PREFACE

Having a background in human health (I studied Health Sciences at the University of Maastricht before), the topic ‘Urban design and human health’ immediately got my attention when I had to choose a topic for my training research. Since I was now enrolled in Energy and Environmental Studies, I thought I shouldn’t choose this topic since it was just an extension of Maastricht. Ton later said, he wouldn’t have let me at that time anyways. So I did not…

After having finished my training research another topic had to be chosen for my final research and thesis. The health interest did not die yet so I thought a combination of Energy and Environmental Sciences and Environmental Health Sciences would be perfect. The previous mentioned topic was still available and Ton was very enthusiastic. He also made two other persons very enthused: Roel Vonk from the Academic Hospital (biomics, UMCG) and Frans Duijm (GGD, Health Service of the Municipality of Groningen, medical environmentalist). Although it was sometimes a challenge to work with 3 supervisors, each with their own specialism and opinions and ideas, I could not have finished my thesis without their help. An advantage of so many supervisors… if one is away, there are always two others left. Since part of writing my thesis was in the summer holiday, this was surely convenient.

The absence of Ton in the beginning did not delay my research since Laurie Hendrickx helped me getting started and getting me on the right track. We had some very useful brainstorm sessions. Other IVEM-help came from René Benders and Anne-Jelle Schilstra. Excel and I did not always get along, fortunately René was there to help. Anne-Jelle provided me background information on land use statistics and was a great help by discussing the land use data acquired.

The land use data brings me to one of my external data sources: Jozef van Genk from the Municipality of Groningen. Being a GIS-expert in the Spatial Planning and Economic Affairs (ROEZ) of the municipality, he provided the data regarding land uses in the city of Groningen and made the random sample of the 100 households which provided me information about distances to activities in the city. Without him, no urban form and distance data would have been available.

Besides providing one of my supervisors, the Health Service of the Municipality of Groningen was a source of health data in the person of Jan Broer, epidemiologist. He made available the data on incidence of T2DM, BMI and healthy exercise norm derived from the recently performed ‘Health Survey 2006’. In this way, data on the area of spatial planning could be coupled to health data.

Furthermore, the IVEM coffee breaks as well as the people in my workroom helped me a lot.
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SUMMARY

More and more people are living in cities. Characteristic of current cities are the higher levels of air pollution and the physical inactivity of its inhabitants due to motorized traffic. Recent IVEM research conducted as part of the collaborative EU project “Toolsust” showed strong differences in car use, cycling and walking among five European city dwellers. A lack of physical activity can attribute to the development of overweight, obesity, metabolic syndrome (MetSyn), and diabetes mellitus type 2 (T2DM) which are risk factors for cardiovascular diseases. The incidence of overweight, obesity, MetSyn, and T2DM is increasing and cardiovascular diseases are the most important cause of death in the Netherlands.

This research aims to develop research questions for further research based on the hypothesis that the mechanism by which obesity, MetSyn, and T2DM are caused is expected to be complementary to the mechanism that causes particulate matter to be damaging to human health and therefore may be additive. More specifically, the influence of urban design on transport choice and particulate matter levels, physical activity and the incidence of obesity and T2DM is examined. The research question therefore is: “Does the literature give evidence of a relation between use of and exposure to emissions of motorized traffic, immobility and the development of obesity, metabolic syndrome and diabetes mellitus type 2?”

Scientific literature was studied for the possible cellular mechanisms responsible for the development of obesity, MetSyn and T2DM. Physical activity trends were examined and scientific literature was studied for the mechanisms responsible for the effects of particulate matter (PM$_{10}$). Obesity, MetSyn and T2DM are characterized by chronical inflammation and oxidative stress and form a risk factor for cardiovascular diseases. The incidence of one of the disorders increases the risk for developing the other; all three disorders are irreversible. Physical activity has declined in recent years because of travelling less by foot or biking and because less domestic work is done. Currently, in the Netherlands, 53% of the population above 12 years of age meets the healthy exercise norm (moderate activity for 30 minutes on at least 5 days of the week) and 10% is totally inactive. In cities, motor vehicles are the primary source of particulate matter, which has various health effects. Exposure to PM$_{10}$ leads to inflammation and oxidative stress as well as the formation of free radicals. Respiratory, cardiovascular and cardiorespiratory mortality and morbidity due to exposure to PM$_{10}$ (short-term, long-term, direct and indirect) in the Netherlands lead to 180 000 lost life years; no threshold level exists regarding health effects. Travelling by different modes of transport gives different PM$_{10}$ exposures; PM$_{10}$ levels were largest in buses and cars and lowest in pedestrians and walkers. However, inhalation factors like concentration and duration of exposure, beside the ventilation rate need to be taken into account when estimating PM$_{10}$ inhalation; exercise increases ventilation rate.

Reducing PM$_{10}$ emission by discouraging travelling by car can also increase physical activity since travel is a major potential source of physical activity in modern life, which is currently not completely utilized. Car ownership is increasing, though ownership decreases with increasing urbanisation. The built environment, in the form of connectivity and proximity, determines transport mode chosen and therefore environmental and human health. In the Netherlands, on average 35 km is travelled daily, most of which is done by car (25 km), followed by bike (3.7 km) and train (3.6 km). Visiting, work and recreative purposes are the most important motives for mobility. Walking and biking is promoted by high connectivity, mixed land use, proximity and the right infrastructure i.e. presence of side walks and biking paths as well as a general feeling of safety. Walking and biking in cities should be promoted, as they decrease air pollution (when it is a substitution for car travel) and increase physical activity. However, even when the urban design is well-suited for biking and walking, government measures are necessary. Individual responsibility is not sufficient to encourage walking and biking since the disadvantages of a car do not outweigh the disadvantages currently present. Measures like high parking tariffs and carrestricted city centres have to discourage travelling by car.

The urban design of the city of Groningen is well suited for encouraging biking and walking; proximity and connectivity are excellent. PM$_{10}$ levels in the city of Groningen strongly fluctuate but are below the PM$_{10}$ norms although the maximum number of exceedings in a year is higher than allowed. The incidence of T2DM as well as the share of population being overweight or obese is in the city of Groningen lower than average. Daily trips in the city of Groningen are generally short and
therefore bikable and/or walkable. Comparative assessments should be made in more cities in more countries to quantify the physical activity, PM$_{10}$ exposure, obesity and T2DM relationship. Other factors like demographics, genetics and dietary patterns should then also be taken into account.

Based on the literature and the data collected there seems to be a relation between use and exposure to emissions of motorised traffic, immobility and the development of diabetes mellitus type 2, metabolic syndrome and obesity. Mechanisms causing the effects of PM$_{10}$, MetSyn and obesity can be similar. Therefore the hypothesis is neither rejected nor confirmed and further research is needed to prove or disprove the hypothesis.
1. INTRODUCTION

City living is a reality for many and is rapidly becoming so for most of the world’s population. (Vlahov & Galea, 2003). Characteristic of current cities are the higher levels of air pollution and the physical inactivity of its inhabitants due to motorized traffic. Recent IVEM research conducted as part of the collaborative EU project “Toolsust” showed strong differences in car use, cycling and walking among five European city dwellers. (Kok, Falkena, Benders, Moll, & Noorman, 2003). Four times more energy per capita is consumed in ‘car’ cities compared to ‘public transport’ cities and almost 15 times as much as in ‘pedestrian’ cities. (Granados, 1998). Beside the energy use for transport, emissions of the different transport modes are also different. Motor vehicles are the primary source of environmental pollutants in urban areas and are responsible for three-fourths of the atmospheric pollution attributed to the transport sector. (Granados, 1998). In cities around the world driving cars contributes to air pollution and the risk of injury, cardiovascular and lung disease and death to road users. (Granados, 1998; Ogilvie, Egan, Hamilton, & Petticrew, 2004). Emissions used as indicator for health problems are nitrogen oxide (NO\textsubscript{2}) and particulate matter (PM\textsubscript{10}). (Colvile, Hutchinson, Mindell, & Warren, 2001; Brunekreef & Holgate, 2002; Weide van der, 2005). The emissions are released in very close proximity of humans which reduces the opportunity for the atmosphere to dilute emissions which would render them less harmful for human health. (Colvile et al., 2001).

Air pollution and human health
An association between high levels of anthropogenic air pollutants and human illnesses has been known for more than half a century. The World Health Organisation has ranked air pollution as one of the top ten contributors to preventable deaths. (Bhatnagar, 2004). For the Netherlands (16 million inhabitants, about 140 000 deaths per year, and an average PM\textsubscript{10} concentration of >30 µg/m\textsuperscript{3}), the number of deaths attributable to day-to-day variations in PM\textsubscript{10} would translate into at least 2100 deaths resulting from air pollution per year—almost twice the number of deaths due to traffic accidents. (Brunekreef et al., 2002) There is a direct relationship between atmospheric pollution and general mortality as well as specific mortality due to cardiovascular disease and lung cancer. (Granados, 1998).

Epidemiological studies show a consistent increased risk for cardiovascular events in relation to both short- and long-term exposure to present-day concentrations of ambient particulate matter. (Brunekreef et al., 2002; Brook et al, 2004; Kappos et al., 2004; Peters, 2005). Cardiovascular disease (CVD) is the leading cause of mortality in the industrialized world. (Bhatnagar, 2004).

Physical inactivity and human health
Travel is a major potential source of physical activity in modern life. (Rodriguez, Khatkak, & Evenson, 2006). Although vehicle ownership in many western countries is approaching market saturation, time behind the wheel is still on the rise, as is miles of travel per capita, albeit to a lesser extent. (Frank & Engelke, 2001). Large or exclusive reliance on the automobile sharply reduces physical exercise. (Granados, 1998). Physical inactivity is associated with multiple adverse health outcomes. (Berrigan & Troiano, 2002). Physical inactivity contributes to increased risk of many chronic diseases and conditions, including obesity, metabolic syndrome, hypertension, non-insulin dependent diabetes and coronary heart disease. One consequence of physical inactivity – obesity – has reached epidemic proportions. (Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003; Spranger et al., 2003; Olijhoek, Martens, Banga, & Visseren, 2005). Time spent in the car as a passenger or driver was positively associated with obesity. Overweight, metabolic syndrome and obesity have been found to be significantly associated with diabetes. (Ford, 1999; Frank, Andresen, & Schmid, 2004; Olijhoek et al., 2005). Diabetes, metabolic syndrome and obesity are increasing and all are affecting cardiovascular health. (Wolffenbuttel, 2003; Bhatnagar, 2004; Zelissen & Mathus-Vliegen, 2004).

