A N L A G E II

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Bicycle and Environment in the City. A Quantification of some Environmental Effects of a Bicycle Oriented Traffic Policy in Groningen.

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BICYCLE AND ENVIRONMENT IN THE CITY

A QUANTIFICATION OF SOME ENVIRONMENTAL EFFECTS OF A BICYCLE ORIENTED TRAFFIC POLICY IN GRONINGEN

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BICYCLE AND ENVIRONMENT IN THE CITY

This report was written as final thesis in the Environmental Dept. of the Prof. H.C. van Hall Instituut in Groningen

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PREFACE

In the last three months of the environmental course at the "Prof. H.C. van Hall Instituut" in Groningen, I worked on this assignment to finish my studies.
During my research into the environmental aspects of traffic, it became clear to me that traffic is a specialized subject. I would like to thank all persons who helped me to get aquainted with this expertise, especially Mr. H. Verhaar (traffic specialist) and Mr. R. van Well (noise-nuisance specialist) of the municipality of Groningen.
My thanks for all other persons who assisted somehow in gathering information.
My special thanks go to Kris van Koppen and Robert de Vroom for the way I was supervised. Also because of our pleasant co-operation I enjoyed working on this report.

Erna Krommendijk, June 1988.

SUMMARY

This study, entitled "Bicycle and Environment in the City", was carried out within the framework of the European research project "Pollicy and Provision for Cyclists in Europe". The object was to investigate the quantitative environmental effects of an increased use of the bicycle in urban traffic, linked to a decreased use of motorized traffic.
For this purpose two traffic situations were compared. The environmental effects of the "actual situation" with 50% cyclists and 31% car commuters in the Groninger resident commuter traffic were compared to the "model situation" with 5% cyclists and 76% car commuters. The decrease of the bicycle traffic would result in an increase of the total volume of car traffic in Groningen by 10%.
The following environmental aspects were studied: air pollution, noise nuisance, infrastructure, energy consumption and health.

As a result of the increasing car traffic in the model situation, the air pollution would increase. Especially CO, NO_x, C_xH_y and lead contribute substantially to air pollution. In the model situation the emissions of CO, NO_x and C_xH_y caused by the total traffic in the province of Groningen would increase with respectively 8, 4 and 8 $^o/oo$. The emissions of NO_x and SO_2 would contribute with 8 $^o/oo$ to the acid deposition caused by the NO_x and SO_2 emissions in the province of Groningen by traffic. These contributions would increase considerably if the additional emissions caused by a more stagnating traffic in the peak hours would be included.
The noise levels on fronts of houses would increase with about 0.3 decibels in the model situation. Since the present limit for redevelopment is 65 decibel, the number of redevelopment cases would increase in the model situation.
The increase of car traffic would result in an additional need for parking space of 22 hectare, i.e. a quarter of the space within the "Diepenring".
The total consumption of energy by traffic is divided into locomotion, production and transportation of fuel, production and maintenance of vehicles, and consumption and maintenance of infrastructure. A car in the commuter traffic consumes 7.5 times more energy per passenger kilometer than a bicycle. The total energy consumption of a car consists for 60% of locomotion energy.
A reduction of bicycle traffic also results in adverse health effects. Car traffic causes air pollution which is inhaled by all road users. Measurements indicate that car drivers themselves inhale the highest concentrations. The exposure to some chemical substances are compared to open air limits. For NO, NO_2 and benzene, the maximum 1 hour values or the high percentiles of 1/2 or 1 hour values are exceeded. The 98-percentile values of CO and NO_2 on foot paths along some Groninger roads were calculated. These concentrations remain for both situations (actual and model) within the limits.

It was tried to quantify the environmental aspects economically as far as possible.
The additional air pollution was quantified economically by calculating the costs to prevent this air pollution. The additional emission of NO_x, CO and C_xH_y could be prevented by the introduction of regulated three way catalytic converters. The

costs would be fl 0.4 million per year. The additional lead emission in the model situation could be prevented by the use of unleaded petrol. The costs would be fl 50,000.- per year. The total expenditure of these air pollution effects would be fl 450,000.- per year.
The increased noise level in the model situation was quantified economically by calculating the increased proceeds of the noise nuisance levy on fuel. This results in a expenditure of fl 20,000.- per year.
The additional space required was quantified economically by calculating the costs if all this parking space would be rented from the minicipallity. This results in a expenditure of fl 6.2 million per year.
The consumption of energy was quantified economically by converting the additional fuel consumption into petrol costs, and the remaining consumption of energy was converted into costs for heavy fuell oil. The total expenditure for energy would be fl 1.6 million per year.
The health effects could not be quantified economically.
The total quantified costs would be fl 7.8 million per year (= 3.3 million ECU).
This would increase by at least 1 million guilders extra per year if the additional air pollution and fuel consumption costs as a result of an increasing traffic congestion would be included.
The calculated fl 7.8 million is fl 519.- per car added to the commuter traffic per year.
These costs concern only the economic effects which could be quantified in an exact way; they are only part of the total environmental effects.

It could be concluded from this study that an increasing bicycle traffic would contribute to a more liveable environment.

SAMENVATTING van "BICYCLE AND ENVIRONMENT IN THE CITY"

Als onderdeel van het EG-onderzoek "A comparison and Evaluation of Policy and Provision for Cyclists in Europe", is het onderzoek "Bicycle and Environment in the City" uitgevoerd. Het doel van deze studie was om kwantitatief inzicht te krijgen in de baten voor het milieu van een verhoogd aandeel van de fiets in het verkeer.
Hiertoe zijn in Groningen de milieu-effekten van het woon-werkverkeer voor twee verschillende verkeerssituaties vergeleken. De ene situatie is de aktuele situatie met 50% fietsers en 22% automobilisten in het interne woon-werkverkeer. In de tweede situatie, een modelsituatie, bestaat het interne woon-werkverkeer voor 5% uit fietsers en voor 55% uit automobilisten. De afname van het fietsverkeer zou een toename van het totale autoverkeer in Groningen met 10% betekenen.
De onderzochte milieu-effekten zijn de volgende: luchtverontreiniging, geluidhinder, ruimtegebruik, energieverbruik en gezondheid.

Door het toenemende autogebruik in de modelsituatie neemt de luchtverontreiniging toe. Vooral de stoffen CO, NO_x, C_xH_y en lood leveren een belangrijke bijdrage aan de totale luchtverontreiniging. De extra uitstoot van CO, NO_x en C_xH_y door het totale verkeer in de provincie Groningen zal met respektievelijk 8, 4 en 8 $^o/oo$ toenemen. De uitstoot van NO_x en SO_2 zal voor 8 $^o/oo$ bijdragen aan de zure depositie, veroorzaakt door de NO_x- en SO_2-uitstoot van het verkeer in de provincie Groningen. Deze emissiecijfers zullen nog aanmerkelijk hoger worden indien de verhoogde uitstoot door een toenemende congestie van het totale verkeer in de spitsuren in rekening wordt gebracht.
De geluidbelasting van gevels zal met ongeveer 0,3 decibel toenemen in de modelsituatie. Aangezien op veel plaatsen de gevelbelasting rond de saneringsgrens van 65 dB(A) ligt, zal het aantal te saneren woningen door deze extra geluidsbelasting toenemen.
Het ruimtegebruik door een toenemend autoverkeer zal voornamelijk veroorzaakt worden door een grotere behoefte aan parkeerplaatsen. In de modelsituatie zal voor het parkeren ongeveer 22 hektare extra nodig zijn, wat overeen komt met een kwart van het oppervlak van de binnenstad van Groningen.
Het totale energieverbruik van het verkeer is opgebouwd uit: voortbeweging, produktie en transport van brandstof, produktie en onderhoud van voertuigen, en aanleg en onderhoud van infrastruktuur. Het energieverbruik door een auto is per kilometer 10 keer zo hoog als die door een fiets. Het energieverbruik van het autoverkeer bestaat voor 60% uit brandstofverbruik.
Afname van het fietsverkeer heeft ook gevolgen voor de gezondheid. Het autoverkeer veroorzaakt luchtverontreiniging die alle weggebruikers inademen. Het blijkt dat de automobilisten zelf de hoogste koncentraties inademen. Blootstelling aan bepaalde stoffen is vergeleken met grenswaarden voor buitenlucht. Voor NO, NO_2 en benzeen worden maximale 1 uurs waarden of hoge percentielen van 1/2 of 1 uurs waarden overschreden. De 98-percentielwaarden van CO en NO_2 langs enkele straten in de stad zijn bepaald. Ook in de modelsituatie blijven deze concentraties binnen de normen.

Getracht is om, waar dat verantwoord mogelijk was, de milieu-effekten als ekonomische kosten te kwantificeren.
De extra luchtverontreiniging door enkele stoffen is ekonomisch gekwantificeerd door te berekenen wat het zou gaan kosten om deze luchtverontreiniging te voorkomen. De extra uitstoot van NO_x, CO en C_xH_y kan voorkomen worden met behulp van geregelde driewegkatalysatoren. De kosten zouden fl 0,4 miljoen per jaar bedragen. de extra loodemissie kan voorkomen worden door gebruik van loodvrije benzine. De kosten zouden ca. fl 50.000,-- per jaar bedragen. Dit leidt tot een kostenpost van fl 450.000,-- per jaar.
De extra geluidbelasting is ekonomisch gekwantificeerd door de toegenomen opbrengst van de geluidhinderheffing op brandstoffen in de model situatie te berekenen. Dit leidt tot een kostenpost van ca. fl 20.000,-- per jaar.
Het extra ruimtegebruik is ekonomisch gekwantificeerd door te berekenen wat het zou kosten als al deze parkeerplaatsen van de gemeente gehuurd zouden worden. Dit leidt tot een kostenpost van fl 6,2 miljoen per jaar.
Het energieverbruik is ekonomische gekwantificeerd door het extra brandstofverbruik om te rekenen in benzinekosten en het overig energieverbruik is omgerekend naar kosten voor zware stookolie. De totale kosten zouden fl 1,6 miljoen per jaar bedragen.
De gezondheidseffekten zijn niet ekonomisch gekwantificeerd.
De berekende extra kosten door milieu-effekten in de model situatie zouden dus ongeveer fl 7,8 miljoen per jaar bedragen. Deze zouden nog eens met minimaal fl 1 miljoen toenemen indien het extra brandstofverbruik en de extra luchtverontreiniging veroorzaakt door kongestie in rekening wordt gebracht.
Fl 7,8 miljoen betekent fl 519,- per jaar per extra automobilist in het interne woon-werkverkeer.
Deze geraamde kosten betreffen alleen de ekonomische effecten die exact gekwantificeerd konden worden; zij vormen slechts een deel van de totale milieueffekten.

Uit deze studie kan gekonkludeerd worden dat een toenemend fietsverkeer zeker zal bijdragen aan een beter leefmilieu in de stad.

