 + 0.003u_z - \log_{10} u_z$;
u_l, u_m, u_z = average speeds [automobiles (l), medium-heavy traffic (m), and heavy traffic (z)], km/hr;
p_l, p_m, p_z = fractions [automobiles (l), medium-heavy traffic (m), and heavy traffic (z)];
d = distance facade to road axis, m; and
L_{max} = maximum noise level, dB(A).

Per road segment (link), the minima are determined of the free flow capacity (C_a, the theoretical capacity, which is environmentally unconstrained) and of X_a.

Figure 1 shows the BPR travel time functions for C_a (solid line) and X_a (dotted line). The minima of both capacities are taken as the capacities determining the travel time when assigning the traffic to the network (the new capacity shown in Figure 2).

If the traffic is assigned to the network according to an equilibrium assignment technique (user-optimal travel time minimization with additional constraints as to the noise level), a desired pattern of traffic flows is obtained. This desired pattern indicates an equilibrium situation as regards travel times and meets the legal standards of noise emission as closely as possible.

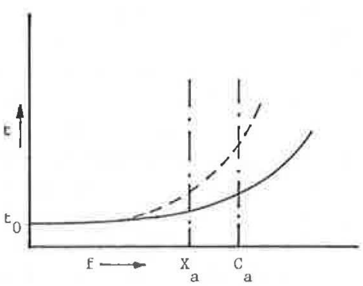


FIGURE 1 Environmental capacity X_a and free flow capacity C_a.

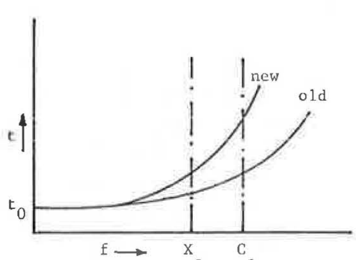


FIGURE 2 Arithmetical capacity, the minimum of the environmental capacity and free flow capacity.

The suitability of the model was tested by applying it to a real site, i.e., Ede-Bennekom (*2*).

As mentioned, the emission of noxious materials (gases) is another environmental threat. Similarly as for noise annoyance, the extent to which air quality requirements may be incorporated into the environmental capacity (and so into the assignment process) was investigated, so that with respect to this problem, too, the standards can be met as much as possible.

AIR QUALITY REQUIREMENTS

The Dutch government has both set the air quality standards and established the computation methodology of air pollution (*6,7*). The model calculations were limited to those for nitrogen oxide and carbon monoxide. Lead is left aside because it was assumed that the introduction of fuels with a reduced lead level will considerably decrease the emission of lead.

In *Technical Aspects of Air Quality Regulations* (*6,7*), standards are set and specifications are given of the model for calculation of air pollution from road traffic (CAR), developed by TNO.

The contribution of traffic to air pollution as a result of carbon monoxide (CO) emission is calculated as follows:

$$[CO] = N * E_s * \Phi * F_{region} * F_b + [CO]_{bg} \quad (\mu g/m^3) \tag{2}$$

$$E_s = (1 - p_v) * E_p + p_v * E_v \quad (\mu g/m\text{-sec}) \tag{3}$$

$$[CO]_{bg} = R_{CO} + S_{CO} * F_a \quad (\mu g/m^3) \tag{4}$$

where

$[CO]$ = resulting concentration of carbon monoxide ($\mu g/m^3$);
N = number of vehicles per 24 hr;
E_s = average emission ($\mu g/m$-sec);
p_v = fraction of nonautomobile traffic;
E_p, E_v = emission parameters for private cars and other traffic, respectively, depending on speed ($\mu g/m$-sec);
Φ = dilution factor (sec/m^2) depending on the type T of ground cover and the distance s between curb and road axis;
F_{region} = meteorological correction factor with respect to regional differences in wind velocity;
F_b = correction factor with respect to the Type I_b of street in relation to the presence of trees;
$[CO]_{bg}$ = background concentration of CO ($\mu g/m^3$);
F_a = distance between Road Segment a and the edge of the built-up area (km); and
R_{CO}, S_{CO} = constants for the measurement of $[CO]_{bg}$ ($\mu g/m^3$ and ng/m^4, respectively).

The type of trees variable I_b takes on the following values:

1 = No trees or a few trees within 30 m from the road axis.
2 = One or more rows of trees with distance between trees <15 m. There are openings between the crowns of the trees.
3 = Crowns of trees hang over the road.