Linking air pollution and physical inactivity
The mechanisms involved in the development of cardiovascular and cardiopulmonary diseases due to the exposure to particulate matter may be the same as those causing diabetes, metabolic syndrome and obesity, as pointed out by several studies. (Ford, 1999; Lippmann et al., 2003; Reilly & Rader, 2003;
The putative biological mechanisms linking air pollution to heart disease involve direct effects of pollutants on the cardiovascular system, blood and lung receptors and/or indirect effects mediated through pulmonary oxidative stress and inflammatory responses. Therefore, people with diabetes, metabolic syndrome or obesity may be even more susceptible to air pollution and have higher risk for air pollution related illness. Recent work on potential mechanisms of action of particulate air pollution point to pathways also influenced by diabetes. (Zanobetti & Schwartz, 2001; Bateson & Schwartz, 2004; Dubowsky et al., 2006; Ostro, Broadwin, Green, Feng, & Lipsett, 2006; Zeka, Zanobetti, & Schwartz, 2006).

**Healthier citizens by changing urban design**

Recent research has begun to focus on the link between public health and the built environment in an effort to combat increasing rates of overweight and obesity found in many Westernized nations. Giving the growing predominance of urban living, interventions that take into account features of the urban environment that have the potential to be widely applicable and to influence the health of vast numbers of people Transportation systems and land development are thought to directly influence transportation choices and a number of studies have linked transportation systems and land-use patterns to choices among different transport modes, including walking. Transport choice is influenced by proximity (distance) and connectivity (directness of travel) and thus urban design. (Saelens, Sallis, & Frank, 2003). Increasing physical activity in the population has been described as the “best buy” for improving public health. Increasing physical activity is beneficial for blood lipids, insulin sensitivity, cardiovascular risk, physical fitness and physiological wellness. (Ogilvie et al., 2004; Zelissen et al., 2004). Walking and cycling offer opportunities for physical activity and pose little threat to other road users. Approximately 83% of all ‘trips’ are short, for non-work purpose and occur relatively close to home. The majority of non-work trips are within walking and cycling distance and are therefore of interest to physical activity, air quality and transportation planning fields. (Saelens et al., 2003). The presence of side walks can for example encourage walking. If the built environment is not structured to encourage pedestrian and bicycle travel, people will opt for the automobile. (Berrigan et al., 2002). Furthermore, studies that examined the exposure of cyclists, car drivers and pedestrians to traffic-related air pollutants found that the exposure of car drivers to pollutants is roughly twice that of bikers. Walking and cycling commuters had significantly lower exposure to pollutants compared to bus and car commuters. (Wijnen, Verhoeff, Jans, & Bruggen, 1995; Rank, Folke, & Jespersen, 2001; Chertok, Voukelatos, Sheppeard, & Rissel, 2004). However, inhalation of pollutants depends on the intensity of exercise and ventilation rates. (Wijnen et al., 1995; Sharman, Cockcroft, & Coombe, 2004).

Besides, in contrast to private automobiles, public transportation, bicycles and walking produce little environmental contamination or injury-related morbidity and mortality. Walking and bicycling are minimally hazardous in themselves, but carry a very high risk of injury when they are done on streets or high-ways shared with automobiles. People living in Active Community Environments have lower BMI’s and the incidence of obesity is lower; moderate physical activity is associated, over the long term, with lower rates of mortality and chronic disease such as diabetes, colon cancer, and heart disease. (Granados, 1998; Frank et al., 2001; Frank et al., 2004).

**Towards healthy cities and citizens**

To increase levels of physical activity to a point where the great majority of the population meets public health standards may require a rethinking of urban form. (Frank & Engelke, 2005). Research conducted in research conducted in the United States and in Europe suggests that urban form has a powerful influence on walking and biking and on overall household activity patterns (Frank et al., 2001). Efforts to increase the pedestrian orientation of the built environment through mixed use development, street connectivity, and good design, among other strategies, can enhance both the feasibility and the attractiveness of walking and bicycling by reducing physical and psychological barriers. (Handy, Boarnet, Ewing, & Killingsworth, 2002). Bringing origins and destinations closer together is related to increased walking and reduces air pollution. (Frank et al., 2005; Rodriguez et al., 2006).

Residents from communities with higher density, greater connectivity and more land use mix report higher rates of walking/cycling for utilitarian purposes than low-density, poorly connected and
single land use neighbourhoods. (Saelens et al., 2003) They also found that more residents of the less walkable neighbourhood were overweight. It is also encouraging to note that the increased numbers of walking trips came at the expense of automobile trips. (Rodriguez et al., 2006)

Since traffic’s harmful consequences are directly related to its volume; reducing automobile use through mass transit and promotion of non-motorized transportation is a key strategy for health promotion. (Granados, 1998). Their overall aims may include improving air quality and road safety, reducing body weight and reducing cardiovascular disease and pulmonary diseases, as shown in a summarizing scheme figure 1.1 on the next page. (Frank et al., 2001; Ogilvie et al., 2004).

1.1 Research aims
This research aims to develop research questions for further research based on the hypothesis that the mechanism by which the physical inactivity related diseases obesity, MetSyn, and T2DM are caused, is expected to be complementary to the mechanism that causes particulate matter to be damaging to human health and therefore may be additive. Therefore, this is an exploring study based on the available scientific literature.

More specifically, the influence of urban design on transport choice and particulate matter levels, physical activity and the incidence of obesity and diabetes mellitus type 2 is examined. In this case this will be done by preliminary comparing available data sets of the city of Groningen, the Netherlands.

1.2 Research question and subquestions
To achieve the research aims, the following research question is formulated:
“Does the literature give evidence of a relation between use of and exposure to emissions of motorised traffic, immobility and the development of obesity, metabolic syndrome and diabetes?”

This research question is divided into the following sub questions:
1) By which mechanism(s) do the lack-of-activity related diseases obesity, MetSyn and diabetes mellitus type 2 develop?
2) a: By which mechanism damages particulate matter human health?
   b: What does the dose-response curve of particulate matter and cardiovascular disease look like?
3) a: What do physical activity and mobility (mode of transport) patterns look like in the Netherlands and how have they changed?
   b: How do mode of transports differ regarding PM$_{10}$ emissions?
4) How can urban design influence mobility/transport choices? (connectiveness, proximity, transport, alternatives, walkability/bikability)

1.3 Boundaries
This study has an explorative character and only focuses on strongly developed countries, specifically the Netherlands. Influences of urban design on transport choice and physical activity therefore can be applied to developed countries. The data collected is all Dutch. Regarding air pollution, particulate matter is used, since this has the most health effects (at low levels) and the most attention.

The hypothetical common mechanism that affects human health regarding air pollution and the effects of physical inactivity is inflammatory; therefore this research focuses on inflammatory effects of particulate matter. Furthermore, the diseases in this research studied caused by physical inactivity are only inflammatory, hence obesity, metabolic syndrome, and diabetes mellitus type 2.

1.4 Methods
Scientific articles are studied for the mechanisms by which diabetes mellitus type 2, metabolic syndrome and obesity develop. The same was done for particulate matter. Literature with a combination of particulate matter and diabetes mellitus type 2 or obesity is looked for as well. Next, the mechanisms are compared to see if they are comparable.
Figure 1.1 Model reflecting how urban design influences environmental and human health by transport choices made

(with every car a % increase in particulate matter)

Urban design

# of % motorised dislocations

Air pollution (particulate matter)

Pathophysiology & syndromes

- diabetes type 2
- metabolic syndrome
- obesity

cardiovascular diseases

# of % nonmotorised dislocations

Physical activity

T2DM, MetSyn and obesity
Incidences of the physical inactivity related diseases in the Netherlands are compared to levels of physical activity over the years to distinguish trends. Health effects of particulate matter, both short- and long-term, are described beside the already mentioned mechanisms to analyze the impact of an increase in particulate matter. The modes of transport that emit particulate matter are described and the amounts of emission. Furthermore, the factors that influence the inhalation of particulate matter, like ventilation rate, concentration and mode of transport, are mentioned to make clear that many factors influence the exposure and inhalation of particulate matter and how one can reduce this inhalation.

Data regarding mobility, physical activity and urban design by Netherlands Statistics are used to give an overview of the current situation. Transport modes and distances daily covered in cities are analyzed to get an overview of modes of transport used, why it is used (motives) and how much. Car ownership is studied as well as how the built environment influences the choice of transport, to investigate how policy measures can reduce car use and promote physical activity by walking and biking.

Finally, the model presented is filled in with data of the city of Groningen to get an idea of the order of magnitude of the problem and what the effect will be on PM$_{10}$ levels and human health of substituting part of the car travel by walking or biking. This is done by creating different scenarios. Furthermore, the data has to support the theories from the literature.

1.5 Content of final report

The chapters of the report each cover a subquestion and are part of the model introduced earlier. Each chapter is therefore drawn into the model to clarify the structure of this report, which is shown on the next page as figure 1.2.

In the second chapter physical inactivity related diseases are described. First the physical activity patterns of the Dutch are described, followed by incidences of diabetes mellitus type 2, metabolic syndrome and obesity. Finally, possible mechanisms by which those diseases develop as well as the characteristics of the diseases are described.

Chapter 3 covers traffic-related particulate pollution and the effects on human health. First the emissions from traffic are described and then the focus is on particulate matter. Characteristics, short- and long-term health effects as well as direct and indirect health effects of particulate matter are described. Furthermore, the mechanisms by which particulate matter causes health effects is investigated as well as susceptible people. Besides, modes of transport as factors influences the exposure to particulate matter are analyzed.

The hypothesis following from the mechanisms described in chapter 2 and 3 is explained in chapter 4. Mobility in cities and how urban design influences this is the topic of chapter 5. The chapter describes the transport options and choices made by humans for certain transport modes. Emissions related to transport modes are described as well as the frequency certain transport modes are used currently. At the end of this chapter is analyzed how urban design influences human health and transport used.

In chapter 6 some preliminary comparing of data sets is done regarding the theories found. Data for the city of Groningen regarding particulate matter levels, physical activity, car ownership, transport choices and daily travel as well as incidences of overweight, obesity, metabolic syndrome and diabetes mellitus type 2 are used for this.