1. INTRODUCTION

As a result of the European Road Safety Year 1986, the Wijsenbeek report "The Bicycle as a Means of Transport" was written. The report was unanimously adopted by the European Parliament in 1987. As one of the more direct results of the Wijsenbeek report, the European Cyclists Federation (ECF) initialized a research project on behalf of the European Commission entitled: "A comparison and Evaluation of Policy and Provision for Cyclists in Europe". The actual research for this project was carried out by IVU-GmbH, a research Institute in Berlin, with the assistance of a student of the van Hall Instituut in Groningen. The object of the study is to search the wide varieties of bicycle use, bicycle policy and provisions for cyclists, which results under certain conditions in an important role of bicycle traffic. The policy framework within which provisions for cyclists are made and engineering solutions that have been provided for cyclists are inventoried in 16 European countries. The contribution of the Van Hall Instituut, laid down in this report, consists of a study into environmental aspects. The three elements, policy, provision and environmental aspects, will result in recommendations for research and policy.

This report is concerned with the environmental aspects of an increased role of the bicycle.
The wish to increase bicycle traffic is among others a result of the many negative effects of motorized traffic on the environment. Increasing bicycle traffic will effect a reduction of these negative effects.
The negative effects of motorized traffic for the environment have been studied by several investigations and many authors have written about the necessity to increase bicycle traffic.
The possibility to introduce a traffic system which meets environmental demands was recently investigated in the Netherlands (Schoemaker, 1988).
The environmental advantages of cycling in comparison with other types of transport have hardly been investigated so far in a quantitative manner.
The object of this study is to investigate the quantitative environmental effects of an increased use of the bicycle in urban traffic linked to a decreased use of motorized traffic. It was not possible to make quantifications of such kind in a general way. Therefore, the commuter traffic in the city of Groningen was selected as a case.
In this study environmental effects of bicycles are compared with environmental effects of cars in the Groninger commuter traffic.
In chapter 2 the methods of comparison are explained further. The traffic situation in European countries is treated first, because of the European background of this study. The selection of both car commuter traffic and the city of Groningen for the case study are also explained in chapter 2.
Chapter 3 is concerned with the traffic situation in the city of Groningen. The two traffic situations to be compared are explained and quantified.
An environmental comparison of the two situations is discussed in chapter 4. The environmental aspects compared are: air pollution, noise nuisance, infra-structure, energy consumption

and health. The environmental effects are quantified as much as possible and are partially quantified economically.
In chapter 6 the environmental and economic conclusions of this study are discussed.
Chapter 7 contains the discussion.

2. METHOD OF COMPARISON

In this chapter the different means of transport in the commuter traffic of different European countries are reviewed (§2.1), because of the European background of the study. In §2.2 and §2.3 the method of working is explained.

2.1 The European commuter traffic

Traffic situations vary from country to country and per country from city to city.
Figure 2.1 shows that in commuter traffic private cars are used most in Belgium, Germany, Luxembourg and the United Kingdom. In the United Kingdom the contribution of bicycles to commuter traffic is the lowest of all EC countries. Only 6% of the commuters go by bike, moped or motorcycle.
Every city has its own characteristic traffic situation. The modal split is among other things dependent on:
-size of the city;
-hilliness of the terrain
-provisions for different types of traffic (infrastructure)
    *bicycles: cycle tracks, integration of public transport and bicycle transport;
    *car traffic: parking space, attainability;
    *public transport: tram, bus, underground and convenient timetables.
-weather;
-theft of bicycles and theft out of cars;
-road safety aspects.

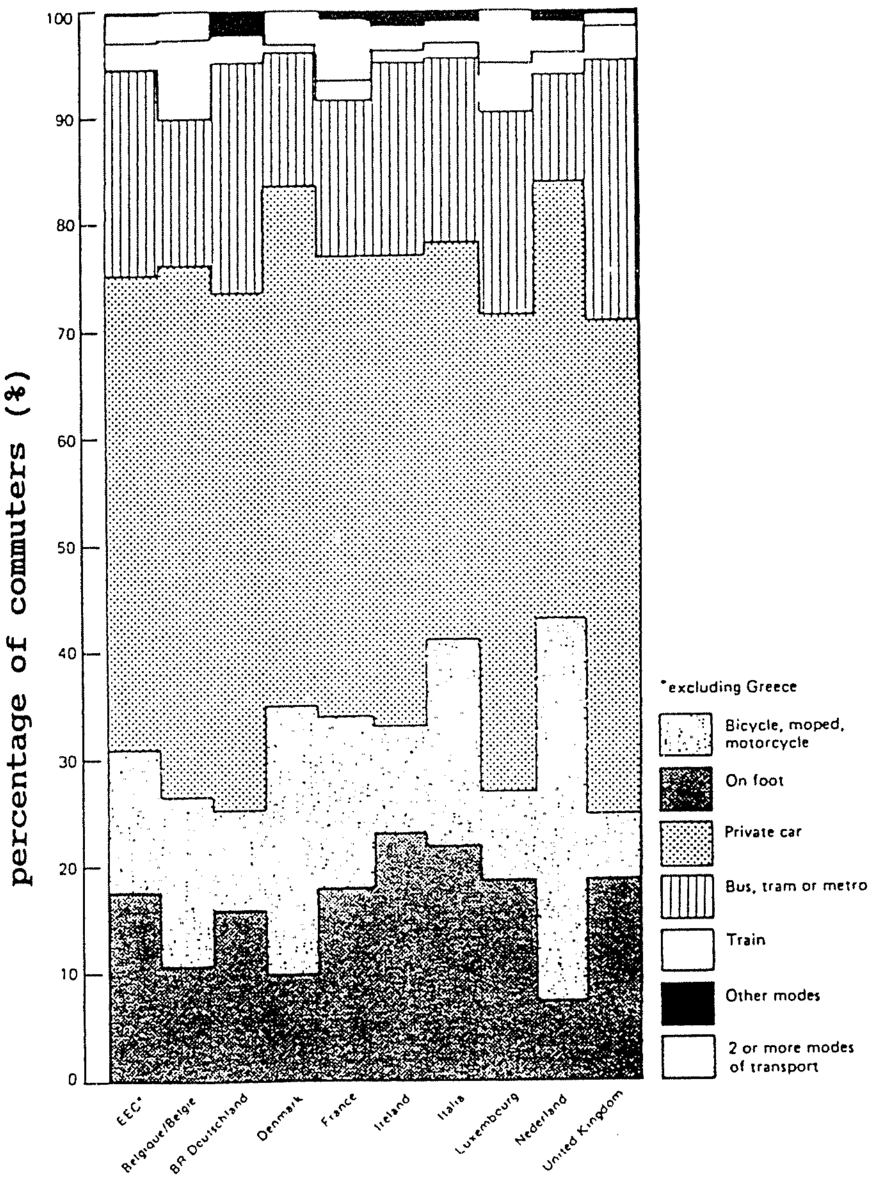

Figure 2.1: Transport mode of commuters in European countries in 1975.
Source: Pickup, 1983.

2.2 Selection of case

The environmental advantages of the bicycle in urban traffic can be assessed by comparing bicycles with other means of transport in various types of traffic.

To obtain a quantitative assessment it is necessary to focus on a well defined case. In this case, car commuter traffic was focused on. Commuter traffic was chosen because it is a well defined type of traffic, the movements of commuters have already been investigated and also because of the often high contribution of cars in commuter traffic. Car traffic was chosen to compare bicycle traffic with, because of the biggest environmental impact of all types of transport. Another reason is that the commuters mostly are in the opportunity to travel by car, because they are older than 18 years. Commuter traffic accumulates during traffic peak hours. Governments often are willing to reduce car traffic in cities because of the congestions. Environmental problems can reinforce these measures.

To obtain a feasible quantitative assessment it was necessary to focus on a well-defined area. The study was focused on the city of Groningen, because it is a medium sized city where the local authorities stimulate bicycle traffic, and information, study material as well as experts in the field of traffic are available. The medium size of Groningen is important because all distances can be travelled by bicycle. This study concentrates on car commuter traffic of residents, because the environmental effects of traffic in cities is discussed.

Groningen is a city with a very high use of the bicycle in resident commuter traffic (50%). To get a good idea of the environmental advantages of bicycles, especially in comparison with car traffic, it was supposed that of the actual 50% bicycle commuters, 90% would change to car use in the resident commuter traffic. A situation in which only 5% of the commuters go by bicycle can be compared with the worst situation in European countries (§2.1).
The shares of other types of transportation remain the same (chapter 4). The modal split in the situation with fewer cyclists, the "model situation", might probably be comparable to some European cities.
In this case the attention could be focused only on the differences between bicycles and cars. The environmental effects in the "actual situation" with 50% cyclists in the commuter traffic were compared to the model situation with 5% cyclists.
The environmental aspects discussed in this study were: air pollution (chapter 5.1), noise-nuisance (chapter 5.2), infrastructure (5.3), energy consumption (5.4) and health (5.5). In the chapter about health only those aspects relating to air pollution were discussed and not the accident rates in traffic. Refuse, originating from disused vehicles are not discussed.
The environmental as well as economic effects were quantified where possible. In chapter 6 the costs made for the environment are calculated.

2.3 The comparison: actual and model situation

To discuss the environmental effects of bicycle traffic in cities, car traffic was chosen to compare the bicycle traffic with. The type of traffic discussed is commuter traffic. The city of Groningen was chosen as study area and the type of traffic concentrated on was resident car commuter traffic.
For two traffic situations, i.e. the "actual situation" and the "model situation", the environmental effects were calculated and compared. It should be noticed that, in contrary to most other comparing studies, the model situation is the "bad" situation, while the actual situation is presented as the "good" alternative. It was tried to quantify also the economic effects as a result of the increased environmental impact in the model situation.

3. TRAFFIC SITUATION IN GRONINGEN

In this chapter it is intended to calculate the traffic volume in the actual and model situation, which is necessary to calculate the environmental impact.
First the structure of the Groninger traffic (3.1) and the specific Groninger commuter traffic (3.2) are discussed.
For the to calculation of noise nuisance and air pollution, traffic intensities on (some) roads have to be known (3.3).

3.1 Traffic structure

Groningen is a city in the North of the Netherlands with ca. 168,000 inhabitants, situated in a relatively quiet area of the Netherlands. It is not a part of a network of cities as the Dutch "Randstad" or the German "Ruhrgebiet".
The traffic is in general relatively simple. The total actual volume of traffic consist of a small percentage of through traffic (table 3.1). The greater part of the travellers finish or start their journeys in the city of Groningen.

type of transport	volumes of traffic (persons or vehicles per day) internal	external	through traffic	total
bicycles (vehicle)	155,600	23,400	0	179,000
%	87	13	-	100
cars (vehicles)	164,300	120,800	13,300	298,400
%	55	40	5	100
public transport	31,700	53,100	3,100	87,900
(persons) %	36	60	4	100

table 3.1: Traffic volumes in the conurbation of Groningen in the actual situation.
N.B.: these volumes include the traffic of Haren (a small town with 15,900 inhabitants to the south of the city of Groningen)
(Source: Hofstra 1986)

Groningen is a real "bicycle city". Among others this is the result of the big number of students and the small size and compact form of the city, so all distances can be travelled by bike. Other reasons are the discouragement of car through traffic in the inner city and the good provisions for cyclists.