The ground cover variable T takes on the following values (see Figure 3):

1 = Flat terrain, no or a few buildings or trees within 100 m from the axis of the road.
2 = All types other than 1, 3, 4, or 5.
3 = More or less unbroken buildings on both sides of the road. Distance to axis of road is less than 3 times the height of the buildings.
4 = The same as 3 but distance from buildings to the road axis is less than 1.5 times the height.
5 = Buildings on one side of the road. Distance to the road axis is less than three times the height. On the other side of the road, there are no buildings or they are far away from the road.

In the direct exhaust emission of nitrogen oxides, there is a large quantity of the rather harmless nitric oxide NO (for which there are no air quality requirements) and a comparatively small quantity of the much more toxic nitrogen dioxide (NO_2). However, by a chemical equilibrium reaction with ozone (O_3), NO is fairly soon converted into NO_2 according to the reaction

$$NO + O_3 \rightleftarrows NO_2 + O_2 \qquad (5)$$

On the basis of the emissions of nitrogen oxides (NO_x), the noxious concentration of NO_2 can be calculated as follows:

$$[NO_x] = \gamma * N * E_s * \Phi * F_{region} * F_b \quad (\mu g/m^3) \qquad (6)$$

$$[NO_2] = \theta * [NO_x] + \frac{\delta * [O_3]_{bg}}{H + [NO_x]} + [NO_2]_{bg} \quad (\mu g/m^3) \qquad (7)$$

$$E_s = (1 - p_v) * E_p + p_v * E_v \quad (\mu g/m\text{-sec}) \qquad (8)$$

$$[NO_2]_{bg} = R_{NO_2} + S_{NO_2} * F_a \quad (\mu g/m^3) \qquad (9)$$

$$[O_3]_{bg} = R_{O_3} + S_{O_3} * F_a \quad (\mu g/m^3) \qquad (10)$$

where

$[NO_x]$ = concentration of nitrogen oxides from direct emission ($\mu g/m^3$);
$[NO_2]$ = resulting concentration of nitrogen dioxide ($\mu g/m^3$);
θ = coefficient (= $\frac{5}{6}$) relating $[NO_2]$ to $[NO_x]$;
γ, δ, H = parameters dependent on the type T of ground cover;
$[NO_2]_{bg}$ = background concentration of NO_2 ($\mu g/m^3$)
$[O_3]_{bg}$ = background concentration of O_3 ($\mu g/m^3$)
R_{NO_2}, S_{NO_2} = constants for calculating $[NO_2]_{bg}$;
R_{O_3}, S_{O_3} = constants for calculating $[O_3]_{bg}$;
E_p, E_v, E_s = emission parameters (differing in numerical value from those for the case of CO); and
Φ, F_b = coefficients (differing in numerical value from those for the case of CO).

Analogous to the way noise annoyance was dealt with, the maximum flow per link is established for which the various

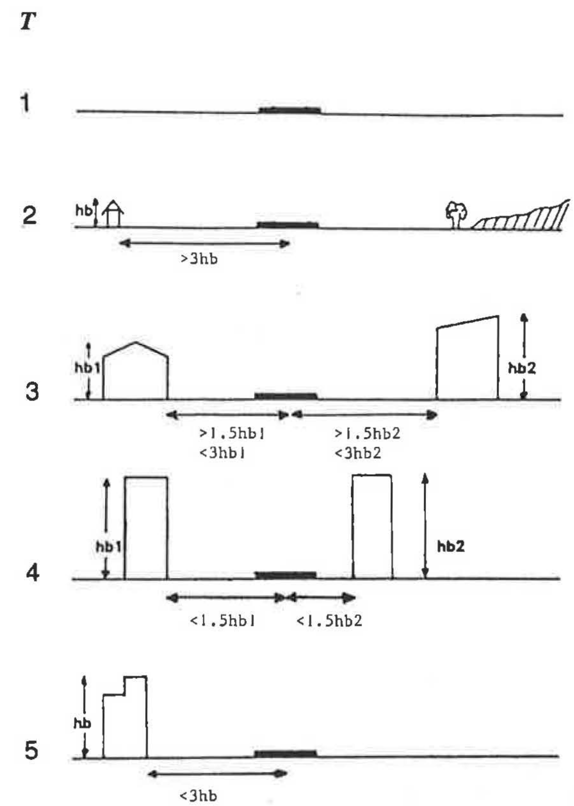


FIGURE 3 Description of ground cover variable *T*.

air polluting materials (gases CO and NO_2) do not exceed the relevant air quality standard.