The final chapter contains the discussion, conclusions and recommendations for further research.
Figure 1.2 Structure of the report: triangles represent topics within a chapter, dotted squares represent chapter covering topics of several chapters (triangles).
2. HEALTH EFFECTS PHYSICAL INACTIVITY

Physical activity is necessary to remain healthy. Travel is a major potential source of physical activity in modern life, especially in urban areas where working, living and leisure is relatively close together. (Rodriguez et al., 2006). However, time behind the wheel is still on the rise in many countries. (Frank et al., 2001). Exclusive reliance on the automobile sharply reduces physical exercise. (Granados, 1998). Physical inactivity is associated with multiple adverse health outcomes; it contributes to increased risk of many chronic diseases and conditions, including obesity, hypertension, non-insulin dependent diabetes and coronary heart disease. Diabetes and obesity are increasing; obesity is even reaching epidemic proportions. Half of the adult population in the western world is sedentary or minimally active, and levels of physical activity are declining. Obesity is increasing in western countries in spite of a decrease in calorie intake, and this is mostly due to increasingly sedentary lifestyles. (WHO Regional Office for Europe, 2000). Overweight, obesity and metabolic syndrome are significantly associated with diabetes. People with obesity are at increased risk for developing metabolic syndrome; prevalence of one, increases the risk for the other. Furthermore, overweight, obesity, diabetes and metabolic syndrome all increase the risk for cardiovascular diseases. (Berrigan et al., 2002; Ewing et al., 2003; Bhatnagar, 2004; Frank et al., 2004).

Cardiovascular diseases are the most important cause of death in developed countries. Although the number of people dying from cardiovascular diseases is declining, still yearly nearly 50.000 people die from it in the Netherlands, which is a third of the total. Daily 845 hospital admissions take place due to cardiovascular diseases which corresponds to more than 300.000 admissions yearly in the Netherlands. (Koek, Engelfriet-Rijk, & Bots, 2006).

In this chapter, physical activity patterns of the Dutch people are studied and the diseases related to physical inactivity are (statistically) described. The focus is on the Dutch population as a typical example of a western life style. The mechanisms by which diabetes mellitus type 2, metabolic syndrome and obesity develop and increase the risk for cardiovascular diseases are also described, to compare those later with the mechanisms by which particulate matter causes cardiovascular diseases.

2.1 Physical (in)activity

It is generally known people have to moderately exercise half an hour a day, five days a week, preferably all days, to remain fit. This is called the ‘Healthy Exercise Norm’, created by a forum of Dutch exercise experts in 1998. This physical activity does not only involve sports, but also a variety of exercise modes during leisure or daily tasks like grocery shopping, cleaning, walking from and to work or school. (Schuit & Leest van, 2005a).

On average, half of the population meets the Healthy Exercise Norm, although regional differences exist. The urban population generally exercises less, and so do people under 18 years of age and above 75 years of age. Furthermore, 10% of the population is physically inactive and the Dutch spend more time ‘sitting’. The percentage of people meeting the healthy exercise norm has been stable during the last 5 years (2001-2005) and is 53%. The most important forms of activities that contribute to meeting the healthy exercise norm are domestic work and daily travel by foot or bike. From 1975 on the percentage norm-actives has decreased from 72% to 63% in 2000. This decrease is mainly caused by spending less time on domestic work. When the domestic work is left out, no decrease in norm-actives was present. (Schuit & Leest van, 2005b). Breedveld (2002) studied the time expenditure of people (>12 years) on four ‘movement’ activities in hours per week, from 19575 to 2000. The categories used are 1) sports, 2) game and recreation, 3) movements per bike and foot and 4) domestic activities like cleaning, vacuuming, gardening but not cooking and (dish)washing, ironing and doing groceries. From the four distinguished movement activities ‘sports’ shows a clear growth. Between 1975 and 2000 the average amount of hours spent on sports has increased from 0.7 hours to 1.4 hours in 1995, dropping to 1.2 hours in 2000. A closer investigation learned that the decrease in 2000 was due to (bad) weather conditions. Activity due to ‘game and recreation’ has remained the same with 1.1 hour a week. Movements per bike and foot have increased until 1995 from 2.5 hours per week in 1975 to 3.1 hours per week in 1995 but were a little less in 2000 (2.6 hours). Activity due to domestic activities have been constant as well with about 6 hours per week, although in 2000 this was less with 5.2 hours per week. Time spent on domestic work remains constant because of two
contrasting developments: at the one side increasing mechanisation and increasing efficiency, at the other side a reduction in household size and decreasing task specialization (increase in task combining) which reduces efficiency. In spite of this, domestic activities remain responsible for the largest amount of activities followed by movements by bike or foot. Furthermore this study shows that sport and game and recreation are almost always insufficient to meet the healthy exercise norm. Both activities have a high share of non-participation (61 and 70% respectively) and if participated, the frequency is low. Regarding the persons that do sport (39%), half of them (53%) does this one day a week. Only 3% of the sporters sports at least 5 days a week minimally half an hour. Thirty percent of the people participate in gaming and recreation; 56% of those people does this one day a week. About 7% spends at least 5 days a week half an hour on game and recreation. Time spent on movements per bike or foot and domestic work is significantly higher as well as the participation rate with 72 and 86% respectively. Both activities contribute to 26% of the population meeting the healthy exercise norm whereas this was only 5% when people just sport and game and recreate. (Breedveld, 2002).

The way Dutch translocate themselves to work, school, relatives, sports also influences physical inactivity. Over the years, the amount of kilometres travelled by car, either as a driver or passenger, increases while travelling by train, bike or foot remains the same and travelling by bus, metro or tram has decreased. (Statistics Netherlands, 2006a). This makes people less active based on their modes of transport.

A decreasing amount of physical activity increases physical inactivity related diseases like diabetes mellitus type 2, metabolic syndrome and obesity. Those diseases and incidence are described in the following paragraphs.

2.2 Diabetes mellitus type 2
Diabetes mellitus type 2 (T2DM) is a chronical metabolic disorder in which the blood sugar level is deregulated. Maintenance of normal blood glucose levels depends on a complex interplay between the insulin responsiveness of skeletal muscle and liver and glucose-stimulated insulin secretion by pancreatic β cells. Defects in the former are responsible for insulin resistance and defects in the latter are responsible for progression to hyperglycaemia (Lowell & Shulman, 2005). Therefore, the main physiological abnormalities are insulin resistance and impaired insulin secretion. (Pradhan, Manson, Rifai, Buring, & Ridker, 2001). Both of these features are likely caused by mitochondrial dysfunction.

Furthermore, heart rate variability is reduced, C-reactive protein levels (C because its calcium-dependent binding) are increased and higher peripheral white cell counts and fibrinogen levels have been observed in persons with diabetes. Those are all risk factors for cardiovascular diseases. (Zanobetti et al., 2001; Bateson et al., 2004).

2.2.1 Inflammation and oxidative stress
A subclinical inflammatory reaction has been shown to precede the onset of type 2 (non-insulin-dependent) diabetes. Chronic inflammation and oxidative stress are prominent in T2DM. (O’Neill et al., 2005). T2DM increases the risk for cardiovascular diseases. In 2003, more then half a million of the Dutch population of 16 million is diagnosed with T2DM and the number is increasing. Also worldwide this trend is observed. (Wolffenbuttel, 2003). Furthermore, an estimated 250.000 diabetics exist that are currently not diagnosed. (Leest van & Verschuren, 2006). Because of increasing overweight and obesity the incidence of T2DM is rising. (Baan & Poos, 2005). Diabetes is associated with severe, accelerated atherosclerotic vascular disease and increased susceptibility to infection. (Lippmann et al., 2003). Despite more than 100 million patients affected worldwide and a dramatic socioeconomic burden, the etiology of T2DM is not yet fully understood.

It has been hypothesized that T2DM is a manifestation of an ongoing acute-phase response that is primarily characterized by alterations of the so-called acute-phase proteins such as C-reactive protein (CRP). (Spranger et al., 2003). CRP is the principal downstream mediator of the acute phase response and is primary derived via interleukin(IL)-6 dependent hepatic biosynthesis. Immunoregulatory functions of CRP include enhancement of leukocyte reactivity, complement fixation, modulation of platelet activation and clearance of cellular debris from sites of active inflammation. Furthermore, increased CRP reduces flow-mediated dilation. (O’Neill et al., 2005). IL-6 is produced in a variety of tissues like activated leukocytes, adipocytes and endothelial cells. (Pradhan
et al., 2001). IL-6 is the major initiator of acute phase response by hepatocytes and a primary determinant of hepatic CRP production. (Luc et al., 2003).

Cross-sectional and prospective studies demonstrate increased concentrations of markers of the acute-phase response in patients with T2DM. One of these studies shows elevated concentrations of IL-6 which increases the risk of T2DM. IL-6 is also a main stimulator of the production of most acute-phase proteins. Also other cytokines like IL-1β and tumor necrosis factor (TNF-α) are central mediators of inflammatory reactions. (Spranger et al., 2003). TNF-α is also increased in people with diabetes. TNF-α may produce insulin resistance by, among other mechanisms, a decrease in autophosphorylation of the insulin receptor, conversion of insulin-receptor substrate-1 into an inhibitor of insulin receptor tyrosine kinase activity, decrease s the GLUT-4 transporter in muscle cells and increases in circulating free fatty acids. The lipid pattern of high triglycerides and low HDL cholesterol is a feature of inflammation and more specifically TNF-α. (Schmidt et al., 1999). Circulating cytokines secreted by the fat tissue can modulate the insulin responsiveness of liver and muscle. (Lowell et al., 2005). Cytokines operate as a network in stimulating the production of acute-phase proteins. The effects of IL-6 on CRP therefore largely depend on an interaction with IL-1β. Combined effects of cytokines therefore modify the risk of future T2DM. Several mechanisms, such as considerable influence of cytokines on lipid metabolism, may be important for the effects of combined elevations of different cytokines. (Spranger et al., 2003). Experimental evidence and more recent cross-sectional data suggest that IL-6 and CRP are associated with hyperglycaemia, insulin resistance and overt T2DM. Both IL-6 and CRP are known to predict the development of cardiovascular disease in otherwise healthy populations. (Pradhan et al., 2001).