Car traffic structure

In Groningen a traffic circulation plan was developed. For car traffic this plan consists of three main parts (gemeente Groningen 1979):

- a system of roads along the canals around the inner city, called the "Diepenring" (completed in 1977);
- a system of ring roads around the city (completed in 1986);
- communications between the "Diepenring" and the system of

ring roads (completed in 1986).

The ring roads open the city for car traffic. They also form the connections between the city of Groningen and the region through junctions on the provincial roads and national highways. The "Diepenring" opens the inner city. In the city center car through traffic was discouraged by dividing the centre into four zones. Driving from one zone into another is not possible without going by the "Diepenring". Facilities for public transport and slow traffic were improved. The communications connect the "Diepenring" with the ring roads for car traffic.

<u>Bicycle traffic structure</u>

In Groningen a network for cycle traffic is being planned, providing connections between the zones and the inner city on the one hand, and between the zones themselves on the other (partly completed). For this network of cycle ways separate cycle tracks beside busy roads and quiet roads are used. Table 3.1 shows the total actual volume of traffic in the conurbation of Groningen.

3.2 Resident commuter traffic

For this study resident commuter traffic by car and bicycle were focussed on. Resident commuter traffic is the result of the movement of people from home to work within the municipal limits (see appendix 1).
In this paragraph the numbers of bicycle and car commuters necessary to compare the actual and model situation were calculated.

In Groningen the actual resident commuter traffic consists of over 50% of cyclists. The average distance for both bicycle and car commuters is about 3.1 km. (Kornegoor 1985/ Tuinstra). With these data the total commuter distances in a year of 230 working days could be calculated (table 3.2). All resident commuters together travel 60 million kilometers per year.

	car	bus	moped	bicycle	pedestrian	total*
persons (abs)	10,300*	2,300	833	23,153	5,047	46,300
(%)	22.3	5.3	1.8	50,3	10.9	
distance ($x10^6$km/year)	14.7	3.3		42.0		60.0

* excluding passengers

table 3.2: Persons and distances in the resident commuter traffic in Groningen.
(Source: Kornegoor 1985)

The percentage of the resident commuter traffic in the total streams was for car traffic 7% and for bicycle traffic 26%.
If, instead of 50% (actual situation), only 5% (model situation) of the commuters go by bike, then 67% of the commuters would go

by car, presupposing that all former cyclists would change to cars (figure 3.1).

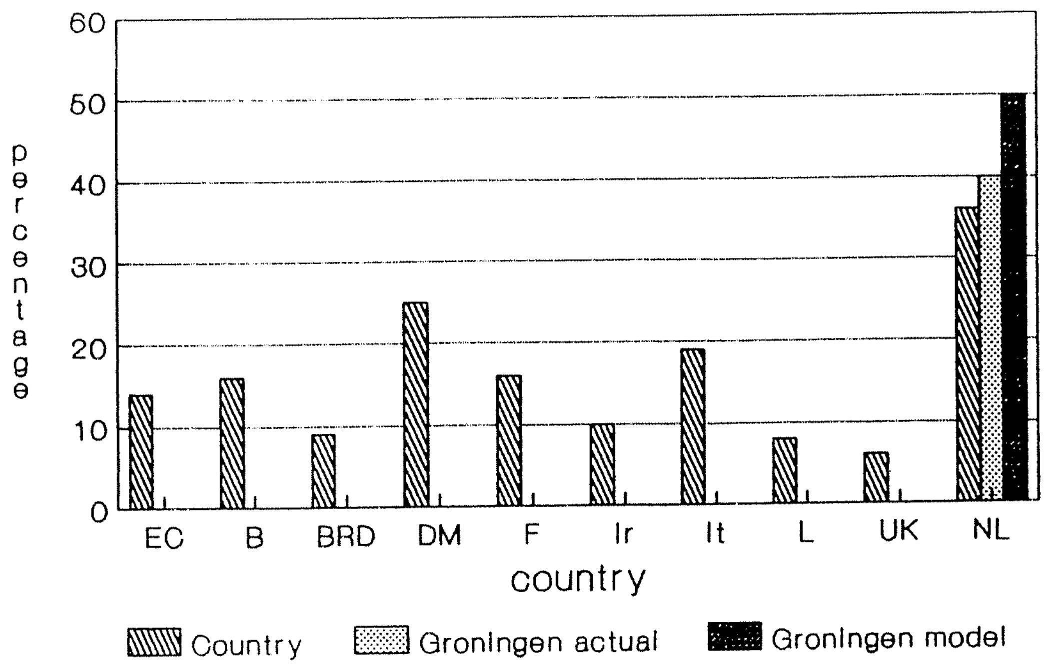

Figure 3.1.b: Percentages of bicycle use in European countries and in the two Groninger situations.
Source: Pickup, 1983.

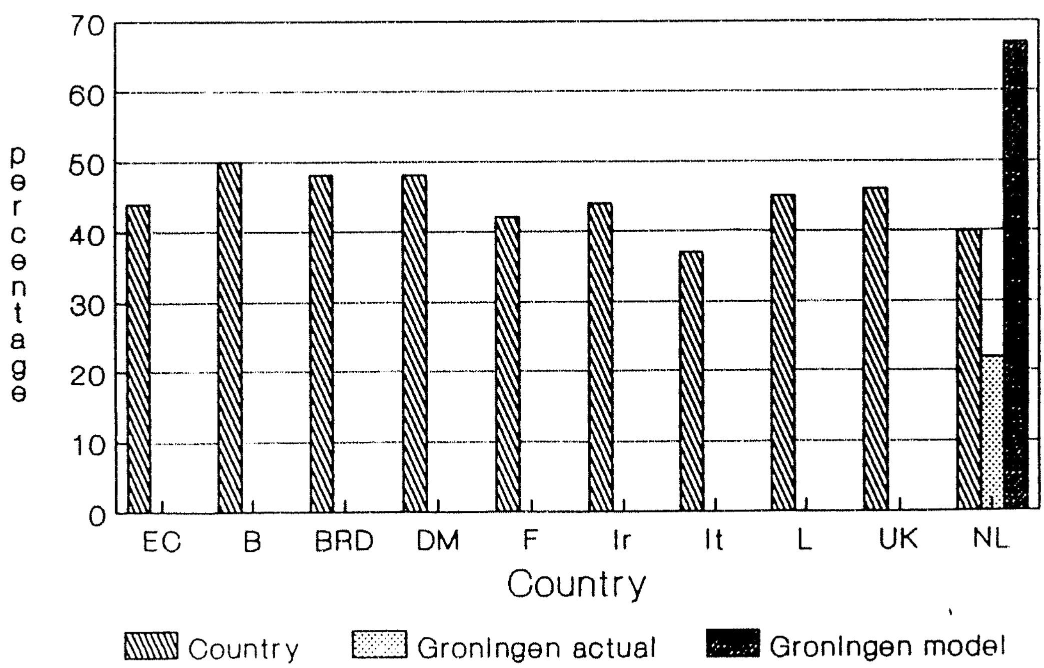

Figure 3.1.b: Percentages of cars in the commuter traffic in European countries and in the Groninger commuter traffic.

The percentage of commuters in the total volumes of traffic would have changed, as shown in table 3.3. In the model situation the percentages resident commuter traffic in the total streams would be for cars 15 and for bicycles 3.

	actual situation	model siuation
bicycle (%)	26	3
car (%)	7	15

table 3.3: Percentages of the resident commuter traffic in the total traffic volume.

Not all bicycles would be exchanged for cars. The occupancy of a car in the commuter traffic is 1.39 (Schoemaker 1988). If 20838 cyclists change from bike to car, 14991 additional cars would be driven in the resident commuter traffic. Table 3.4 shows the differences between the actual and the model situation. The total car traffic increased by 10 percent and the total bicycle traffic decreased by 23 percent. The total vehicle distance travelled decreased by 17%.

	bicycles			cars		
	actual	model	increase (%)	actual	model	increase (%)
commuters (vehicles/day)	46,306	4,630	-90	220,600	50,582	+146
total streams (vehicles/day)	179,000	137,324	-23	298,400	328,382	+ 10
travel distance (x 10^6 km/year)	33.0	3.3	-90	14.7	36.1	+146

table 3.4: the traffic in Groningen for the actual and model situation.

3.3 Traffic on the cordon around the inner city

At several points in Groningen the traffic is counted. Seventeen of these points together form the cordon around the inner city (see appendix 1). All travelers, going in or out the inner city have to travel along one of these roads. For thirteen of these points the volumes of traffic were calculated.
If the actual traffic intensities are known, the intensities for the model situation can be calculated. For this calculation the visual countings of 1987 were used, because they differentiate between types of traffic, counted every hour between 7 a.m. and 6 p.m. for one day (gemeente Groningen 1987). Together with the figures of mechanical countings for these points, the volumes of traffic could be calculated for 24 hours (appendix 2).
The total commuter traffic, including the outward commuters, counted 72,200 car trips a day. The resident commuter traffic counted 20,600 trips per day (Kornegoor 1985). This means that

29% of the total commuter traffic is resident commuter traffic.

Non-resident commuter traffic follows for the greater part the ring roads. However, we supposed that the contribution of the resident commuter traffic counted 30% of the total commuter traffic on the cordon, because these roads for the greater part are communications between the "Diepenring" and the ring roads so they are also important for the outward commuters. According to Verhaar (1988) 80% of the traffic between 7-9 o'clock is car commuter traffic. This means that 24% of the car traffic on the cordon consisted of resident commuter traffic.
In the model situation, the resident car commuter traffic increased by 146% (table 3.4). Between 7 and 9 a.m. the total traffic increased by 35%.
The car traffic streams for 24-hours are necessary to calculate the air pollution on foot paths (see 4.5). The commuter traffic takes for 29% place between 7 and 9 a.m. (CBS, 1985). In 24 hours the increase on the various roads could be calculated by multiplying the increase between 7 and 9 o'clock by 3.4. This results in an average increase on the roads on the cordon of 15%. This is in agreement with the fact that the roads are more important for commuter traffic than the average road in Groningen; the average increase of car traffic is 10% (table 3.4).
The car traffic streams between 7 a.m. and 6 p.m. were important to calculate the noise level (§4.2). The commuter traffic takes for 81% place between 7 a.m. and 6 p.m.. The increase between 7 and 9 a.m. had to be multiplied by 2.8 to calculate the increase of the traffic streams between 7 a.m. and 6 p.m. (appendix 2).The average increase between 7 a.m. and 6 p.m. was calculated to be 17%. This means that the resident commuter traffic increased relatively more in this period than in 24-hours.