From Equation 2, the maximum day flow (Q) can be determined on the basis of the air quality standard $[CO]_{max}$ for CO from the expression

$$Q(CO) = \frac{[CO]_{max} - [CO]_{bg}}{E_s * \Phi * F_{region} * F_b} \quad (veh/day) \qquad (11)$$

The environmental capacity $X(CO)$ for the emission of CO can then be computed from the expressions

$$X(CO) = \frac{Q(CO)}{10} \quad \text{(for one-way roads)} \qquad (12)$$

$$X(CO) = \frac{Q(CO)}{20} \quad \text{(for two-way roads)} \qquad (13)$$

During peak hours, the flow is assumed to be 10 percent of the 24-hr flow, and for two-way roads, 5 percent of the total flow (in both directions).

For the maximum concentration ($[CO]_{max}$), a temporarily increased limiting value of 15 000 $\mu g/m^3$ was established. This value will be decreased in four stages down to 6,000 $\mu g/m^3$ in the year 2000.

The maximum day flow on the basis of the standard for NO_2 can be calculated as follows:

$$Q(NO_2) = \frac{[NO_x]_{max}}{P * E_s * \Phi * F_{region} * F_b} \quad (veh/day) \qquad (14)$$

$[NO_x]_{max}$ can be calculated from Equation 7 as follows:

$$[NO_x]_{max} = [-B + (B^2 - 4AC)^{1/2}]/2A \quad (15)$$

where

$$A = \gamma \quad (16)$$

$$B = \gamma * H + \delta * [O_3]_{bg} + [NO_2]_{bg} - [NO_2]_{max} \quad (17)$$

$$C = H * ([NO_2]_{bg} - [NO_2]_{max}) \quad (18)$$

For $[NO_2]_{max}$, a temporarily increased limiting value of 160 $\mu g/m^3$ was established. This value will be decreased in two stages down to 135 $\mu g/m^3$ in the year 2000.

The environmental capacity for the emission of nitrogen oxides can be calculated by dividing the maximum day flow by 10 (for one-way roads) or by 20 (for two-way roads), respectively.

$$X(NO_2) = \frac{Q(NO_2)}{10} \quad \text{(for one-way roads)} \quad (19)$$

$$X(NO_2) = \frac{Q(NO_2)}{20} \quad \text{(for two-way roads)} \quad (20)$$

Incorporation of the air pollution standards in the model means that a great number of additional data must be introduced. Road segment coefficients will have to be introduced relative to

- Type I_b of trees,
- Type T of ground cover,
- Weighting coefficient J indicating the number of dwellings or residents per road segment.

Incorporation of J, the number of dwellings or residents per road segment, is based on the assumption that the effects of air pollutants should be weighted higher for road segments that are densely populated (many dwellings or residents along the road) than for road segments that are sparsely populated.

Furthermore, for every road segment a the distance up to the edge of the built-up area (F_a, see Equations 4, 9, and 10) is to be measured (see Figure 4). A number of additional nodes located at the edge of the built-up area were therefore defined (see Figure 5). The distance of a road segment up to the edge of the built-up area can then be computed by means of the x and y coordinates from the expression

$$F_a = \text{Max}(D_{pI}, D_{pII}) \quad (21)$$

where

$$D_{pI} = \text{Min}(d_n) \quad (22)$$

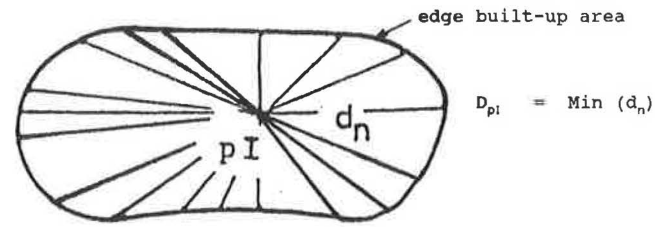


FIGURE 5 Distance from a node to the edge of the built-up area.

As with the noise aspect, it is possible to omit capacity computations with relation to the air quality for particular links, if, for instance, these have a clear traffic flow function. Per link, the capacity may now be calculated, i.e., the minimum value of the free flow capacity (C_a) and the environmental capacities for, respectively, noise, air quality for CO, and air quality for NO_2.

Per environmental aspect, an indication of the capacity reduction of the entire network can be obtained, on the basis of the limits set by the environmental standards, from the expression

$$\text{RESCAP}(I) = \left[\sum_{j=1}^{\text{NLINK}} \frac{\text{Min}(\text{ENVCAP}_j(I), \text{CAP}_j)}{\text{CAP}_j} * 100\right] / \text{NLINK} \quad (23)$$

where

RESCAP(I) = remaining network capacity with respect to environmental Aspect I, percent;
CAP_j = free flow capacity of Link j;
$\text{ENVCAP}_j(I)$ = environmental capacity of Link j with respect to environmental Aspect I; and
NLINK = number of links.