Furthermore, several lines of evidence link excessive vascular oxidative stress to the impairment of NO action in patients with diabetes, which develops because of altered endothelial functions. Oxidative stress is a condition in which cells are subjected to excessive levels of molecular oxygen or its chemical derivatives called reactive oxygen species (ROS). Abundant availability of ROS reduces the bioavailability of nitric oxide (NO), the most important endogenous vasodilator agent. Superoxide anion (O$_2^-$) is the most important ROS that directly causes contraction of vascular smooth muscle cells. It also quickly scavenges NO within the vascular wall resulting in a reduction of its biological half-life. Endothelial secretion of NO counterbalances the direct vasoconstrictive effects of, among others, angiotensin II and endothelin on the vascular smooth muscle. Inhibition of NO synthesis therefore leads to significant peripheral vasoconstriction and elevation of blood pressure. (Bayraktutan, 2002). Endothelial nitric oxide synthase (eNOS) produces both NO and the superoxide anion radical (O$_2^•$), suggesting that the bioactivity of NO from the vascular endothelium depends on the relative concentrations of those two. Insulin resistance impairs NO-mediated vasodilation and therefore may be a pathogenic factor for abnormal regulation of vascular tone through an imbalance of NO and O$_2^•$ production. (Bayraktutan, 2002; Miatello, Cruzado, & Risler, 2004) TNF-α downregulates the expression of NOS. Oxidative stress may also arise because of enhanced generation of free radicals as a consequence of glucose auto-oxidation or pseudohypoxia. Free radicals advance endothelial dysfunction by promoting growth. This may also arise from deficiency of free radical-metabolizing enzymes. A form of oxidative stress as a direct consequence of interactions between NO and oxygen-derived radicals represents a common pathological mechanism in risk factors for atherosclerosis including diabetes. (Bayraktutan, 2002).

Another potential molecular mechanism how inflammation may be involved in the pathogenesis of T2DM is the sensitization of insulin signalling by salicylates induced via inhibition of the activity of IkB kinase β. IL-1β activates the IkB kinase β and might thereby induce insulin resistance. (Spranger et al., 2003). Insulin resistance in metabolically active tissues may also be promoted by altered endothelial permeability and diminished peripheral blood flow that limit insulin delivery. (O'Neil et al., 2005) Subjects with diabetes show less vascular reactivity, both flow and nitroglycerin mediated and endothelial function is impaired among patients with diabetes. (O'Neil et al., 2005).

2.2.2 Hyperglycaemia and insulin resistance
All forms of diabetes are characterized by chronic hyperglycaemia and the development of diabetes-specific microvascular pathology. Diabetes is further associated with impaired endothelial dysfunction
which includes impairment of anti-inflammatory and antiproliferative functions as well as vasodilatation reduction. The endothelium covers the entire inner surface of all the blood vessels. It lies between circulating blood and the vascular smooth muscle and plays pivotal roles in the regulation of vascular tone and endothelial integrity as well as in the maintenance of blood fluidity and homeostasis. The endothelium acts as an inhibitory regulator of vascular contraction, leukocyte adhesion, vascular smooth muscle cell growth and platelet aggregation. However, the characteristics of the endothelium change in response to changes in the system, like for example hyperglycaemia. Endothelial cells grown under hyperglycaemic conditions show an increase in $O_2$ levels which causes contraction of vascular smooth muscle cells. $O_2$ reacts with NO to produce peroxynitrite (ONOO$^{-}$), another oxidant that increases oxidative stress and elicits endothelial dysfunction by promoting tissue injury. To perform all those functions, the endothelium synthesizes or releases several vasoactive substances like the vasodilator NO and the vasoconstrictor angiotensin II and endothelin-1. (Bayraktutan, 2002).

Earlier in the course of diabetes, intracellular hyperglycaemia causes abnormalities in blood flow and increased vascular permeability. This reflects decreased activity of vasodilators such as nitric oxide (NO), increased activity of vasoconstrictors like angiotensin II and endothelin-1 and elaboration of permeability factors such as vascular endothelial growth factors. (Brownlee, 2001). There is a clear relationship between the level of hyperglycaemia and the development of complications like cardiovascular diseases in persons with T2DM. The United Kingdom Prospective Diabetes Study shows that every 1% rise in HbA1c (glucose) level increases the risk for cardiovascular diseases with 11%. Sugar is toxic for the vascular wall and therefore hyperglycaemia has a negative effect on endothelial function, coagulation and fibrinolysis. Furthermore, hyperglycaemia leads to accumulation of Advanced Glycation Endproducts (AGEs) and can induce oxidative stress. (Wolffenbuttel, 2003; O'Neill et al., 2005). AGEs are found in increased amounts in diabetic retinal vessels and renal glomeruli. (Brownlee, 2001). This process of non-enzymatic glycation of proteins plays an important role in the vascular complications of diabetes. In endothelial cells exposed to high glucose, intracellular AGE formation occurs within a week. Production of intracellular AGE precursors damages target cells by three general mechanisms. First, intracellular proteins modified by AGEs have altered function; AGE-induced biochemical modifications of collagen and elastin lead to pathological changes in the vascular function, like decreased elasticity and sensibility. Second, extracellular matrix components modified by AGE precursors interact abnormally with other matrix components and with the receptors for matrix proteins (integrins) on cells. AGE modification of type IV collagen’s cell-binding domains decreases endothelial cell adhesion for example. Third, plasma proteins modified by AGE precursors bind to AGE receptors on endothelial cells, mesangial cells and macrophages, inducing receptor-mediated production of reactive oxygen species. This AGE receptor ligation activates the pleiotropic transcription factor NF-kB, causing pathological changes in gene expression. Absorption of AGE-peptides via specific receptors on macrophages can initiate a cascade of events in which cytokines and growth factors will be produced, eventually leading to an increased permeability of the vascular wall for proteins, activation of monocytes and proliferation of smooth muscle cells. (Brownlee, 2001; Wolffenbuttel, 2003)

The hyperglycaemia is induced by the overproduction of superoxide by the mitochondrial electron-transport chain. When the electrochemical potential difference generated by the proton gradient across the inner mitochondrial membrane is high, the lifetime of superoxide-generating electron-transport intermediates is prolonged. There seems to be a threshold value above which superoxide production is markedly increased by hyperglycaemia increases the proton gradient above this threshold value as a result of overproduction of electron donors by the TCA (tricarboxylic acid) cycle. This, in turn, causes a marked increase in the production of superoxide by endothelial cells. Overexpression of manganese superoxide dismutase (MnSOD), the mitochondrial form of superoxide dismutase, abolishes the signal generated by the reactive oxygen species, and overexpression of uncoupling protein-1 (UCP-1) collapses the proton electrochemical gradient and prevents hyperglycaemia-induced overproduction of reactive oxygen species. (Brownlee, 2001).

Insulin resistance arises from defects in mitochondrial fatty acid oxidation, which lead to increases in intracellular fatty acid metabolites that disrupt insulin signalling. (Brownlee, 2001). Mitochondrial dysfunction in β cells may predispose individuals to develop β cell dysfunction and T2DM. In individuals with T2DM, β cells do not sense glucose properly and therefore do not release
appropriate amounts of insulin. Glucose sensing requires oxidative mitochondrial metabolism. Oxidative metabolism of glucose involves the transfer of energy stored within the carbon bonds of glucose the third phosphate of ATP. A proton electrochemical potential gradient across the mitochondrial inner membrane is created. These protons re-enter the mitochondrial matrix via ATP synthase with the use of energy stored within the electrochemical gradient. UCP-2, an integral membrane protein, leaks protons across the inner membranes when activated hence uncouples glucose oxidative metabolism from ATP production. Since it decreases the amount of ATP generated from glucose, UCP-2 negatively regulates glucose-stimulated insulin secretion. UCP-2 expression (in \( \beta \) cells) is stimulated by hyperglycaemia. Superoxide stimulates the proton leak activity of UCP-2 which will lead to a large stimulation of the proton leak and therefore lead to \( \beta \) cell dysfunction. (Lowell et al., 2005).

Insulin resistance and glucose-intolerance are also associated with other pathogenetic factors like increased triglyceride levels, high blood pressure, fat in the abdomen and increased levels of cholesterol. (Brownlee, 2001; Wolffsenbuttel, 2003).

### 2.3 Metabolic Syndrome/Insulin Resistance Syndrome

Metabolic Syndrome (MetSyn) is a clustering of atherosclerotic cardiovascular disease risk factors characterized by visceral adiposity, insulin resistance, hyperglycaemia, low HDL cholesterol and systemic inflammatory state. (Reilly et al., 2003; Olijhoek et al., 2005). A clustering of atherosclerotic cardiovascular disease risk factors was also known under the name ‘Syndrome X’; insulin resistance played an important role and that is why others called it ‘insulin resistance syndrome’. Clear diagnostic criteria for those syndromes remained absent, but in 1998 the World Health Organisation (WHO) defined metabolic syndrome as: “diabetes or disturbed glucose tolerance or insulin resistance and presence of two of the following characteristics: albumin-excretion of \( \geq 20 \) mg/min or albumin-creatinin ratio of \( \geq 20 \) mg/g, BMI > 30 kg/m\(^2\) and/or WHR > 0.90 (\( \beta \)) or > 0.85 (\( \beta \)), triglyceride value \( \geq 1.7 \) mmol/L and/or HDL < 0.9 mmol/L (\( \beta \)) or < 1.0 mmol/L (\( \beta \)), blood pressure \( \geq 140/90 \) mmHg and/or medication.” However, the National Cholesterol Education Program requires 3 of those risk factors and also the values of limits of those factors are not equal in different institutions. This makes diagnosing ‘metabolic syndrome’ quite difficult. (Olijhoek et al., 2005).

Since obesity is an important risk factor for MetSyn, the incidence has risen over the years as has overweight and obesity. About one fifth of the seemingly healthy population appears to have metabolic syndrome and the prevalence will only rise. From the people with T2DM 80% has metabolic syndrome when using the WHO definition. (Olijhoek et al., 2005). The diagnosis MetSyn identifies substantial additional cardiovascular risk above and beyond the individual risk factors. CVD mortality is increased almost twofold in individuals with MetSyn. (Robinson & Graham, 2004). Key components of MetSyn include beside the already mentioned central obesity, insulin resistance and chronic inflammation; dyslipidemia, hypertension, procoagulation and impaired fibrinolysis. (Reilly et al., 2003).