3.4 <u>Congestion</u>

In Groningen the traffic jam problems are not very high in the actual situation. There are only few places where during short periods of the morning and/or evening peak hour congestion problems are found.
Traffic jam problems are difficult to analyze. In the model situation the number of traffic jams would increase, and on the places where traffic jams already occur in the actual situation, the problems would increase.
For two points, where traffic problems already exist, the congestion was calculated. Countings were carried out between 7 and 9 a.m.. In both situations there is a continuous traffic jam between 8 and 9 a.m.. In this period the traffic would increase by 35% in the model situation (§3.3). In the first situation the average waiting time for traffic lights would change from 2.7 minutes in the actual situation to 13 minutes in the model situation. So an increase of the traffic by 35% would result in an increase of the waiting time by 380%.
In the second situation the waiting time would increase by 150%, from 6 to 15 minutes.
A relatively small increase of the traffic in existing traffic jam situations would cause a more than proportional increase of the traffic jams and the waiting time.

The rate of increase is among others dependent on the number of traffic lights for one traffic stream, the cycle time of the traffic light system, the volumes of traffic and the traffic capacity of junctions.
In the actual situation these two traffic points are not representative for all important junctions. But it would be realistic to calculate with an increase of the waiting time by 5 minutes for all traffic in the peak hours.
The quantification of the total increasing congestion problems in the model situation would be an individual study.
The assumed effects of congestion were included in the calculations of air pollution and fuel consumption to give an indication of the additional effects.

4. ENVIRONMENTAL ASPECTS.

The situation with 50% cyclists in the resident commuter traffic (actual situation) will be compared with the model situation, where the percentage of cyclists would be reduced to 5.
The aspects described are: air pollution (emissions and concentrations in the air), noise-nuisance, infrastructure, consumption of fuel and natural resources, and health.
First the effects are described, then the effects are quantified and finally the environmental effects are translated into economic terms.
The stream of refuse matter that arises after the life-time of a vehicle is not discussed in this study.

4.1 Air pollution

Bicycles emit during their life-time only rubber through wear of the tires, which can be neglected in comparison with car tire wear. Bicycles do not produce any exhaust gases, so when comparing the air pollution of cars and bicycles, only car traffic has to be studied.

4.1.1 Types of emissions.

Emissions by exhaust gases

Car traffic emits a range of chemical substances by their exhaust fumes. The most important pollutants are carbon-monoxide(CO); nitrogen-oxides (NOx); benzene, polycyclic hydrocarbons (PCHs) and other hydrocarbons(CxHy); sulphurdioxide (SO2); lead combinations; and aerosols in general.
Figure 4.1.1 shows how important traffic is in the total emissions for some chemical substances (CBS, 1986-a)
Except for SO_2 and aerosols, the chemical substances of figure 4.1.1 are caused for the greater part by passenger cars. The parts of the total traffic emissions caused by passenger cars in built-up area are shown in figure 4.1.2..
The emissions are dependent on e.g.: type of fuel (petrol, diesel or LPG), type and weight of car, driving speed, driving behaviour and weather. The type of fuel is important. Petrol is especially responsible for the emissions of carbon monoxide, nitrogen oxides, benzene and other hydrocarbons, and lead. LPG especially causes emissions of nitrogen oxides, hydrocarbons, formaldehyde and stench. Diesel finally causes especially air pollution through the emission of sulphur dioxide, polycyclic hydrocarbons, aldehydes, soot and stench (Den Hout 1983).
The emissions also vary with driving speed. The emissions of CO and hydrocarbons are higher at low speeds (in the built-up area) and the emissions of NO_x and SO_2 are higher at high speeds (on national highways).

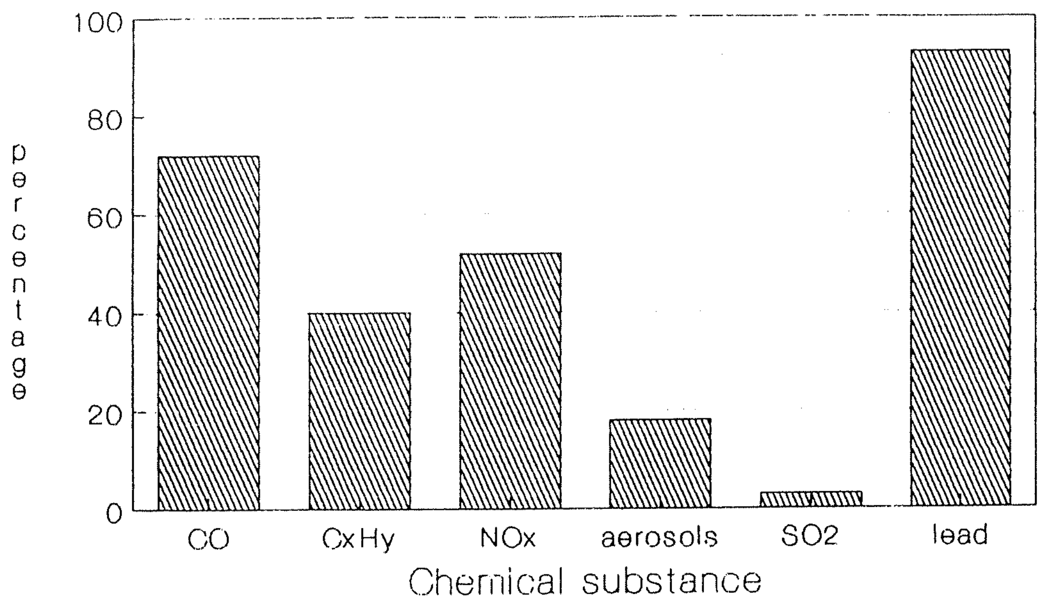

Figure 4.1.1: Part of total emissions caused by traffic in the Netherlands (1982).
Source: CBS 1986-a

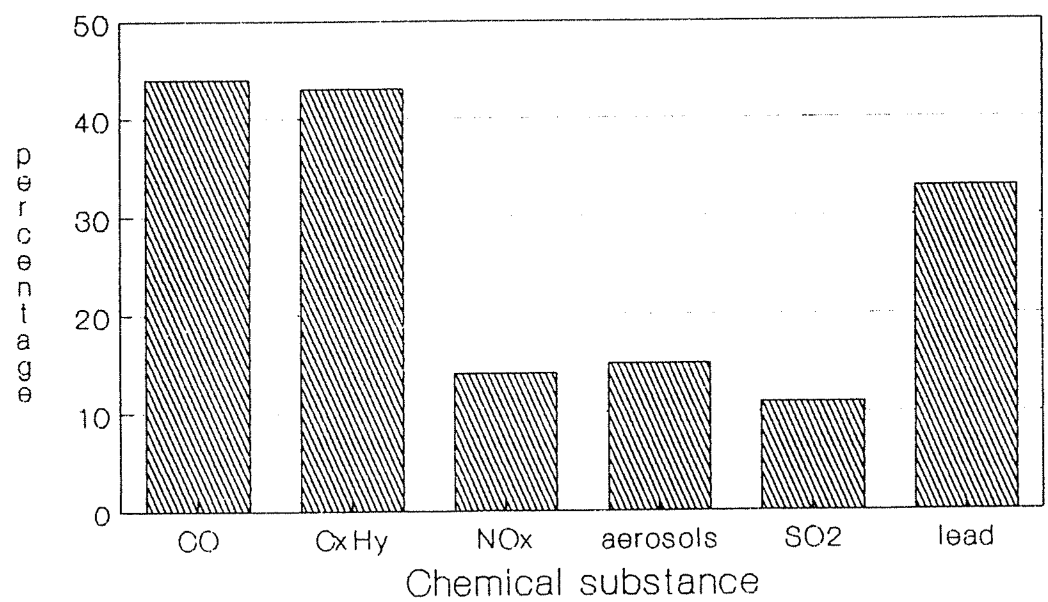

Figure 4.1.2: Part of total traffic emissions caused by passenger cars in the built-up area (1984).
Source: CBS, 1986-a.

Other emissions

Hydrocarbons are also emitted through evaporation from driving and parked cars, which mainly takes place in the built-up area because cars remain within the built up area during the greater part of the day. This is especially so for car commuter traffic.

The emission of liquids is caused by leaking of oils, petrol and accumulator acids from driving and parked cars (Akkerman, 1987).

An other source of emission is connected with the wear of parts of vehicles during driving and braking. The wearing-materials are: asbestos, rubber- and road particles and heavy metals as chromium, copper, nickel, zinc and cadmium. Asbestos is a substance in brake-linings (10-60%) (Akkerman 1987).

4.1.2 Calculation of emissions

The emissions of different chemical substances will be calculated for resident commuter traffic in the actual and model situation defined in this paragraph.

Exhaust gases

The emissions of NO_x, C_xH_y and CO depend on driving speed. Emissions of SO_2 and lead are directly proportional to the consumption of fuel and these emissions were calculated for the average Dutch car.
In built-up area three types of traffic are usually distinguished for CBS-experiments (CBS, 1986):

1. flowing traffic (26 km/hour);
2. European test cycle (ECE-test) (19km/hour);
3. stagnating traffic (13.5 km/hour).

Table 4.1.1 shows the average exhaust per kilometer in the average situation in built-up area (CBS 1986-a). The emission of lead has decreased since 1986, when the maximum lead concentration in petrol was decreased from 0.4 (g/l) to 0.15 (g/l)and unleaded petrol was introduced as well.

chemical substances	emissions (gram/kilometer) CO	C_xH_y	NO_x	aerosols	SO_2 3)	lead 2) 3)
type of fuel						
petrol (82%) 1)	22.4	3.99	2.03	0.07		
diesel (6%)	3.82	1.12	1.18	1.06		
LPG (11%)	1.90	1.25	1.25	0.04		
total (100%)	18.8	3.50	1.87	0.13	0.052	0.017

1) percentage of the fuel consumption of each type of fuel
2) lead emissions have changed since 1984, when leaded petrol was introduced and the maximum lead concentration of petrol was reduced form 0.4 (g/l) to 0.15 (g/l) in 1986
3) calculated for the average Dutch traffic

table 4.1.1: Emissions per kilometer by passenger cars in the built-up area at an average speed in 1984. (Source: CBS, 1986-a)

The total emission per year can be calculated for the actual and model situation by multiplying the covered distances in the commuter traffic per car with the emission factors (table 4.1.2).

	situation	
	actual	model
distance ($x10^6$ km/year)	14.7	36.1
emissions (tons/year)		
CO	276	679
C_xH_y	51	126
NO_x (as NO_2)	27	68
aerosols	1.91	4.69
SO_2	0.76	1.88
lead	0.25	0.61

table 4.1.2: Emissions per year caused by exhaust gases for the actual and model situation.

The additional emission of CO, SO_2, NO_x and C_xH_y contribute to the total emissions caused by traffic in the province of Groningen with respectively 8, 1, 4 and 8 $^o/oo$ (Ministerie van VROM, 1984).

The increase of car commuter traffic causes an increase of the emissions. The emissions will also increase as a result of more stagnating traffic, especially during peak hours. As a result of the assumed additional waiting time per car commuter in the peak hours (§3.4), the emissions of air pollutants would raise.
An engine emits per 5 minutes idling: 22.5 grams CO, 3.7 grams C_xH_y and 0.64 grams NO_x (calculated with data of emissions by an average speed of 6 km/hour (Ministry of Health and Environmental Protection, 1980)). This would be emitted by all cars in the peak hours (= 29% of 328,382 cars). The total additional emissions per year would be: 548 tons of CO, 90 tons of C_xH_y and 15.6 tons of NO_x.