For the total of environmental aspects considered, the remaining network capacity can be calculated as follows:

$$\text{RESCAP(O)} = \left[\sum_{j=1}^{\text{NLINK}} \frac{\text{Min}(\text{INFO2}_j, \text{CAP}_j)}{\text{CAP}_j} * 100\right] / \text{NLINK} \quad (24)$$

where

RESCAP(O) = remaining network capacity with respect to all the environmental aspects, percent; and
INFO2_j = lowest environmental capacity of Link j.

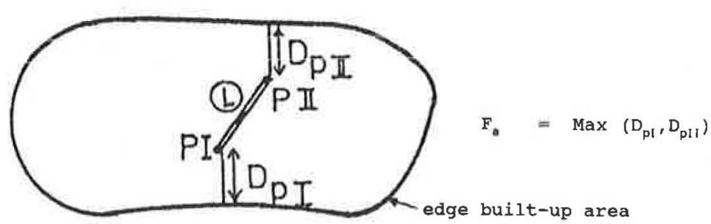


FIGURE 4 Distance from a link to the edge of the built-up area.

ANALYSES

Sensitivity Analysis

By means of a sensitivity analysis, the effects of the following five parameters on the environmental capacity were investigated for CO and NO_2.

1. Distance to edge of built-up area F_a,
2. Average speed u,
3. Percentage P_v of other vehicles (nonautomobiles),
4. Type of trees I_b, and
5. Type of ground cover T.

As to the values of the other parameters, three situations were distinguished in the calculations (with regard to air quality):

- The other parameters have favorable values,
- The other parameters have average values, and
- The other parameters have unfavorable values.

Some of the results of these sensitivity analyses are shown in Figures 6 and 7. The figures indicate the effects of modifications of average speed and percentage of other traffic. For CO, the maximum flow (environmental capacity) increases with average speed and with the percentage of other traffic; as for NO_2, on the other hand, the maximum flow decreases in both cases. In all cases, the limiting value for NO_2 determines the outcome.

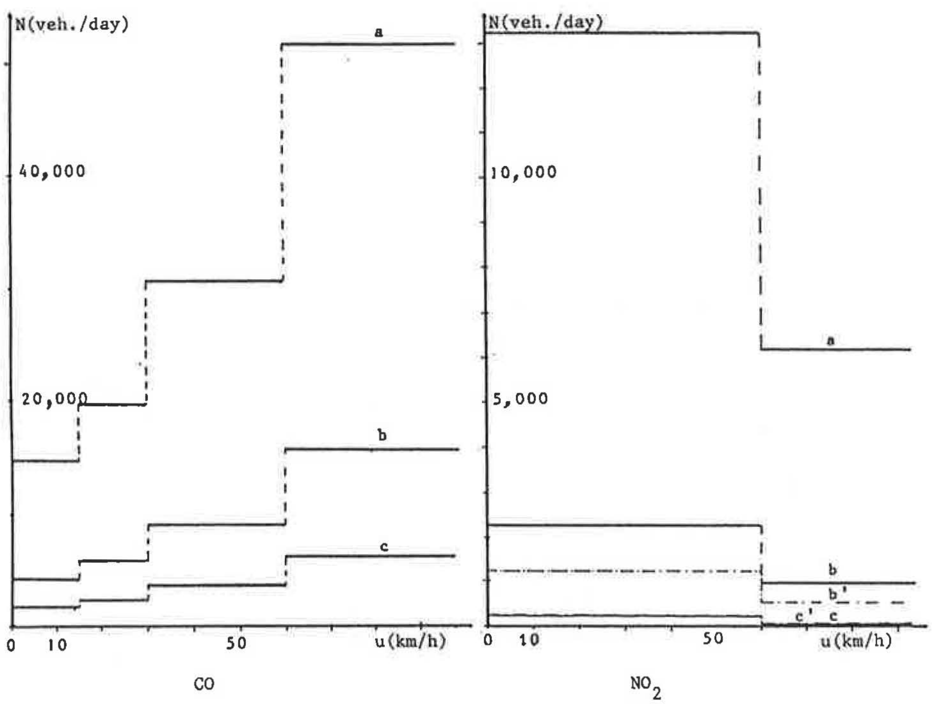
Other important results of the sensitvity analysis follow.