Insulin resistance is an important part of metabolic syndrome and is characterized by an insufficient reaction of target organs on physiological concentrations of insulin in the blood. Key regulators of insulin sensitivity are adipose tissue and free fatty acids. (Ukkola & Santaniemi, 2002; Olijhoek et al., 2005). Insulin resistance has been associated with subclinical inflammation involving cytokines derived from adipose tissue, or adipocytokines. There is substantial evidence that alterations in adipose tissue metabolism, especially with regard to excess visceral fat, play a role in the development of metabolic syndrome. (Robinson et al., 2004). Fat tissue is then not longer an inert storage but becomes an organ with important endocrinological functions. Adipocytes produce adipocytokines that are involved in the energy balance. Overweight and obesity increase the amount of adipocytokines like TNF-\( \alpha \), leptin and IL-6; adiponectin decreases. In adipocytes this can lead to a reduced sensitivity for insulin, which reduces absorption of glucose in adipocytes. At the same time the inhibiting effect of insulin on lipolysis in fat cells is suppressed, which increases the release of free fatty acids. In muscle cells of the skeleton the absorption of glucose decreases because insulin binding on the receptor leads to a disturbed signal transduction. The increased amount of FFAs in the liver will lead to suppression of the inhibiting effect of insulin on gluconeogenesis and therefore will increase the hepatic glucose production. Insulin stimulates the release of endothelin which is a powerful...
vasoconstrictor. This leads to endothelial dysfunction that involves inflammation, increased amount of cytokines and an increased plasma concentration of FFAs. (Olijhoek et al., 2005).

Cytokines have considerable influence on lipid metabolism. Both IL-6 and IL-1β for example act on the liver to produce the characteristic dyslipidemia of the metabolic syndrome. Dyslipidemia is characterized by elevated triglycerides (TG) and low levels of HDL-C. Elevated TG levels are possibly due to an increased flux of free fatty acids from the periphery to the liver that in the insulin-resistant state drives hepatic TG synthesis, as shown in studies in cell culture. (Spranger et al., 2003)

Recent evidence suggests that innate immunity and inflammation play a role in the development of insulin resistance and predict the development of T2DM. Thus, the pathophysiology of insulin resistance, the MetSyn cluster and atherosclerotic cardiovascular events may have a common proximal inflammatory basis. (Reilly et al., 2003).

2.4 Overweight and obesity

Obesity is defined (by the World Health Organisation) as a chronic disease coupled with fat accumulation in the body in such a way that health risks develop. (Zelissen et al., 2004). Physical inactivity is the most important cause of obesity. Overweight and serious overweight, obesity, are diagnosed generally by the Body Mass Index (BMI). The BMI is calculated by dividing the body weight in kilograms by the square of the body length in meters. According to the guidelines of the World Health Organisation is someone overweight when the BMI is between 25.0 - 29.9 kg/m² and obese when the BMI is larger than 30 kg/m². An alternative method of determining obesity is measuring the waist circumference; a waist circumference of 88 cm or more in women and 102 or more cm in men is known as visceral obesity. Overweight and particularly obesity are a risk factor for a number of disorder especially T2DM and cardiovascular diseases. The prevalence of overweight and obesity is increasing. In 2004 47% of the Dutch population aged over 20 was overweight, while this was 33% in 1981. Obesity is diagnosed in 11% of the current population while this was 5% in 1981. (Leest van et al., 2006).

Adipose tissue has endocrine functions that communicates with the brain and peripheral tissues by secreting hormones regulating appetite and metabolism. These functions are modulated by the location of the adipose tissue, that is subcutaneous versus visceral, by the size of the average adipocyte in the tissue and by adipocyte metabolism of glucose and corticosteroids. Several adipocyte-derived factors contribute to systemic insulin resistance. One such factor is the increased level of adipocyte-derived free fatty acids that contribute to insulin resistance in liver and muscle in obesity. Adiponectin enhances insulin action and is reduced in obesity. (Lazar, 2005). It has been suggested that TNF-α can modulate adiponectin secretion from adipocytes and hence mediate the effect on insulin metabolism. Adiponectin is also a link between obesity and related atherosclerosis. Adiponectin levels are known to be lower in patients with coronary artery disease. Furthermore, adiponectin modulates endothelial function and has an inhibitory effect on vascular smooth muscle cell proliferation. It also induces increased expression of molecules involved in fatty acid oxidation and energy dissipation in skeletal muscle, leading to decreased triglyceride content in skeletal muscle. Moreover, adiponectin is accumulated more preferably to the injured vascular wall than intact vessels and has been shown to suppress macrophage-to-foam cell transformation. Therefore, adiponectin may also be involved in the modulation of inflammation. (Ukkola et al., 2002).

The most important consequences of obesity are a disturbed glucose metabolism: insulin resistance that eventually leads to T2DM, dyslipidemia and hypertension. The latter three are known as the metabolic syndrome as described before. In obese persons that develop T2DM, β cells do not secrete enough insulin to compensate for the increased demand. This β cell failure is likely caused by inadequate expansion of the β cell mass and/or failure of the existing β cell mass to respond to glucose. Obese individuals also have smaller mitochondria with reduced bio-energetic capacity compared with lean persons. (Lowell et al., 2005).

In persons with obesity, leptin levels are elevated. Leptin is a hormone produced by adipose tissue just like TNF-α, resistin, IL-6 and adiponectin. All of those, except the latter, are increased in obesity. (Ukkola et al., 2002). Leptin levels increase in proportion to fat mass and promotes cholesterol ester synthesis in macrophages in a hyperglycemic environment which is an important process in the formation of foam cells in atherosclerosis. (Xu et al., 2003). Leptin functions
physiologically as a signal of energy stores, inhibiting food intake and accelerating energy metabolism. Leptin is thought to play a role in obesity-associated insulin resistance (and diabetes). (Lazar, 2005).

Obesity mediates cytokine production and leads to systemic elevation of IL-6 and CRP. (Pradhan et al., 2001). CRP and IL-6 were positively and significantly correlated with BMI. (Lazar et al., 2003; Danesh et al., 2004) IL-6 is an important adipocyte signalling molecule released from visceral and subcutaneous fat stores. (Pradhan et al., 2001). Higher inflammation levels are observed among individuals with obesity compared to individuals without this condition. (Dubowsky et al., 2006). Obesity-induced inflammation is initiated in white adipose tissue (WAT) but becomes systemic with the steady increase of adiposity or insulin resistance. (Xu et al., 2003).

Several mechanisms may link obesity and elevated concentration of CRP. The expression of TNF-α and circulating concentrations of TNF-α are increased in obesity. TNF-α can stimulate the production of CRP, inhibits adiponectin gene expression, causes insulin resistance and promote the production of macrophage migration inhibitory factor, a proinflammatory cytokine. (Ford, 1999; Ukkola et al., 2002). TNF-α stimulates the expression of preadipocytes and preadipocytes have the potential to “transdifferentiate” into macrophages. (Xu et al., 2003). Macrophage infiltration of adipose tissue is characteristic of obesity and likely a direct response to the abnormal fat metabolism caused by the increasing adiposity. (Xu et al., 2003; Lazar, 2005). Macrophages, upon activation, secrete numerous cytokines and chemokines like TNF-α, IL-1, IL-6 and MCP that are known to cause insulin resistance in adipocytes. These cytokines and chemokines further activate macrophages to increase lymphokine production and secretion. As a consequence, insulin signalling in adipocytes could become increasingly impaired, eventually leading to massive adipocyte lipolysis, necrosis and systemic insulin resistance.

Key findings:
- a lack of physical activity can lead to the development of overweight, obesity, MetSyn and T2DM that can result in CVD
- obesity, MetSyn and T2DM are characterized by chronic inflammation and oxidative stress and form a riskfactor for cardiovascular diseases.
- incidence of one of these disorders, increases the risk for developing the other; all three disorders tend to be difficult, if not impossible, to reverse

Additional findings:
- incidence of overweight, obesity, MetSyn and T2DM is increasing; cardiovascular diseases are the most important cause of death in the Netherlands
- physical activity has declined because of traveling less by foot or biking and less domestic work is done. Currently, in the Netherlands, 53% of the population meets the healthy exercise norm and 10% is virtually inactive
3. TRAFFIC-RELATED PARTICULATE POLLUTION AND HUMAN HEALTH

Motor vehicles are the major source of environmental pollutants in urban areas. (Granados, 1998). Related to most health problems are nitrogen dioxide (NO₂) and particulate matter (PM₁₀). (Colvile et al., 2001; Brunekreef et al., 2002; Weide van der, 2005). The emissions are released in very close proximity of humans which reduces the opportunity for the atmosphere to dilute emissions which would render them less likely to damage human health. (Colvile et al., 2001).

An association between high levels of anthropogenic air pollutants and human illnesses has been known for more than half a century. Several hundred published epidemiological studies exist linking air pollution with human illnesses. (Annema & Booij, 1994). In the Netherlands, 2 to 5 % of the yearly disease burden is estimated to be caused by the physical environment based on environment related health loss due to short time air pollution (particulate matter, ozone), noise, radiation (UV and radon) and moisture in houses. (Netherlands Environmental Assessment Agency, 2005a). Among air pollutants, elevations of particulate matter show the most strongest associations with disease.

Therefore, the effects and possible mechanisms that cause the effect of particulate matter (PM₁₀) as well as people at increased risk for health effects, are described in this chapter.

3.1 PM₁₀

Particulate matters are particles of which half has a diameter of 10 µm. Particulate matter is mainly derived from traffic (especially wearing out of tires and roads by traffic, but also emissions) but also has other sources like all varieties of combustion (electricity plants, wood burning) and industry. (Annema et al., 1994; Netherlands Environmental Assessment Agency, 2005a).

Guidelines regarding the concentration of PM₁₀ in the air are made on European level and implemented on national level. The yearly average concentration of PM₁₀ in the Netherlands should not exceed 40 µg/m³. The daily PM₁₀ concentration (24-hour average) should not exceed 50 µg/m³. However, it is allowed to exceed the daily norm of 50 µg/m³ 35 times a year. (Netherlands Ministry of Housing Spatial Planning and the Environment, 2005).

3.2 Health effects of particulate matter

Several health effects are attributed to exposure to particulate matter. Health effects depend on the deposition of particulate matter which is related to the size of the particles. (Rombout, Bree van, & Blamen, 2000). There are three levels particulate matter enters the body: nasal cavity and pharynx, the trachea and the bronchi and the alveoli. (Netherlands Ministry of Housing Spatial Planning and the Environment & Dutch Ministry of Agriculture Nature and Food Quality, 1985).