The emission of NOx and SO2 contribute to the acid deposition as follows (CBS, 1986-b):

- SO2: 31.2 mol equivalents per kg;
- NO2: 21.7 mol equivalents per kg.

The additional SO2 emission (excluding the emission caused by congestion) causes a contribution to the acid deposition of:
$1.12 \times 10^3 \times 31.2 = 34.9 \times 10^3$ moleq/year
and NO_2 (excluding congestion emission):
$41.0 \times 10^3 \times 21.7 = 890 \times 10^3$ moleq/year.
The total additional contribution to the acid deposition is 925 x 10^3 mol-equivalents per year. The total emission of SO_2 and NO_x expressed in acid equivalents by traffic in the province of Groningen is (Min. van VROM, 1984):
$(781x10^3 \times 31.2) + (9.245x10^3 \times 21.7) = 203x10^6$ mol-equivalents acid. The increased emissions in the model situation contribute to the traffic emission of acid equivalents caused by SO_2 and NO_x in the province of Groningen by 4 $^o/oo$.

Other emissions

The evaporation of hydrocarbons from driving and parked cars is 7.5 grams per vehicle per day (Den Hout, 1983). Particularly for cars parked in the sun, the evaporation is high.

The emission of leaking oils is valued at 4.29 mg per vehicle kilometer. The additional emission of leaking oil in the model situation is 91 kg per year. This is a negligible proportion when compared to the draining of about 63 tons of finished oil which enters the sewage systems of Groningen due to changing of oil by private car owners (Gemert, 1987).

The emissions of solid materials is shown in table 4.1.3. The contributions of heavy metals are small in the total emission streams, but are important because they are on the black and grey lists.

chemical substance	emission (mg/vehicle km)	additional emission (kg/year)
rubber	3.50	74.9
chromium	5.22×10^{-2}	1.1
copper	8.10×10^{-2}	1.7
nickel	1.24×10^{-1}	2.7
zinc	9.87×10^{-1}	21.1
cadmium	8.77×10^{-3}	0.19

table 4.1.3: Additional emissions of solid materials by passenger cars in the model situation. (Source: Akkerman, 1987)

4.1.3 Concentrations

For the roads on the cordon around the inner city the concentrations of CO and NOx were calculated with the CAR-model (TNO, 1988). The results are discussed in chapter 4.5 (Health).

4.1.4 Economic quantification of air pollution effects

It was difficult to quantify the economic effects of air pollution. In this paragraph only the emissions of CO, C_xH_y, NO_x and lead are quantified economically.
To quantify the additional costs in the model situation, the following method was chosen. Taking the line that the additional cars in the model situation should not emit anyting, the costs to reduce the total emissions to the value of the actual situation were calculated.

The increased emissions of CO, CxHy and NOx could be reduced by means of a catalytic converter. It could be calculated how many catalytic converters would be necessary to reduce the emissions of the model situation to those of the actual situation.
For a regulated three way catalytic converter the emissions and

fuel consumption decrease as follows (Min. van VROM and V&W, 1987):

NOx: -50 to -80%
CxHy: -60 to -90%
CO: -60 to -90%
fuel: 0 to -7%.

When the reduction of NO_x has decreased to 50% the car has driven about 120,000 kilometers. In 120,000 kilometers the average NO_x reduction is 72%. This conversion of NO_x is normative because NO_x has the lowest conversion efficiency of the three above mentioned chemical substances. To decrease the emission in the model situation to that of the actual situation the reduction has to be 60%. This reduction could be achieved by supplying 83% of the cars in the resident commuter traffic with a catalytic converter. The costs of a three way catalytic converter would be paid by an increased special consumer tax for cars. The difference of this tax for a car with or without a catalytic converter is fl 1700.-. The costs per kilometer are fl 1700/120,000. In the model situation the resident car commuters would travel a distance of 36.1×10^6 kilometers per year. The costs of the reduction of NO_x by catalytic converters would be fl 439,470.-. The reduction of the emissions of C_xH_y and CO would be higher than 60%.
The emissions as a result of the assumed 5 minutes waiting time per car in the peak hours also could be quantified economically by calculating the reduction costs. These additional reduction achieved by the use of three way catalytic converters would be about fl 62,000.-- per year. Of course this is an assumption.

The increased lead emission in the model situation could be quantified economically by calculating the additional costs of the production of unleaded petrol. These production costs are higher because unleaded petrol must have a more exact composition to prevent knocking of the engine.
As mentioned above 60% of the emissions would have to be reduced in the model situation. To achieve this reduciton of the lead emission, 60% of the used fuel would have to be unleaded. The production of unleaded petrol costs 4.5 Dutch cents per liter more than of petrol with 0.4 gram lead per liter (0.4 g/l was the maximal lead concentration in 1984). The distribution of two types of fuel (leaded and unleaded) costs about 2 cents extra per liter.
The total costs to prevent the additional lead emission would be fl 49,505.-.

4.2 <u>Noise nuisance</u>

In this paragraph the sound level of motorized traffic on the roads of the cordon around the inner city are calculated (4.2.2). First the consequences of noise nuisance, quantification of noise levels and the method to express the sound level of traffic noise are discussed (4.2.1). Finally the costs of noise nuisance are calculated (4.2.3)

4.2.1 Backgrounds

Road traffic noise has many effects on human health as:

disturbance of rest and sleep, adverse effect on work performance and concentration, fear and fright effects, and subjective feelings of disturbance. In addition, road traffic noise can disturb communication.

The basis for measuring noise nuisance by motorized traffic is the Leq-level, or the equivalent sound-level. This Leq level turns an in time changing sound level into an, energetically equal, not changing sound level. The sound level is based on a logarithmic scale. The equivalent sound level to characterize traffic noise is expressed in dB(A) decibels measured as the human ear observes them.
According to the "Wet Geluidhinder" (= Dutch law on noise nuisance), the 24-hours Leq-level is important to establish the acceptability of traffic noise. This 24-hours level is the highest of the following two values:

- the day Leq-level (7a.m. - 7 p.m.);
- the night Leq-level (11 p.m - 7 a.m.) plus 10 dB(A).

The evening period (7 p.m. - 11 p.m.) is a transitional period and is not important for the law. For traffic in cities the noise level of the day period is in general normative.

For living conditions in an average residential quarter, a

qualification of the traffic noise levels was made (Kleinhoonte van Os, 1975):

Leq in dB(A)	qualification
≤ 40	excellent
≤ 45	good
≤ 50	fairly good
≤ 55	reasonable
≤ 60	moderate
≤ 65	fairly bad
≤ 70	bad
≤ 75	very bad

4.2.2 Sound level on the cordon around the inner city

The level of noise on fronts of houses can be determined with models.
The Centre for Environmental Studies (=Milieukundig Studiecentrum) of the University of Groningen did a study about the sound level of road traffic in the city of Groningen in 1979 (MSG, 1980).
In that study the following formula was developed to calculate the sound level on fronts of houses in Groningen:

$$Leq = 45 + 10\log\{\Sigma_{ij}\ a_i.N_{ij}\ [1/(R_j+15) + (0.6F_2)/(2b-R_j-1.5)]\} + C_w.$$

L_eq = equivalent noise level dB(A)
a_i = multiply rate according to sort of traffic
N_{1j} = number of passenger cars per hour
N_{2j} = number of mopeds and motor cycles per hour
N_{3j} = number of freight traffic per hour

R_j = distance from the middle of the road j to the measure point (m)
F_2 = built-up fraction on the other side of the road
b = width of the road between the fronts (m)
C_w = correction for the type of road

for passenger cars: a_i=1=1.0
for mopeds and motor cycles: a_i=2=5.4
for trucks and buses: a_i=3=20

for brick-pavement: C_w=1.5 dB(A)
for asphalt: C_w=0 dB(A)

This formula and the actual traffic information (Gem. Groningen, 1988) were used to calculate the sound level on the roads on the cordon around the inner city (appendix 3). In this calculation the contribution of mopeds and motor-cycles was not included, so the noise-levels will be a little higher than were calculated. In the actual situation all noise levels exceeded the level of 60 dB(A) and in 6 situations the level of 65 db(A) was exceeded. All noise levels were lower than 70 dB(A). (table 4.2.1).

Leq (dB(A))	situation actual (number of situations)	situation model (number of situations)
> 60	0	0
60 - 70	10	8
70 - 75	3	5
> 75	0	0

table 4.2.1: Noise level on fronts of houses in the 13 streets of the cordon around the inner city.

The increase of the sound level in the model situation would be 0.3 to 0.4 dB(A) during the day period.
To compare: a doubling of the traffic streams (i.e. a doubling of the energy level of sound) means an increase of 3 dB(A).
The increase of the sound level would be small because of the increase of passenger car traffic only. If freight traffic would increase also, the sound level would increase more. In the calculation method one truck counts for 20 passenger cars.

4.2.3 Economic quantifications of noise effects

The redevelopment limit is 60 dB(A), but only situations with a noise level above 65 dB(A) are subsidized at this moment. Every redevelopment case will be subsidized with 4 to 5 thousand Dutch guilders (Well v., 1988).
On most of the main entrance roads and the main roads giving access to the zones the limit of 65 dB(A) is already exceeded (Gemeente Groningen, 1987).
There would be situations where the limit of 65 dB(A) would be passed caused by the increased traffic, but it is not possible to calculate the number of additional redevelopment situations at

this moment.

The subsidies for redevelopment cases are financed by a levy for noise nuisance on fuel. In 1984-1987 this noise nuisance levy was fl 1.02 per hectoliter. With an increase of the fuel consumption of 1937 x 10^3 liters per year in the model situation (paragraph 5.4), the additional yield of the levy would be fl 19,757,-- per year.

4.3 Infrastructure

The infrastructure was supposed to remain unchanged, except for the extra car parking space needed during the day time. Especially space for long-time parking, i.e. more than 4 hours, would be necessary.
The additional space (4.3.1) and the costs of it (4.3.2) were quantified.

4.3.1 Parking-space

The policy of the municipality of Groningen is aimed at opposing the parking of commuter cars in the inner city. The functions of the inner city are diverse and space is scarce. Short term parking results in more visits to the inner city (Gemeente Groningen, 1985).
The authorities do not plan extra parking space in the inner city for commuter cars. All extra parking space needed for the model situation was supposed to be outside the inner city.
For every car, a space of about 17 m^2 is necessary if parking concentrates on parking places in the open air (fig 4.3.1). This includes the place for the parking of a car as well as the space for turning and driving.
The parking space necessary for bicycles in open air is about ten times smaller than for cars (Schweingruber, 1983). Figure 4.3.2 shows two types of parking spaces for bicycles which need 1.7 m^2 per bicycle (ASVV 1986).