- The sensitivity of the maximum flow for a particular parameter increases with the extent to which the values of the other parameters are favorable,
- The maximum flow decreases with increasing ground cover,
- The maximum flow decreases with increasing distance to the edge of the built-up area, and
- The maximum flow decreases with an increasing number of trees along the road. (This is a short-term effect. In the long term, the presence of trees will have a positive effect on air quality.)

Model Calculations

In order to test the model, the network and the OD table of Ede-Benekom for the year 1995 were used, as drawn up by IWIS/TNO (*8*).

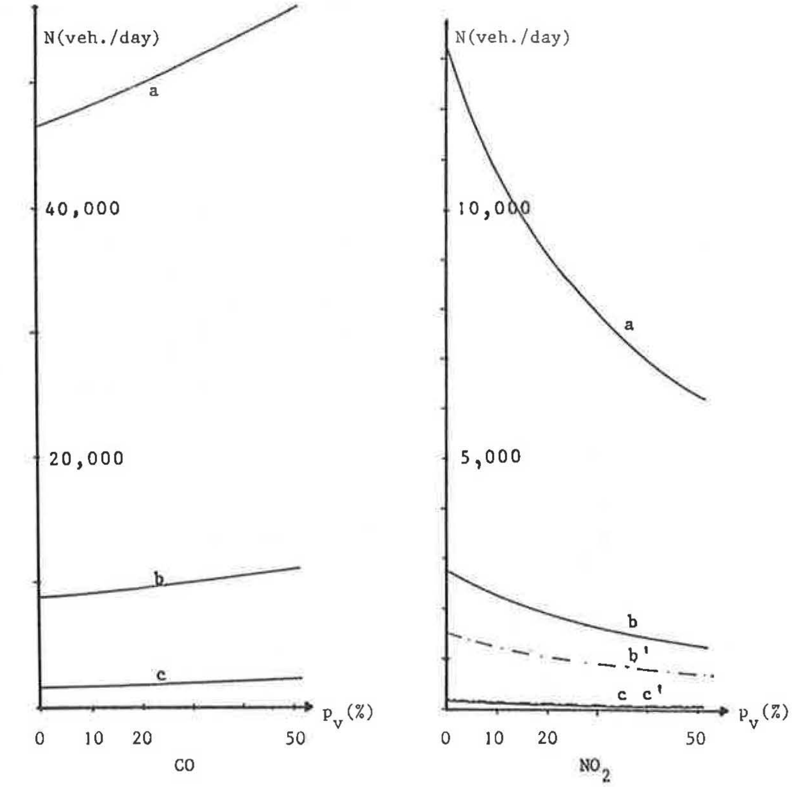
The network contains 264 nodes, comprising 57 centroids, and 859 one-way links (see Figure 8). The categorization in



Standard CO = 15000 $\mu g/m^3$, standard NO_2 = 160 $\mu g/m^3$, F_{region} = 1.05

a	: F_a = 0 km,	p_v = 0%,	T = 1,	I_b = 1
b	: F_a = 5 km,	p_v = 10%,	T = 3A,	I_b = 2
b'	: F_a = 5 km,	p_v = 10%,	T = 4,	I_b = 2
c	: F_a = 10 km,	p_v = 30%,	T = 3B,	I_b = 3
c'	: F_a = 10 km,	p_v = 30%,	T = 4,	I_b = 3

FIGURE 6 Relation between maximum day flow (*N*) (from the point of view of the standards for CO and NO_2) and the average speed (*u*).



Standard CO = 15000 $\mu g/m^3$, standard NO_2 = 160 $\mu g/m^3$, F_{region} = 1.05

a	: F_a = 0 km,	u = u_a,	T = 1,	I_b = 1
b	: F_a = 5 km,	u = u_b,	T = 3A,	I_b = 2
b'	: F_a = 5 km,	u = u_b,	T = 4,	I_b = 2
c	: F_a = 10 km,	u = u_d,	T = 3B,	I_b = 3
c'	: F_a = 10 km,	u = u_d,	T = 4,	I_b = 3

FIGURE 7 Relation between maximum day flow (N) (from the point of view of the standards for CO and NO_2) and the percentage of other traffic (p_v).

types of road was made according to, among other things, road cross section, average flow, and average speed. Per category of link, a fixed free flow speed, free flow capacity, and percentage of medium-heavy and heavy traffic were determined. The distance facade to road axis, ground cover, type of trees, and distance road segment to the edge of the built-up area vary for each link. The variables *F* region (meteorological correction coefficient for wind velocity), $[CO]_{max}$, and $[NO_2]_{max}$ have the same values for the whole network.