Particles with a diameter of 4.5 µm and less are capable of entering the alveoli. Those small particles penetrate more deeply into the air passages of the lungs than larger particles. Deposition at the alveolar level is important because vital gas exchange occurs here as the barrier separating the air from the blood is thin (< 0.5 µm) and because clearance of particles from this area is slower than from the conducting airways. Furthermore small particles carry per weight amount more toxicly absorbed material which is why they are, beside the smaller size and therefore larger penetration, cause more health risks. As particles pass along the airways they are deposited by the processes of impaction, sedimentation and diffusion: the latter affects only the very small particles in the mixture.

Particles with a diameter of less than 10 µm enter the nose and particles larger than 10 µm are eliminated for 100% by the nose. Because particles larger than about 10 µm in diameter usually do not pass the upper airways (nose, mouth, pharynx, larynx) to reach the air passages of the lung, it has become conventional to measure the mass of particles of diameter of less than about 10 µm per cubic meter of air and to describe this measurement as PM₁₀ or less than 2.5 µm per cubic meter of air when we talk about PM₂.₅ (Rombout et al., 2000; Committee on the Medical Effects of Air Pollution, 2006).

For the Netherlands (16 million inhabitants, about 140 000 deaths per year, and an average PM₁₀ concentration of >30 µg/m³), the number of deaths attributable to day-to-day variations in PM₁₀ would translate into at least 2100 deaths resulting from air pollution per year—almost twice the number of deaths due to traffic accidents. (Brunekreef et al., 2002).
A distinction is made in health effects of the short term variations of concentration, the acute effects, and the long-term variations, known as chronic effects. This paragraph describes the short- and long-term health effects of particulate matter exposure.

3.2.1 Health effects short-term variations of PM concentration

Particles smaller than 10 µm get deposited in the alveoli. Deposition can result in a reduced lung function, increased sensitivity for infections, damage to lung tissue and deterioration of cardiopulmonary diseases. (Schmith & Sloss, 1998). Short-term exposure to elevated PM\textsubscript{10} significantly contributes to increased acute cardiovascular mortality. Air pollution accelerates heart rate, diminishes heart rate variability (HRV) and increases the incidence of arrhythmias. (Bhatnagar, 2004).

Furthermore, hospital admissions for several cardiovascular, respiratory and pulmonary diseases acutely increase in response to higher ambient PM\textsubscript{10} concentrations. (Eeden van & Hogg, 2002; Brook et al., 2004). Each 10 µg/m\textsuperscript{3} increase in PM\textsubscript{10} increases daily total and cardiopulmonary mortality with 0.21% according to the National Mortality and Morbidity Air Pollution Study (NMMAPS) based on data from 90 of the largest cities in the United States. The same rise in PM\textsubscript{10} increases cardiovascular deaths with 0.69%. A pooled analysis of hospital admissions shows significant increases in admission rates of 0.8% and 0.7% for heart failure and ischemic heart disease for each 10 µg/m\textsuperscript{3} elevation in PM\textsubscript{10}. (Brook et al., 2004). All-cause mortality increased with 0.6% following a 10 µg/m\textsuperscript{3} change in 2-day average PM\textsubscript{2.5} concentration. (Ostro et al., 2006).

Numerous studies show a positive association between daily mortality and particulate air pollution, even at concentrations below regulatory limits. This led to research regarding the shape of the exposure-response relation. Figure 3.1 shows the rate of change of daily mortality when exposed to PM\textsubscript{10} in the twenty largest cities of the United States from 1987 to 1994, divided into total mortality and cardiovascular and respiratory mortality. (Daniels, Dominici, Samet, & Zeger, 2000).

The curve for cardiorespiratory mortality is roughly linear, which is consistent with the absence of a threshold. This suggests that there is no level of exposure to PM\textsubscript{10} where there are not health effects. (Daniels et al., 2000). The curve for total mortality is exponential. This curve also exists for exposure to PM\textsubscript{2.5} and is shown as figure 3.2. Figure 3.2 shows the percentage increase in daily deaths due to exposure to PM\textsubscript{2.5} in six cities in the United States from 1979 to 1988. A linear relationship is seen down to 2 µg/m\textsuperscript{3}, also indicating no threshold regarding health effects. An 1.5% increase in mortality was found with each 10 µg/m\textsuperscript{3} increase in PM\textsubscript{2.5}. (Schwartz, Laden, & Zanobetti, 2002). However, the effects of PM\textsubscript{2.5} and PM\textsubscript{10} on health can not be compared as the particles have different sources and composition. (Brunekreef, 2005).
In absolute numbers, 200 hospital admissions for acute cardiovascular diseases in the Netherlands can be yearly attributed to exposure to PM\(_{10}\) as well as 700 hospital admissions for pulmonary diseases. Regarding pulmonary complaints/diseases, under the children population from 7 to 12 years, 10,300 children daily reported pulmonary complaints regarding the upper airways. This population also daily had 600 asthma attacks and 1,600 children daily have to use medicines because of asthma due to exposure to PM\(_{10}\). From the total population, 2,500 people report daily complaints regarding the lower airways. (Netherlands Ministry of Housing Spatial Planning and the Environment, 2004). In the Netherlands yearly 2300 to 3500 people, with an average of 3000, die sooner because of short-term increases of exposure to PM\(_{10}\). The length of life-shortening is however small and assumed to be a couple of days till months. (Buijsman et al., 2005).

![Figure 3.2 Increase in daily deaths due to exposure to PM\(_{2.5}\) in six cities in the United States from 1979 to 1988. The shaded area indicates the pointwise 95% confidence intervals at each point; the line shown is a least-squares regression line through the estimated points. (Schwartz et al., 2002).](image)

### 3.2.2 Health effects long-term variations of PM concentration
Long-term exposure to particulate matter increases all-cause, cardiopulmonary and lung cancer morbidity and mortality. Data from the American Cancer Society (ACS) cohort estimated that for each 10 µg/m\(^3\) increase in annual average exposure to PM\(_{2.5}\) long-term all-cause, cardiopulmonary and lung cancer mortality were increased by approximately 4%, 6% and 8% respectively. The relationship between PM\(_{10}\) and adverse health effects was linear without a safe threshold level. (Brook et al., 2004) The risk of cardiovascular mortality increases with deaths attributable to ischemic heart disease, arrhythmias and heart failure. (Mills et al., 2005). With respect of morbidity, respiratory symptoms, lung growth and function of the immune system are affected. (Kappos et al., 2004).

In addition to increased mortality in adults, increased respiratory effects in children associated with long-term PM\(_{10}\) exposures were reported in the Harvard Six City Study. Furthermore, the Children’s Health Study (CHS) in southern California showed that PM\(_{2.5}\) is significantly associated with slower growth of lung function in children. (Lippmann et al., 2003).

The long-term of exposure to PM\(_{10}\) in the Netherlands results in chronical effects that contribute to earlier deaths; about 12,000 to 24,000 people yearly die sooner with an average of
18,000. (Buijsman et al., 2005). The environment-related health burden is often expressed in Disability Adjusted Life Years: DALY. One DALY means that one person is will die one year sooner. The DALY for exposure to PM$_{10}$ is estimated to be 11 per 1000 persons. In the Netherlands with a population of 16 million, this amounts to nearly 180,000 lost life years due to the long-term exposure to PM$_{10}$. (Netherlands Ministry of Housing Spatial Planning and the Environment, 2004; Buijsman et al., 2005).

### 3.3 Mechanisms by which particulate matter damages human health

Many negative health effects can be assigned to the exposure to particulate matter. Less is clear about the potential mechanisms. Several mechanistic pathways have been described including enhanced coagulation/thrombosis, a propensity of arrhythmias, acute arterial vasoconstriction, systemic inflammatory responses and the chronic promotion of atherosclerosis. Ultrafine particles by virtue of their extremely small size may enter pulmonary capillary blood and be rapidly transported to extrapulmonary tissues such as liver, bone marrow and heart, with either direct or indirect effects on organ function. (Lippmann et al., 2003; Bhatnagar, 2004; Brook et al., 2004). An overview is given of the potential mechanisms suggested by several studies.

#### 3.3.1 Mechanisms direct effects

Direct effects of particulate matter involve the cardiovascular system, blood and lung receptors. Inhalation of particles evokes both a pulmonary and a systemic inflammatory response in humans. Agents like particles can cross the pulmonary epithelium into the circulation. (Lippmann et al., 2003; Brook et al., 2004). The alveolar macrophage and bronchial epithelial cells are critically important in processing inhaled airborne particles. Alveolar macrophages exposed to atmospheric particulate matter phagocytose the particles and produce tumor necrosis factor (TNF)-α in a dose-dependent fashion. (Eeden van et al., 2002). Macrophages play a key role in arterogenesis by releasing proinflammatory cytokines and forming foam cells in subendothelial lesions; a hallmark of foam cells is cholesterol accumulation. (Vogel et al., 2005). The presence of soluble transition metals in PM$_{10}$ enhances the inflammatory responses via increased oxidative stress. Oxidative stress activates specific transcription factors including nuclear factor-κB and activator protein-1 which upregulate the expression of genes for cytokines, chemokines and other proinflammatory mediators. Intra-airway transcription of mRNA for interleukin (IL)-8 (attracts PMNs to sites of injury) is increased and production of IL-8 and growth-regulating-oncogene-α (GRO) is increased which promotes airway inflammation. The inflammatory response increases adhesion molecules in the liver that facilitate the passage of inflammatory cells from the circulation into the airways. In the blood, platelets and polymorphonuclear leukocytes (PMNs, an immune cell) increase which suggests that the bone marrow has been stimulated by the particles to release these cells. It is possible that the acute systemic inflammation and oxidative stress are responsible for triggering endothelial dysfunction leading to vasoconstriction. (Brook et al., 2004). The endothelium is a major target of oxidative stress and this interaction plays an important role in the pathophysiology of vascular disease; endothelial dysfunction predicts the likelihood of future cardiovascular events and death. (Mills et al., 2005). Recent observations show increased conduit artery vasoconstriction in flow-limited occlusive arteries or rupture unstable plaques, but the underlying cellular and molecular mechanisms remain unclear. (Bhatnagar, 2004). Mills et al (2005) suggests that superoxide radicals, produced as a consequence of oxidative stress, combines with NO to form peroxynitrite, thus reducing NO bioavailability in the vessel wall and shifting the balance toward vasoconstriction.