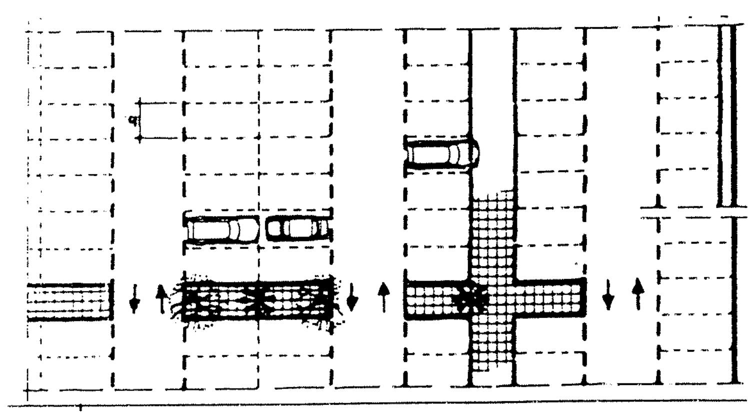

Figure 4.3.1: A type of car parking requiring 17 m^2 per car.

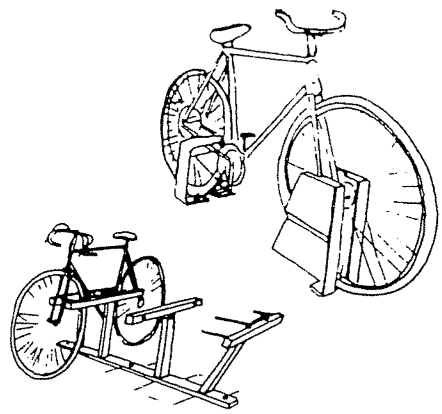

Figure 4.3.2: Two types of parking requiring 1.7 m^2 per bicycle.

The additional space for parking necessary in the model situation would be 22.0 x 10^4 m^2 (table 4.3.1). This is 24% of the space of the inner city within the "Diepenring".
If car ownership would increase in the model situation, this would cause an additional need of parking space for the parking near to the residence of the commuters.

type of transport	additional number of vehicles in the model situation	additional parking space (x 10^4 m^2)
car	+ 14,991	+ 25.5
bicycle	- 20,838	- 3.5
total		+ 22.0

table 4.3.1: Additional parking space required for the model situation.

4.3.2 Economic quantification of parking space

The municipality calculates f480,-- rent per year for one parking unit. It does not make any difference what type of parking unit is paid for (Gemeente Groningen, 1988). 22x10^4 m^2 consist of 12,940 parking units.
Additional parking space would not be financed by paying rent, because most companies buy grounds for their company including parking-space. But calculating rent is a method to quantify the costs of the additional parking space, which would have to be paid by industry and private persons.
In the model situation the additional rent would be 12,940 x fl 480,-- = fl 6,211,200,-- per year.
The additional amount of parking space required is so high that the building of parking garages would be necessary. This especially would be the case for car drivers who work in or near to the inner city. One parking garage for 250 to 300 cars costs 6 to 8 million guilders. It could not be quantified how much parking units in parking garages would be necessary.

4.4 Consumption of energy and natural resources

The consumption of energy by car and bicycle traffic consists among others of fuel consumption by cars (4.4.1) and of consumption of resources by cars and bicycles (4.4.2). The production and maintenance of vehicles and infrastructure also consume energy. In 4.4.3 a method to calculate the complete consumption of energy by cars and bicycles is discussed. The costs of the increase of energy consumption in the model situation are calculated in 4.4.4.

4.4.1 Fuel consumption

The additional fuel consumption in the model situation could be calculated by multiplying the fuel consumption per kilometer for one car by the additional number of cars.

The average consumption of fuel depends on the sort of fuel (CBS, 1986-a) (table 4.4.1).The consumption of fuel in the actual and model situation calculated on the basis of the consumption shown in table 4.4.1 (table 4.4.2).

type of fuel	consumption (liters/100 km)
petrol	8.8
diesel	7.8
LPG	11.5

table 4.4.1: Average fuel consumption for different types of fuel in 1984.
(Source: CBS, 1986-a)

type of fuel	distance (10^6 km/year) situation actual	model	consumption of fuel (10^3 l/year) situation actual	model
petrol (82%)	12.1	29.7	1065	2613
diesel (6%)	0.9	2.2	70	172
LPG (2%)	1.7	4.2	196	483
total	14.7	36.1		

table 4.4.2: Fuel consumption for the actual and model situation.

Finally the additional fuel consumption as a result of the assumed additional congestion were calculated. For every minute an engine idles, 16.8 cc fuel is used (AGV, 1988). If every car should idle five minutes longer during the peak hours the additional fuel consumption would be 8000 liters per day.
With 256 working-days per year, the extra fuel consumption would be about 2 million liters a year. The extra consumption by slowing down, accelerating and changing gears were not included in this calculation.

4.4.2 Consumption of natural resources

The additional consumption of natural resources in the model situation could be calculated if the increase of possession of cars were known. This is not possible according to the Dutch Central Office of Statistics (CBS, 1988).
For the production of an average European car and an average Sparta bicycle the average quantities of several materials are known (table 4.4.3). One average European car needs many more different types of materials for the production than one bicycle and a car is 53 times heavier than a bicycle.

material	mass (kg) car	bicycle
sheet steel	550	} 14.0
other steel	227	
cast iron	131	
aluminium[1])	15	0.5
lead	12	
zinc[1])	5	
copper[1])	9	0.5
glass	35	
rubber	55	2.5
plastics	44	1.5
paint	14	
paper, cloth, board	15	
total materials	1112	19

[1]) + alloys

table 4.4.3: Vehicle mass requirement analysis of a medium European car and a medium Sparta bicycle. (Sources: Henham, 1983; Sparta, 1988)

4.4.3 Energy consumption

The energy required for traffic consists of (Schoemaker, 1988):
- energy necessary for locomotion,
- energy necessary for production and transport of fuel,
- energy necessary for construction and maintenance of the vehicle,
- energy necessary for laying out and maintenance of the infrastructure.

If the energy consumption per kilometer for these aspects were known, the total additional energy consumption in the model situation could be calculated, which is done in this paragraph. The energy costs for the infrastructure can be neglected in this calculation.

The average energy consumption per person kilometer for car and bicycle traffic are shown in table 4.4.4.

energy necessary for:	energy consumption (kJ / passenger km) vehicle passenger car	bicycle
locomotion	1620	-
production and transport of fuel	325	-
construction and care of vehicles	780	720
total	2725	720

Table 4.4.4: Energy factors for passenger traffic in 1984.
(Source: Schoemaker, 1988)

For different reasons, the occupancy of cars is changing and so is the energy consumption per person-kilometer (table 4.4.5).
An average Dutch car used in commuter traffic consumes 4.8 times more energy per kilometer than an average Dutch bicycle. The energy necessary for car driving consists for 60% of locomotion energy.
The energy consumption for an average Dutch bicycle is high (720 kJ per kilometer) because of the low average distance covered during its life time.
The energy consumption for bicycles was calculated by taking the Dutch fleet of bicycles and the average mileage of the Dutch bicycle (Heuvel, v.d.,1988). Because of the low use of some bicycles, the energy consumption per kilometer is high (720 kJ/km). If only the bicycles in the Groninger commuter traffic were considered, the energy consumption per kilometer would be lower. The mileage of an average Dutch bicycle is 942 km (CBS, 1985) and the average life-time of a bike is 5.5 years. In the Groninger commuter traffic the yearly mileage is 1472 km per bicycle. Supposing that the bicycles are not used for other purposes, the energy consumption would be 460 (kJ/km). In this situation an average Dutch commuter car uses 7.5 times more energy per passenger kilometer than an average Dutch bicycle.

vehicle	occupancy (persons/vehicle)	energy (kJ/passenger km)	(kJ/vehicle km)
<u>car</u>			
work/school	1.39	3450	4796
shopping/ provision	1.75	2725	4769
business	1.11	4320	4795
social/ recreation	2.04	2350	4794
<u>bicycle</u>	1.00	460	460

Table 4.4.5: Energy consumption per purpose.
(Source: car traffic: Schoemaker, 1988)

For the actual and model situation the energy consumption of the commuter traffic could be calculated (table 4.4.6). The energy consumption in the commuter traffic would double in the model situation, while the total mileage would decrease by 17%. The additional energy consumption in the model situation would be 89 x 10^{12} Joules per year.

vehicle	energy consumption (kJ/km)	distance ($\times 10^6$ km/year) situation actual	model	energy consumption (J/year) situation actual	model
car	4796	14.7	36.1	70.5	173.1
bicycle	460	33.0	3.3	15.1	1.5
total		47.7	39.4	85.6	174.6

Table 4.4.6: Energy consumption in the actual and model situation.

4.4.4 Economic quantification of energy consumption

The costs of energy can be calculated in several ways. The increased energy consumption is only caused by the increase of car traffic. The additional energy consumption is divided into energy for locomotion (60% of the total energy consumption), production, construction and maintenance. The costs for locomotion were joined with petrol costs. 60% of 89.10^{12} J for locomotion means fl 804,140.- per year. The other 40% of the energy consumption was translated into costs of heavy fuel oil, frequently used for industrial production of energy. The costs of 3.56×10^{13} Joules in the form of heavy fuel oil would be fl 258,410.- (table 4.4.7). Prices were without excise duty and VAT (Value Added Tax).
The total extra costs of energy consumption in the model situation would be fl 1,062,550,- per year.

type of fuel	heat of combustion	extra energy consumption (10^{12}J/year)	costs	extra costs (fl/year)
petrol	32.3×10^9 (J/m^3)	53.4	486.40 (fl/m^3)	804,140.-
heavy fuel oil	40.2×10^9 (J/kg)	35.6	291.80 (fl/1000kg)	258,410.-
total		89.0		1,062,550.

table 4.4.7 : Additional energy costs in the model situation.
Sources: heat of combustion: Koninklijke PBNA
costs of petrol: Shell
costs of heavy fuel oil: BP

The assumed fuel consumption caused by an additional waiting time of 5 minutes per car in the peak hours could be quantified economically too. The additional costs would be about fl 970,000.-- per year.

4.5 Health

The effects of traffic on humans can be divided into health of cyclists and car drivers and public health. Each of these can be subdivided into the accident rates and other negative effects as e.g. effects of air pollution and noise-nuisance.
In this paragraph the chances to be involved in an accident are not included.
The concentrations of some chemical substances in cars in the commuter traffic are introduced in 4.5.1 and the concentrations of CO and NO_2 on pathways beside roads on the cordon around the inner city are calculated in 4.5.2. Finally the inhaled concentrations of some heavy metals by car drivers and cyclists in the commuter traffic are discussed in 4.5.3

4.5.1 Concentrations in cars

In commuter traffic the car is the most unhealthy vehicle to travel in.
In cars concentrations of several exhaust gases are very high. The inside of the car has an open connection with the outside. The air in an unventilated car is renewed every two minutes, and concentrations are the highest in the middle of the traffic stream (Den Tonkelaar 1983/1988). TNO did an inquiry after the concentrations of exhaust gases in cars in commuter traffic.
The concentrations of CO, NO, NO_2, benzene, toluene and lead are shown in table 4.5.1. According to Den Tonkelaar (1988), the concentrations in the Groninger commuter traffic will be the same as in this inquiry in Delft and surroundings. The background concentrations do not influence the concentrations on a road with dense traffic.

	number of samples	medium	50-P	95-P	98-P	maximum
CO(mg/m^3)	4231	6.7	4.9	15.9	23.0	68.0
NO	3859	436	372	918	1123	2670
NO_2	3877	77	58	177	227	640
benzene	4184	66	54	170	263	2500
toluene	4125	176	111	497	752	9200
lead	125	3.6	3.0	7.9	9.0	9.7

average time = 28 minutes, average speed 46 km/hour.

table 4.5.1: concentrations ($\mu g/m^3$) in cars in commuter traffic.
(Source: Den Tonkelaar 1983)

The exposure to these chemical substances are compared to open air limits. For some substances the maximal 1 hour values or high percentiles of 1/2 or 1 hour values are exceeded. The values of

NO_2 exceed the Dutch open air limits and those of the EC. NO- and benzene concentrations exceed the German open air limits (table 4.5.3).