For the area, calculations were carried out for four scenarios:

1. A traditional equilibrium assignment, not taking into account environmental standards.
2. An equilibrium assignment taking into account the noise standard [60 dB(A)].
3. An equilibrium assignment taking into account the noise standard and the temporarily increased limiting values with respect to the air quality standards (CO: 15 000 $\mu g/m^3$; NO_2: 160 $\mu g/m^3$).
4. An equilibrium assignment taking into account the noise standard and very strict requirements regarding the air quality standards (CO: 3 000 $\mu g/m^3$; NO_2: 80 $\mu g/m^3$). These standards are far below the maximum concentrations established for the Netherlands for the year 2000 (CO: 6 000 $\mu g/m^3$; NO_2: 135 $\mu g/m^3$, see (*6,7*)].

The influence of the various quality standards on the traffic pattern is presented in Table 1 in which the remaining capacities [RESCAP(*I*)] for differing scenarios have been calculated.

In Ede-Bennekom, the influence of the air quality standards does not become noticeable until the very strict requirements are applied (Scenario 4).

Table 2 presents the traffic flow effects and the environmental effects resulting from the various assignments. (For explanation of class boundaries, see Table 3.) In order to get an impression of a possible oversaturation all over the network, the average saturation degree for the busiest directions of all roads together and the quietest directions of all roads together is determined. Scenario 2 will always exhibit larger values than Scenario 1 because most saturation degrees depend on the environmental capacity (which usually is smaller than the free flow capacity). Although noise annoyance is a subjective matter, investigations have indicated a remarkable

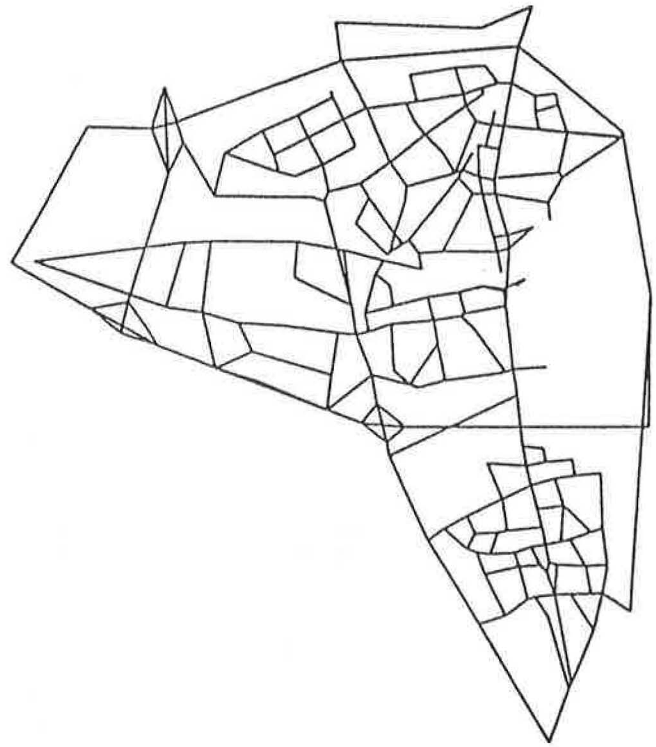


FIGURE 8 Network of Ede-Bennekom (*8*).

TABLE 1 REMAINING CAPACITIES [RESCAP(*I*), *I* = 1–4] IN THE FOUR SCENARIOS (PERCENT)

	Scenario			
Criterion	1	2	3	4
Noise	100	55.8	55.8	55.8
CO	100	100	100	95.1
NO_2	100	100	99.9	55.5
All criteria together	100	55.8	55.8	50.8

correspondence between the number of people strongly annoyed and the noise level (*2*).

For noise levels beyond the noise standard of 60 dB(A), noise brackets of 3 dB(A) have been defined, because this bracket size corresponds to doubling of the traffic flow.

The class boundaries for CO and NO_2 are more or less arbitrary (6 percent of the temporarily increased standard). No evidence could be obtained about the seriousness of the effects of an excess of the emission standards for CO and NO_2.