Diesel exhaust particles (DEPs), a major constituent of PM$_{10}$, can through oxidant effects (reactive oxygen species are created) on mitochondria, induce apoptosis or necrosis of macrophages and respiratory epithelial cells. Macrophage apoptosis will lead to decreased phagocytic defenses in the lung. (Dellinger et al., 2001; Lippmann et al., 2003; Brook et al., 2004). Inhalation of DEPs impairs two important and complementary aspects of vascular function: the regulation of vascular tone and endogenous fibrinolysis. This abnormality may have prothrombotic consequences that could possibly result in acute cardiovascular events. (Mills et al., 2005). Furthermore, endotoxin, which has been found to be accountable for cytokine production related to PM$_{10}$ exposure, induces proinflammatory cytokine production; increase lung inflammation, airway responsiveness and systemic immune cell populations; and decreases lung function. PM$_{10}$ will interact with lung receptors
and activate pulmonary neural reflexes. Sensory neurons in contact with irritant particles can be stimulated to release neuropeptides which can initiate airway inflammatory events, including the release of cytokines, vasodilation and mucus secretion. Neuropeptides act on a variety of cell types within the lung like epithelial and smooth muscle cells (that cause modulation of inflammation and increased airway responsiveness) but also immune cells which amplify the inflammatory response.

Particulate matter itself also contains radicals and those radicals can initiate damage to DNA through a catalytic cycle involving ROS. Radicals can reduce oxygen to form superoxide (\(O_2^-\)) that leads to the formation of hydrogen peroxide. This in turn yields the biologically damaging hydroxyl radical in a metal ion-dependent reaction. Metals are found in combustion generated particles. The hydroxyl radical causes DNA strand breaks but also damages lipids and proteins. (Dellinger et al., 2001).

Inflammation plays a significant role in the genesis of plaque instability. Air pollution mediated systemic inflammation therefore possibly instigates acute plaque instability and sudden cardiovascular events in the short term. Acute systemic inflammation and oxidative stress possibly trigger endothelial dysfunction leading to vasoconstriction. Alternatively, increased production of endothelins may play a role in the acute vasoconstriction. At present, the precise mechanisms underlying the rapid alterations in vascular tone remain to be resolved. However, a few published reports support the relevance of these findings by demonstrating an effect of air pollution on cardiovascular hemodynamics. Ambient air pollution increases blood pressure in cardiac rehabilitation patients and in adults with lung disease. Sudden arterial vasoconstriction (and/or possibly endothelial dysfunction) could conceivably instigate acute coronary syndromes by triggering plaque instability or by decreasing myocardial perfusion in patients with existing atherosclerosis. (Brook et al., 2004). Moreover, endothelins released from endothelial cells activate monocytes and are potent vascular smooth-muscle constrictors. Endothelin also influences the inflammatory response by modulating leukocyte–endothelial cell interactions, thereby promoting the recruitment of leukocytes into vessel walls. (Eeden van et al., 2002).

Furthermore, it is plausible that ultrafine particle exposure imposes an effect on repolarization, either through an indirect effect via the autonomic nervous system or by directly affecting ion channel function in ventricular myocardium through a yet unknown mechanism. (Lippmann et al., 2003).

Mortality associated with air pollution might be further explained, at least in part, by alterations in the autonomic input to the heart. Heart rate variability (HRV), resting heart rate, and blood pressure are modulated by a balance between the 2 determinants of autonomic tone (the sympathetic and parasympathetic nervous systems). Decreased HRV predicts an increased risk of cardiovascular morbidity and mortality in the elderly and those with significant heart disease. Since overall HRV decreases in response to ambient PM\(_{10}\) exposure, decreased parasympathetic input to the heart may provide an important mechanistic link between air pollution and cardiovascular mortality by promoting fatal arrhythmias. In general, the decrease of HRV occurs rapidly and is inversely proportional to the increase in the concentration of PM\(_{10}\). The underlying mechanisms responsible remain unclear but may involve activation of pulmonary neural reflex arcs, direct effects of pollutants on cardiac ion channels, or consequences of the heightened systemic inflammatory state. (Brook et al., 2004).

3.3.2 Mechanisms indirect effects

Less acute (several hours to days) and chronic indirect effects may occur via pulmonary oxidative stress/inflammation induced by inhaled pollutants. Subsequently this may contribute to a systemic inflammatory state, which may in turn be capable of activating hemostatic pathways, impairing vascular function, and accelerating atherosclerosis.

Exposure to PM\(_{10}\) increases fibrinogen which is a key component in blood coagulation and platelet thrombosis and a major determinant of blood viscosity. Blood viscosity has been associated with severity of cardiovascular disease and increases in association with increased levels of ambient total suspended particles. Fibrinogen is also well established as an important independent risk factor for myocardial infarction and stroke. (Brook et al., 2004). Elevations of fibrinogen are associated with inflammatory changes such as neutrophil activation. (Schwartz, 2001). Eighteen hours after exposure to concentrated ambient particles (CAPS), cells and fluid from bronchoalveolar lavage shows a mild (dose dependent) increase in neutrophils in both the bronchial and alveolar fractions (lower respiratory
tract), blood fibrinogen levels were also higher. (Ghio, Kim, & Devlin, 2000). Epidemiological data suggest potential effects of particulate air pollution on blood coagulation. Enhanced platelet aggregation may further promote acute thrombosis formation after exposure to diesel exhaust and ultrafine particles (UFPs). (Brook et al., 2004).

Exposure of human lung macrophages to urban PM$_{10}$ leads to increased levels of serum IL-6, IL-1$\beta$ and granulocyte macrophage colony-stimulating factor. Increased levels of IL-6 are associated with an increased risk of cardiovascular events and mortality. (Brook et al., 2004). IL-1$\beta$ is one of the acute response cytokines that induces cytokine production by many cells, stimulates hematopoiesis, activates endothelial cells and induces the acute-phase response. (Eeden van et al., 2002). IL-6 is directly involved in regulation of the synthesis of C-reactive protein (CRP) in the liver. CRP is a sensitive indicator of infection, injury, and inflammation and is linked to increased risk of cardiovascular disease. CRP concentration is positively associated with exposure to total suspended particles and PM$_{10}$. The mechanisms by which CRP increases the risk of cardiovascular events is the subject of intense research. One possibility is that CRP impairs endothelial vasoreactivity in individuals with preexisting coronary artery disease. In addition, CRP may contribute directly to the development and progression of atherosclerosis via a number of mechanisms that involve enhanced formation of foam cells, recruitment of monocytes into the arterial wall, stimulation of prothrombotic tissue factors, decreased NO synthase activity, and expression of adhesion molecules.

Inflammation plays a significant role in the genesis of atherosclerosis. It is therefore possible, that air pollution- mediated systemic inflammation promotes atherosclerosis formation over the long term. Chronic, repeated inflammatory challenge of the airways may result in airway remodelling that leads to irreversible lung disease. (Brook et al., 2004).

3.4 Transport mode and PM$_{10}$ exposure in cities

Pollutants vary in their temporal distribution, with concentrations of particles being highest during mid-day while other are highest with morning rush hour. Overall, pollutant levels tend to be lowest in low traffic areas and before 7 a.m. and after 8 p.m. (Basrur, 2003). It thus depends on the time of the day what exposure one might experience. More factors determine the exposure and inhalation of particulate matter. One of those factors is the mode of transport. Studies that examined the exposure of cyclists, car drivers and pedestrians to traffic-related air pollutants found that the exposure of car drivers to pollutants is roughly twice that of bikers. Walking and cycling commuters had significantly lower exposure to pollutants compared to bus and car commuters since bikers and walkers often use the borders of the road further away from the car exhausts and are less held up by traffic jams. There is an extremely rapid decline in concentration of ultrafine particle counts with increasing distance away form the pollutant source, such as from major road to the backstreets but also from street to sidewalk. (Wijnen et al., 1995; Rank et al., 2001; Chertok et al., 2004; Kaur et al., 2006).

The exposure of walkers to particulate matter fluctuates mainly in response to the proximity to traffic, which is the main pollution source. Exposure peaks are therefore identified particularly at traffic crossings as individuals waited adjacent to the traffic to cross the roads or when trapped on ‘traffic islands’ in the middle of the road. A large difference in exposure is also experienced when comparing the side of the sidewalk people walk on and their behaviour; walking close to the buildingside edge of the pavement and avoiding smokers versus people walking close to the kerb reduces PM$_{10}$ exposure by 10-30%. (Kaur et al., 2006).

Cyclers are constantly travelling within the vehicle emission area and therefore always at a closer proximity to the pollution source than the pedestrians- hence their total exposure levels appeared to be generally greater. UFP exposure varied largely depending on the traffic density, types of vehicles nearby/around at the time, the ability of the cyclist to ‘dodge’ in and out between vehicles and the proximity to the vehicle exhaust pipes. The positioning of the cyclist on the road also influenced exposure and this was often dictated by safety, preparation from turning/exiting and avoiding congestion. The cyclists’ use of the bus lane located adjacent to the pavement further influenced exposure compared with cycling along the traffic lanes used by other vehicles. (Kaur et al., 2006).

Car passengers and drivers are exposed to more particulate matter compared to walkers and bikers as they are in the middle of the road and the exhaust emissions of preceding cars enter the interior of cars. Also the emissions of the driver’s own car contribute to a higher exposure.
Furthermore, a car (and a bus and taxi as well) are more indoor environments although this also indicates that exposure peaks are not as variable. There seems to be a ‘smoothing effect’ due to the protection offered by the car shell. This protection is also seen in buses and taxis, although in buses this is much larger due to less ventilation possibilities. (Wijnen et al., 1995; Kaur et al., 2006).

Taxi drivers and passengers generally have the same particulate matter exposures although in taxis there is a significant influence from the previous use of the taxi; smokers in the taxi previously or the taxi used to transport material significantly increases exposure. The cleanliness of the taxi also influences individual exposure. (Kaur et al., 2006).