4.5.2 Concentrations on the foot paths

The concentrations of CO and NO_2 near roads can be calculated with the CAR-model (TNO, 1988).
For the roads on the cordon around the inner city, the concentrations were calculated for the actual and model situation (table 4.5.3).

The average 98-percentile concentration of NO_2 would increase from 99 to 102 μg per m^3 and that of the 98-percentile concentration of CO from 3050 to 3175 μg per m^3. The legally permitted concentrations of the 98% average concentration for 8 hours of CO in air is 6000 μg per m^3. For the 98 percentile of NO_2 one-hour average, the requirements are respectively 135 and 160 μg per m^3 (Ministeries van VROM and V&W, 1987).
These limits were not exceeded in any case.
The concentrations of NO_2 and CO on cycle tracks beside roads will be a little higher than on footpaths which lie further from the road.

chemical substance	country	standard	
CO (mg/m^3)	NL	6	98-P, 8 hour
	BRD	30	98-P, 1/2 hour
		10	yearly medium
	I/UK	40	1 hour medium
	I	57.2	1/2 hour medium
	Fr	115	maximum
	WHO	29	1 hour medium
		55	1/2 hour medium
		115	1/4 hour medium
NO_2 ($\mu g/m^3$)	NL	50	50-P
		110	95-P, 1hour
		135	98-P, 1hour
	BRD	300	98-P, 1/2 hour
	EC	50	50-P, 1 hour(guideline)
		200	98-P, 1 hour
		135	98-P, 1/2 hour(guideline)
SO_2 ($\mu g/m^3$)	NL	830	maximal 1 hour medium
	BRD	400	98-P, 1/2 hour
	I	790	1 hour medium
benzene ($\mu g/m^3$)	NL*	10	yearly medium
		1	yearly medium (guideline)
	BRD	300	99-P, 1/2 hour
lead ($\mu g/m^3$)	NL	0.5	yearly medium
		2	98-P, 24 hour medium
NO ($\mu g/m^3$)	BRD	600	95-P, 1/2 hour

* = draft standard

Table 4.5.2.a: Upper limits of some air pollution chemicals in the EC.
(Sources: Tonkelaar, 1983; Vereniging Lucht, 1986)

	CO	NO	NO2	Benzene	lead
NL	-	o	+	?	?
EC	o	o	+	o	?
WHO	-	o	?	o	o
BRD	-	+	-	+	?

+ = limits are exceeded
- = limits are not exceeded
o = no existing standards
? = no comparable standards

Table 4.5.2.b: Comparison of the standards with the concentrations found in cars.

4.5.3 Heavy metals

In Germany the "Arbeits und Umwelt Schutz e.V." in Bremen investigated how much heavy metals are inhaled by users of different types of traffic (Wahrlich 1985). The test persons travelled the same typical commuter routes in Bremen by different means of transport in the morning peak hour. Cyclists travelled on tracks separate from the main road. The inhaled concentrations of iron, copper, zinc, bromine and lead were measured. The concentrations were divided into two parts: one part that reached no further than mouth, nose and throat and a second part that penetrated the lungs. It appeared that drivers in cars without ventilation inhale concentrations which are about two and a half time higher than those for cyclists (table 4.5.3).

Not all measured components are equally harmful. Iron e.g. is a useful metal for humans in low concentrations. The concentrations measured were harmless. Lead, on the other hand, can be toxic and accumulates in bones, liver and kidneys. The most sensitive biologic systems for negative effects of lead are the building of haemoglobin, kidneys and the central nerve system.

The further from the road the lower the concentrations. At 25 meters from the road the concentrations are 50% of the concentrations on the middle of the road. At 50 meters this is 25% and at 100 meters, 10%.

material	inhaled concentrations					
	mouth/nose/throat			lungs		
	bike	car+	car-	bike	car +	car -
iron	1739	1193	1177	386	711	542
copper	45	175	57	29	204	96
zinc	101	133	145	45	148	97
bromine	140	390	337	108	370	282
lead	92	112	132	141	678	349

car + = car with ventilation
car - = car without ventilation

table 4.5.3: Inhaled concentrations in commuter traffic (ng/m^3). (Source: Wahrlich, 1985)

4.5.4 Conclusions

It was not possible to quantify the health effects econimically. The quantification of the effects of CO, NO_x and C_xH_y were discussed earlier in §4.1.
The values of CO and NO_2 on footpaths and in car commuter traffic could not be compared because of the varying measuring periods, but it is clear that in cars limits for NO_2 are exceeded and on footpaths they are not.
The concentrations of chemical substances emitted by traffic were the highest in the middle of the road and on footpaths the concentrations were lower than on separated cycle tracks.

5. CONCLUSIONS

An increase of the Groninger resident car commuter traffic by 146% (from 31 to 76% (including car passengers)), all other volumes of motorized traffic remaining equal, would cause several environmental effects.
In this study the environmental and economic effects of some air pollutants, noise nuisance, parking space, consumption of energy, and some health aspects are quantified.

Air pollution

- the emission of combustion gases is the most important source of air pollution by car traffic;
- the additional emissions of CO, SO_2, NO_x and C_xH_y add respectively 8, 1, 4 and 8 $^o/oo$ to the total emissions caused by traffic in the province of Groningen and the additional SO_2 and NO_x emissions by traffic would add 4 $^o/oo$ to the quantity of acid SO_2 and NO_x emissions by traffic in the province of Groningen;
- the reduction of the additionally emitted CO, NO_x and C_xH_y in the model situation is economically quantified by calculating the costs of regulated three way catalytic converters. The costs would be fl 439,470.- per year (table 5.1), which would have to be paid by the car drivers.
- the reduction of the additionally emitted lead in the model situation is economically quantified by calculating the costs of unleaded petrol. The costs would be fl 49,505 per year.
- An assumption of the additional air pollution caused by traffic congestion was made. The emission of CO and C_xH_y would rise with 350% in comparison with the actual situation. The increase of NO_x would be 210%. The assessed additional costs to reduce this inccrease would be fl 62,000.- per year.
- most air pollution effects could not be quantified economically.

Noise nuisance

- the increase of the equivalent sound level (Leq) in the model situation would be about 0.3 - 0.4 dB(A) on the cordon roads around the inner city. This is a relatively small increase, but in practice this leads to an increasing number of redevelopment cases.
- the increase of the resident car commuter traffic would raise the proceeds of the noise nuisance levy on fuel with fl 19,757.- per year, to be paid by the car commuters.

Infrastructure

- the requirement for additional parking space would increase;
- the increase of additional parking space would be 22 hectares, i.e. a quarter of the space of the inner city within the "Diepenring";
- the costs of the increased parking space, calculated as rent to be paid by industry and private persons to the municipality of Groningen would be fl 6,211,200.- per year.
- if the additional space for parking can not be found, it

would be necessary to build parking garages.

Consumption of energy and natural resources

- the additional consumption of energy could be calculated partly as extra fuel consumption, which would be 1548 m^3 petrol, 102 m^3 diesel and 287 m^3 LPG per year;
- the production of a car takes 53 times more materials than the production of a bicycle;
- the total energy consumption of a vehicle can be divided into energy for locomotion, production of fuel, production and maintenance of vehicles as well as of infrastructure. Car commuter traffic consumes 7.5 times more energy per passenger kilometer than bicycle commuter traffic. The total consumption of energy would increase with 89×10^{12} Joules in the model situation;
- the increased consumption of energy would cost fl 1,062,550.- per year, to be paid by car users.
- an increase of the waiting time by 5 minutes for all cars in the peak hours in the model situation would raise the fuel consumption costs by fl 973,000.--.

Health

For both actual and model situation:

- the concentrations of chemical substances are the highest on the middle of the road and decrease in the direction of cycle track and foot path;
- inside cars in commuter traffic the concentrations of NO_2, NO and benzene exceed the open air limits;
- car commuters inhale much higher concentrations of iron, copper, zinc, bromine and lead than bicycle commuters riding on cycle tracks.

When the actual and model situation are compared:

- the increase of the concentrations of CO and NO_2 in the model situation on foot paths do not lead to an exceeding of limits.
- an increasing car commuter traffic would raise the concentrations of chemical substances. The car commuters themselves inhale the highest concentrations, but other road users would also inhale the higher concentrations of chemical substances.
- for health in general, and for the personal health of commuters in particular, it would be better to travel by bike than by car, the more so as a decreasing car traffic would at the same time mean decreasing concentrations of air pollutants;
- in the model situation the concentrations of NOx and CO would remain within the limits on Groninger foot paths along the cordon roads around the inner city;
- the health effects could not be quantified economically.

The total economically quantified aspects of the quantified environmental impact of the model situation are shown in table 5.1. The assessed additional costs caused by congestion would be about 1 million Dutch guilders.

environmental aspect	costs of	additional costs in the model situation (fl/year)	(ECU/year)*
air pollution	catalytic converters	439,470.-	
	unleaded petrol	49,505.-	
noise-nuisance	noise-nuisance levy on fuel	19,757.-	
infrastructure	parking space	6,211,200.-	
energy consumption	fuel consumption for driving	804,140.-	
	other energy consumption	258,410.-	
	total	7,782.482.-	3,348,024.-

* Rate of exchange on 6 May 1988: 1 ECU-guilder = fl 2.3245.

table 5.1: Costs of environmental impact caused by increasing car traffic

The economic effects would be caused for the greater part by the extra space required for parking.
The costs to reduce the additional pollution would be relatively low, but only the chemical substances reduced by catalytic converters (CO, NO_x and C_xH_y) have been included in this calculation.
The increasing car commuter traffic would result in a small increase of costs for redevelopment on account of traffic noise-nuisance.

The costs of the calculated environmental impact per additional resident car commuter would be: 7,782,482.-/14,991 = fl 519.-- = 223.-- ECU per year.
These costs are conservative because not all environmental effects were treated exhaustively.
The economic quantifications should not be interpreted as estimated expenses of a solution for the problem. By paying the calculated costs, most of the problems would not be solved. In addition many environmental aspects of traffic were not dicussed in this study, such as: further types of refuse, accident rates, the economic quantifications of air polluting chemicals, the consumption of non-energy natural resources, and health aspects.
The costs caused by an increasing car commuter traffic could be translated into proceeds caused by an increasing bicycle commuter traffic.