The results of the calculations as presented in Table 2 indicate the following:

- Air quality standards are of little or no significance (first column, Table 2, Scenarios 2 and 3). Scenario 3 is identical to Scenario 2. However, introduction of the noise standard does have a distinct influence on the traffic flow (compare Scenarios 1 and 2).
- When applying the very strict air quality standards (second column, Table 2, Scenario 4), a qualitative improvement and a quantitative deterioration occur (compare Scenarios 2, 3, and 4). The total number of road segments and the summed length of the road segments where one or more air quality standards are exceeded increase, but the magnitude of these excesses decreases. These occurrences are caused by a redistribution of the traffic from road segments far above the standard to road segments with a flow smaller than the environmental capacity. Remarkably, this redistribution manifests itself more strongly in the case of the less critical CO.
- When only the noise standard is applied, the air quality is also drastically improved (compare Scenarios 1 and 2, very strict standards). The added incorporation of the air quality standards has a varying effect on the assessments of the acoustic quality (somewhat more annoyance but fewer road segments where standards are strongly exceeded). These findings seem to indicate the need for compromises between the various quality requirements.
- Incorporation of the very strict air quality standards leads to an increase in the total vehicle mileage. In order to prevent environmental standards being exceeded, detours are made. The average number of vehicles (related to the free flow capacity) also increases. This increase is partly caused by the increase in mileage and partly by the assignment of the traffic to alternative routes with a low free flow capacity.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the tests performed, the following conclusions were drawn:

- Assuming (temporarily) increased limiting values, air quality standards do not play any part in assessing environ-

TABLE 2 RESULTS OF APPLYING STANDARDS

		Temporarily increased standards Standard Noise = 60 dB(A) Standard CO = 15000 $\mu g/m^3$ Standard NO_2 = 160 $\mu g/m^3$			Very strict standards Standard Noise = 60 dB(A) Standard CO = 3000 $\mu g/m^3$ Standard NO_2 = 80 $\mu g/m^3$		
Scenario		1	2	3	1	2	4
Noise	Class 1	24	55	55	24	55	59
	Class 2	30	24	24	30	24	32
	Class 3	28	13	13	28	13	8
	Class 4	3	0	0	3	0	0
	Class 5	0	0	0	0	0	0
	Index 1[1]	43628	41139	41139	43628	41139	42442
	Index 2[2]	43145	39747	39747	43145	39747	42190
	Index 3[3]	7794	6713	6713	7794	6713	6971
CO	Class 1	0	0	0	20	7	12
	Class 2	0	0	0	1	1	0
	Class 3	0	0	0	0	0	0
	Class 4	0	0	0	0	0	0
	Class 5	0	0	0	0	0	0
	Index 1[1]	0	0	0	4850	1190	3110
	Index 2[2]	0	0	0	1826488	626967	300356
	Index 3[3]	0	0	0	113059	71318	25762
NO_2	Class 1	0	0	0	40	50	55
	Class 2	0	0	0	12	14	19
	Class 3	0	0	0	18	4	4
	Class 4	0	0	0	7	1	1
	Class 5	0	0	0	1	1	0
	Index 1[1]	0	0	0	21310	19050	22400
	Index 2[2]	0	0	0	290734	167672	165858
	Index 3[3]	0	0	0	49130	23326	21191
Kilometrage (km)		89750	108717	108717	89750	108717	113503
Satur. degree (%		20.5	44.8	44.8	20.3	44.8	52.5
of free flow cap)		15.7	34.5	34.5	15.7	34.5	40.7

[1]) Total length of all road sections (a_j) exceeding Noise Standard (L_{norm}), CO standard resp. NO_2 standard.

[2]) For each class the total length of the road sections (see [1]) is multiplied by the excess of the standard (for noise the annoyance factor c_i). For CO: $\sum_j a_j * ([CO]_j - \text{Standard CO})$; for NO_2 : $\sum_j a_j * ([NO_2]_j - \text{Standard } NO_2)$.
The noise standard L_{max} = 60 dB(A) corresponds with an annoyance factor equal to 1; an excess of x dB(A) results in an annoyance factor $c_i = \exp.(0.1143x)$ (see also [2]).

[3]) See [2]) but length of road is replaced by number of dwellings along the road.

TABLE 3 CLASS BOUNDARIES FOR ENVIRONMENTAL ASPECTS

Class Boundaries for Noise Annoyance [dB(A)], L_{norm} = 60 dB(A)	
L_{norm}	< Class 1 ≤ L_{norm} + 3
L_{norm} + 3	< Class 2 ≤ L_{norm} + 6
L_{norm} + 6	< Class 3 ≤ L_{norm} + 9
L_{norm} + 9	< Class 4 ≤ L_{norm} + 12
	Class 5 > L_{norm} + 12
Class Boundaries for CO Emissions ($\mu g/m^3$), $[CO]_{max}$ = 15 000 $\mu g/m^3$	
$[CO]_{max}$	< Class 1 ≤ $[CO]_{max}$ + 1000
$[CO]_{max}$ + 1000	< Class 2 ≤ $[CO]_{max}$ + 2000
$[CO]_{max}$ + 2000	< Class 3 ≤ $[CO]_{max}$ + 3000
$[CO]_{max}$ + 3000	< Class 4 ≤ $[CO]_{max}$ + 4000
	Class 5 > $[CO]_{max}$ + 4000
Class Boundaries for NO_2 Emissions ($\mu g/m^3$), $[NO_2]_{max}$ = 160 $\mu g/m^3$	
$[NO_2]_{max}$	< Class 1 ≤ $[NO_2]_{max}$ + 10
$[NO_2]_{max}$ + 10	< Class 2 ≤ $[NO_2]_{max}$ + 20
$[NO_2]_{max}$ + 20	< Class 3 ≤ $[NO_2]_{max}$ + 30
$[NO_2]_{max}$ + 30	< Class 4 ≤ $[NO_2]_{max}$ + 40
	Class 5 > $[NO_2]_{max}$ + 40