It is not realistic to suppose that an increasing car commuter traffic can be viewed in isolation. The overall environmental and economic effects would be much more severe if other types of car traffic would also increase.

be higher to counter all negative effects for the environment. It is highly probable that not any price will be high enough to cancel all negative effects of car traffic.
Against these backgrounds bicycle traffic in European cities should be stimulated more than it is done nowadays!

6. Discussion

In this study it was tried to quantify the environmental effects of bicycle commuter traffic in cities in comparison to car commuter traffic.
Although several conclusions can be drawn, the comparison of the actual and model situation is not complete and there are also uncertainties.
Some subjects which were not discussed are:
- refuse matter, because the increase in the number of car owners was not known;
- accident rates as a part of the health of travellers and other safety aspects;
- the economic quantification of health aspects since this is not possible at this moment.

The effects of the increasing traffic congestion could not be quantified precisely, but an assessment was made. The calculated costs of this assessment form an conservative indication for the increasing air pollution and fuel consumption as a result of the more stagnating traffic in the model situation.
The following remarks can be made for the methods of assessment used:
- the method to quantify the costs of the additional air pollution by NO_x, C_xH_y and CO was based on the application of catalytic converters. This only holds when the converters are working well and when they are treated in the right way. Twice refuelling with leaded petrol reduces the conversion by half (Klaver, 1987). To avoid knocking of the engine other chemicals than lead are added to petrol. These chemicals are aromatic hydrocarbons such as benzene and toluene, alcohols and ethers. Benzene and toluene are very hazardous to health and the limits for benzene are exceeded already. Prussic acid and Platinum can also be emitted by a catalytic converter.
- redevelopment of areas where the noise level would be exceeded is not the most welcome solution. Inside the houses the situation would only be improved if windows and doors are kept closed.
- the costs of increased parking space can be calculated, but never the less, parking would still take up a space which most probably could not be found in the city of Groningen. It would be necessary to build parking garages, which would cost much more than the calculated 6 million guilders.
- the secundary negative effects of energy consumption, such as air pollution, thermal pollution and refuse were not included in this study.
- the energy consumption of bicycles would be lower, if the use of the bicycles would be more intensive. It is not probable that the bicycles used in commuter traffic would not be used for other purposes as well.
- the health risks of motorized traffic are not very clear. The mixture of chemical substances as in exhaust gases might cause more effects, still unknown, than the single substances do.

It was not possible to quantify all environmental effects of a projected increase of car commuter traffic, not to mention all economic effects. In this study only the economic effects which could be quantified were calculated. In reality additional costs for the environment by an increasing car commuter traffic would

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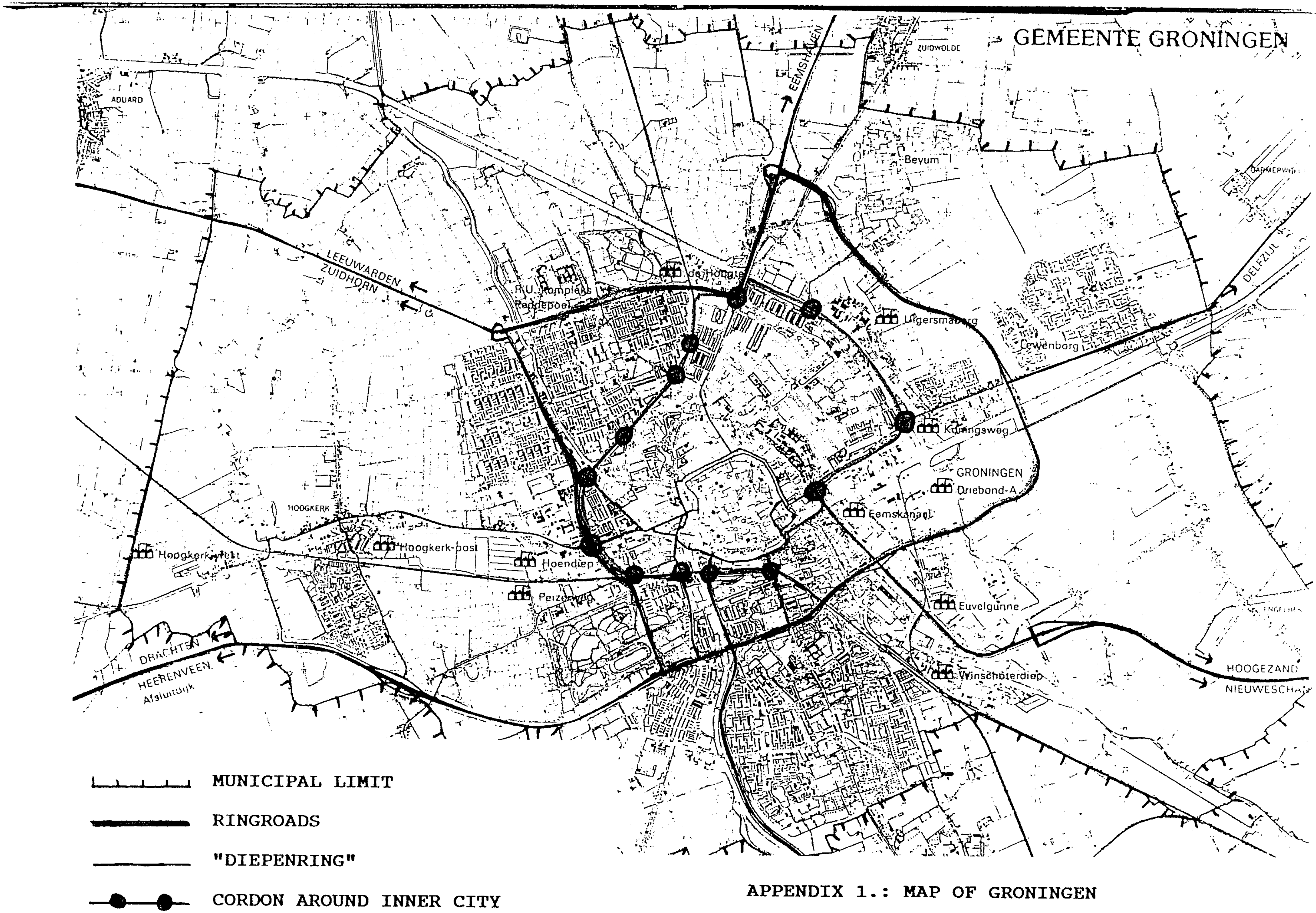

APPENDIX 1.: MAP OF GRONINGEN

Road	passenger cars 7 - 9 a.m. situation actual	model1)	7 a.m. - 6 p.m. situation actal	model2)	24 hours situation actual3)	model4)	increase (%) 7-9a.m.	7-18	0-24
Friese Straatweg	608	821	4056	4652	5496	6220	35	15	13
Hoendiep	1379	1862	7355	8707	9738	11380	35	18	17
Peizerweg	763	1030	3389	4137	4593	5501	35	22	20
Paterswoldseweg	1052	1420	7480	8510	10136	11387	35	14	12
Emmaviaduct	2558	3453	12871	15377	17442	20485	35	19	17
Herewegviaduct	1094	1477	7870	8942	10665	11967	35	14	12
Europaweg	4302	5808	22082	26299	29924	35044	35	19	17
Damsterdiep	1714	2314	9479	11159	12845	14885	35	18	16
Korrewegbrug	549	741	3538	4076	4794	5447	35	15	14
Bedumerweg	1417	1913	9238	10627	12575	14261	35	15	13
Asingastraat	423	571	3738	4152	5066	5569	35	11	10
Noorderst.str.	877	1184	6289	7149	8522	9566	35	14	12
Prinsesseweg	740	999	5419	6144	7344	8225	35	13	12

1) model situation = actual situation x 1.35.
2) model situation = actual situation + 2.8 x increase 7 - 9 a.m..
3) actual situation = (visual countings 7a.m. - 6p.m./0.642) x 0.87.
4) model situation = actual situation + 3.4 x increase 7 - 9 a.m..

Appendix 2.: Passenger car streams on the roads of the cordon around the inner town.

Road	intensity passenger cars 7a.m.-6p.m. (cars/hour) situation		freight traffic 7a.m. - 6 p.m. (cars/hour)	Rj	F_2	b (m)	Cw (dB(A))	noise level (dB(A)) situation	
	actual	model	actual=model					actual	model
Friese Straatweg	369	423	12	17.5	0.9	35	-	60.9	61.2
Hoendiep	669	792	41	13	-	-	-	65.1	65.5
Peizerweg	308	376	17	20	0.4	34.5	-	60.1	60.5
Paterswoldseweg	680	774	32	12.5	1.0	25	-	65.7	66.0
Emmaviaduct	1170	1398	71	23.5	0.5	89.5	-	65.4	65.7
Herewegviaduct	715	812	16	14.5	0.7	30	-	63.9	64.2
Europaweg	2007	2390	143	40	0	60	-	65.7	66.0
Damsterdiep	862	1015	61	12.5	0.5	50	-	66.9	67.2
Korrewegbrug	322	371	10	12	1.0	25.5	-	61.7	62.1
Bedumerweg	840	966	49	18	1.0	70	-	65.1	65.4
Asingastraat	340	378	11	15	1.0	32.5	-	61.1	61.4
Noorderstat.str.	572	650	27	15.5	1.0	32.5	-	64.0	64.3
Prinsesseweg	493	559	21	16	1.0	32.5	1.5	64.5	64.8

Appendix 3: Noise levels on fronts of houses on roads of the cordon around the inner town.

Road	traffic streams (cars/day) passenger cars situation acutal	model	trucks 1) situation act.=mod.	concentrations on foot paths ($\mu g/m^3$) CO 2) situation actual	model	NO_2 3) situation actual	model
Friese Straatweg	5496	6220	522	3100	3200	96	98
Hoendiep	9738	11380	659	3200	3400	120	128
Peizerweg	4593	5501	218	2200	2200	81	83
Paterswoldseweg	10136	11387	686	4000	4200	111	114
Herewegviaduct	10665	11967	722	3300	3400	100	102
Europaweg	29924	35044	2232	3300	3500	100	103
Damsterdiep	12845	14885	1110	3800	4100	127	131
Korrewegbrug	4794	5447	324	2100	2100	72	74
Bedumerweg	12575	14261	848	2800	2900	103	107
Asingastraat	5066	5569	179	2500	2500	81	83
Noorderstat.str.	8522	9566	301	3300	3600	103	106
Prinsesseweg	7344	8225	497	3000	3000	96	99

1) percentage trucks calcualted in the period between 7 a.m. and 6 p.m.. If the percentage of trucks was not known the average percentage of the other roads was taken: 6.3%.

2) 98-percentile, 1 hour medium.

3) 98-percentile, 8 hour medium.

Appendix 4: Air pollution on foot paths beside the roads of the cordon around the inner town, calculated with the car-model.