mental annoyance in the Ede-Bennekom network. (In a compact town, this may be entirely different).

- Application of strict standards clearly indicate that incorporation of environmental annoyance with respect to air pollution influences the results of the assignment process.
- The effects of the various environmental aspects on the traffic assignment process may be graded as follows: (a) noise, (b) air quality for NO_2, and (c) air quality for CO.
- If different environmental standards are incorporated into the assignment process two effects may be observed: (a) in many cases adjusting the assignment process for one environmental aspect leads to an improvement of other environmental aspects that were not incorporated into the assignment process; and (b) by adding an environmental aspect, the improvements in the traffic circulation calculated for another environmental aspect may be partly nullified.

Besides the recommendations with respect to noise annoyance as stated by Houtman and Immers (*2*), it may, for a greater understanding of the problems of air quality and the applicability of the relevant software, be interesting to investigate the following points:

- Application of the model in a situation more problematic as regards air pollution, e.g., a medium-size, compact town (e.g., Delft).
- Research into the magnitude of the annoyance as a function of the extent to which the air quality standards are exceeded. (In the present model, the excess itself is taken as a measure of the annoyance experienced).
- Incorporation of the increasing travel times in calculations of environmental effects.

The results of the model calculations indicate where a reduction of the free flow capacity should be implemented to meet the environmental standards. Possible measures that can be applied to reduce the capacity of a road section are reducing the number of lanes, reducing the lane width, displacing the road axis, changing the signal settings, and introducing speed ramps (*9*).

REFERENCES

1. R. Hamerslag, B. H. Immers, and W. H. Scheltes. The Influence of Economic Recession and Changing Fuel Prices on Car Mobility in the Netherlands. *Proc., 4th World Conference on Transport Research*, Vol. 2, 1986, Vancouver, British Columbia, pp. 1030–1050.
2. J. W. Houtman and B. H. Immers. A Traffic Assignment Model to Reduce Noise Annoyance in Urban Networks. In *Transportation Research Record 1143*, TRB, National Research Council, Washington, D.C., 1988, pp. 17–21.
3. J. W. Houtman. *Research into the Effects of Speed Reducing Measures on Travel Time in Networks*. Research Report, Department of Transortation Planning and Highway Engineering, Delft University of Technology, Delft, The Netherlands, Feb. 1985.
4. N. G. J. Oosterbaan. *A Model for the Calculation of Environmental-Friendly Traffic Flows in Relation to the Standards for Noise Annoyance and the Emission of Noxious Gasses*. Research Report, Department of Transportation Planning and Highway Engineering, Delft University of Technology, Delft, The Netherlands, June 1988.
5. Ministry for Housing, Physical Planning, and Environmental Protection. *Noise Level Calculation Methods (in Accordance With the Noise Annoyance Act)*. Staatsuitgeverij, Hague, The Netherlands, 1981.
6. Ministry for Housing, Physical Planning, and Environmental Protection. Technical Aspects of Air Quality Regulations, Carbon Monoxide and Lead. *Publication Series Air*, Vol. 52, Staatsuitgeverij, Hague, Oct. 1986.
7. Ministry for Housing, Physical Planning and Environmental Protection. Technical Aspects of Air Quality Regulations, Nitrogen Dioxide. *Publication Series Air*, Vol. 64, Staatsuitgeverij, Hague, The Netherlands, Aug. 1987.
8. IWIS/TNO. *Traffic Study Ede/Bennekom 1979*, Vols. A and B (1980) and Final Report, Phase 2, Vols. I and II, Delft, The Netherlands, 1981.
9. J. W. Houtman. Possibilities for Speed Reduction of Car Traffic in Urban Networks. Research Report, Department of Transportation Planning and Highway Engineering, Delft University of Technology, Delft, The Netherlands, Feb. 1985.

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