Travelling by bus results in the largest average particulate matter exposure. The bus is a closed system where inside air hardly gets replaced by outside air. Exposure therefore largely depends on the situation inside the bus. Ultrafine particle exposure (UFP) on buses on busy roads versus backstreet roads was not that different and very few fluctuations in exposure were noticed although delayed fluctuations in exposure related to external traffic does happen. Individuals waiting at the bus stop often experienced elevated exposures as traffic passed by. The UFP exposure is influenced by the position within the bus; exposure is higher when seated or standing by the doors where pollution enters. Furthermore, exposure is higher when the bus contains more passengers. (Kaur et al., 2006). Finally, travel time should be taken into account. Typically, travelling by bus, tram or subway takes longer than doing the same trip by car; this automatically results in a longer exposure time.

3.5 Exercising and PM\textsubscript{10} inhalation

Although walkers and bikers seem to have the least exposure to particulate matter, the question remains if they have the least intake since movement in the form of physical activity means an increase in ventilation rate and diffusion capacity thus indicating that more air and pollutants are inhaled. The greater the activity level, the higher the respiratory rate and resultant intake of air. (Basrur, 2003; Sharman et al., 2004). Furthermore the inhalation also depends on the length of the exposure which on the travel time and this is probably not equal. Few research is done regarding air pollution inhalation during exercise. A summary follows below.

The amount of air pollutants that people take into their lungs depends on many factors, including their activity level and resultant respiratory rate, their mode of breathing (mouth versus nose), and the concentration of pollutants at that particular time and microenvironment as well as the length of exposure. Particles with an aerodynamic diameter smaller than about 0.3 µm are deposited in the whole respiratory system decreasingly with rising physical exertion, while the opposite is observed for particles with an aerodynamic diameter larger than about 0.7 µm (except for the highest physical activity). Resting, sitting activity, light exercise and heavy exercise are characterised by ventilation rates of 7.5, 9, 25 and 50 L per minutes respectively. (Salma, Balashazy, Hofmann, & Zaray, 2002). There is also an exponential decline in concentrations of many air pollutants with increasing distance from the busy road.

A cyclist inhales on average 29 L per min compared to 12 L for car drivers; cyclists therefore inhale on average 2.3 times more air compared to a car driver. Even at low intensities, a significant rise in pulmonary ventilation and diffusion capacity occurs. Therefore, the uptake of pollutants by bikers sometimes approaches that of the car drivers. (Wijnen et al., 1995; Sharman et al., 2004). Vigorous exercise, as done by athletes, results in exceptionally high ventilation rates that result in very high doses to the lung tissue, far in excess of those encountered by the general public. Children also have higher ventilation rates than adults. Typically, a young child will inhale approximately 5 times more air per kilogram of body weight per day than an adult does. In a given micro-environment, children therefore receive a higher dose of air contaminants compared to adults because of generally higher activity levels and respiratory rates. (Villarreal-Calderon et al., 2002; Basrur, 2003; Florida-James, Donaldson, & Stone, 2004). Heavier exercise i.e. higher ventilation rates also results in a different inhalation pattern; besides nasal breathing oral breathing will occur. During exercise at higher intensities, a greater portion of air is taken in via the mouth, up to 60% of the inhaled air. Deposition of particles strongly depends on the actual combination of nose and mouth-breathing; the fractional penetration of pollutants to the lung is greater when breathing by mouth compared to the nose as it is not filtered as well. (Salma et al., 2002; Basrur, 2003; Sharman et al., 2004). However, it is noteworthy that exercise increases respiratory efficiency so that a fit person actually inhales less air than does an unfit person undergoing the same level of physical activity. As a result, pollutant
exposure will be lower in the fit person compared with the less fit individual. (Basrur, 2003). A person using the car for transport instead of the bike or walking, may however be shorter on its way and therefore inhale less air. If those people inhale less particulate matter remains unclear as this depends on the concentration, duration of exposure and the ventilation rate.

**Key findings:**
- Motor vehicles are the major source of particulate matter in urban areas, which has various health effects.
- Exposure to PM$_{10}$ leads to inflammation and oxidative stress as well as the formation of free radicals.
- PM$_{10}$ exposure can attribute to CVD.
- Respiratory, cardiovascular and cardiopulmonary mortality and morbidity due to exposure to PM$_{10}$ (short-term, long-term, direct and indirect) in the Netherlands lead to 180 000 life years lost; no apparent threshold level exists regarding health effects.
- Traveling by different modes of transport gives different PM$_{10}$ exposures; PM$_{10}$ levels were largest in buses and cars and lowest in pedestrians and walkers.
- Inhalation of PM$_{10}$ depends on concentration, duration of exposure and ventilation rate. Therefore, it remains unclear by which mode of transport PM$_{10}$ inhalation is largest.
4. HYPOTHESIS

Although it is established that air pollution, in particular PM$_{10}$, effects human health, less is known about specific individuals or subsets of patients at increased risk. Recent studies suggest that the elderly and those with a low socioeconomic status are particularly susceptible populations as well as patients with underlying respiratory, coronary or pulmonary disease and diabetics. (Brook et al., 2004; Kappos et al., 2004; Ostro et al., 2006; Zeka et al., 2006).

Since obesity, diabetes and metabolic syndrome are all caused by inflammation and inflammation plays a key role in the way PM$_{10}$ effects human health, people with one of those diseases may be at increased risk from exposure to PM$_{10}$. Furthermore, exposure to PM$_{10}$ can lead to cardiovascular diseases but so do obesity, diabetes and metabolic syndrome. This has also been suggested in several studies: “While the biological mechanisms behind these associations remain uncertain, several investigators have hypothesized that oxidative stress in the lungs from inhaled particulate matter (PM$_{10}$) leads to a systemic inflammatory cascade that can increase cardiovascular risk among susceptible individuals.” (Dubowsky et al., 2006). The paragraphs below describe how the diabetics, obese and people with metabolic syndrome are possibly more susceptible to particulate matter and therefore have an increased risk for cardiovascular diseases leading to the hypothesis that exposure to PM$_{10}$ and development of type 2 diabetes mellitus, metabolic syndrome and obesity develops via the same mechanisms and may work additionally if not synergetically.

4.1 Diabetes mellitus type 2

Type 2 diabetes mellitus and atherosclerotic cardiovascular disease share many antecedent factors that frequently coexist, which has given rise to the concept of common “soil”. This cluster of risk factors, such as uric acid, and dyslipidemia, are strongly related to fasting insulin concentrations and central obesity, and are also associated with raised concentrations of inflammatory markers in people with and without diabetes. (Schmidt et al., 1999).

Several time-series report that diabetics are at increased risk from exposure to PM$_{10}$; their susceptibility may derive from prior vascular damage to the heart. Fibrinogen plasma levels are also elevated in diabetics. (Ghio et al., 2000; Bateson et al., 2004; Kappos et al., 2004). Recent work on potential mechanisms of action of particulate air pollution point to pathways also influenced by diabetes. In recent studies, exposure to airborne particles is associated with reduced heart rate variability, increased CRP concentration and higher peripheral white cell counts and fibrinogen levels. Diabetes is a chronic disease characterized by disturbances in all of these cardiovascular risk factors and diabetics therefore may be at increased risk of PM$_{10}$ associated cardiovascular events. These similarities indicate that particles and diabetes may affect some of the same pathways, and suggest the possibility of a synergistic effect. (Zanobetti et al., 2001).

A prospective cohort study shows that among people who have had one or more myocardial infarctions, the impact of diabetes on survival is similar to that of a prior myocardial infarction, indicating that the history of both conditions further worsened survival. This suggests a similar mechanism mediating the adverse effects of myocardial infarction and diabetes on mortality – possibly related to remodeling of the left ventricle. Particulate-induced sympathovagal imbalance could be a precipitating event that would correspond with increased mortality among people with diabetes. Endothelial function is one aspect of cardiovascular health that is impaired among patients with diabetes. Patients with diabetes are generally at increased risk of death, and this appears to be related in part to higher levels of CRP, decreased heart rate variability, increased plasma fibrinogen levels, and other markers of increased systemic inflammation. Particulate air pollution has also been associated with all of these factors. If patients with diabetes have already overwhelmed their compensatory mechanisms for dealing with these risks, interaction is plausible. (Bateson et al., 2004). Diabetes as a secondary condition has been hypothesized to increase the susceptibility of the capillary system to influences from exposures to particulate matter. A twofold increase in the effects for respiratory and stroke deaths was found in the presence of diabetes when exposed to particulate matter. (Zeka et al., 2006).

Particulate-induced sympathovagal imbalance could be a precipitating event that would correspond with increased mortality among people with diabetes. Endothelial function is one aspect of
cardiovascular health that is impaired among patients with diabetes. Patients with diabetes are generally at increased risk of death, and this appears to be related in part to higher levels of CRP, decreased heart rate variability, increased plasma fibrinogen levels, and other markers of increased systemic inflammation. Particulate air pollution has also been associated with all of these factors. If patients with diabetes have already overwhelmed their compensatory mechanisms for dealing with these risks, interaction is plausible. (Lippmann et al., 2003).

Enhanced susceptibility for air pollution related cardiovascular events has been shown for older individuals and persons with conditions associated with chronic inflammation such as diabetes. Based on these findings, it is conceivable that the short-term effects of PM$_{10}$ on inflammation also may be enhanced among individuals with existing inflammation. CRP levels elevate when the level of PM$_{10}$ exposure is higher. CRP levels increase even more when people have diabetes and get exposed to PM$_{10}$. (Dubowsky et al., 2006).

Recent cross-sectional data suggest that IL-6 and CRP, two sensitive physiological markers of subclinical systemic inflammation are associated with overt type 2 diabetes. Both of these inflammatory biomarkers are known to predict the development of cardiovascular disease in otherwise healthy populations. (Pradhan et al., 2001).

Epidemiological studies suggest that people with diabetes are vulnerable to cardiovascular health effects associated with exposure to particulate air pollution. (O'Neill et al., 2005). Single subgroup analysis show that people with diabetes are at greater risk of adverse events associated with air pollution in general and particulate matter in particular. Each 10 µg in the concentration of PM$_{10}$ leads to a 1.14% increase in the risk of dying in a study population; this risk is 1.49% among people with diabetes. (Bateson et al., 2004). Endothelial and vascular function in patients with diabetes is impaired and may be related to increased cardiovascular risk. People with diabetes type 2 may be more vulnerable to the acute effects of particles for many reasons, including chronic inflammation/oxidative stress, imbalances in vasoactive mediators in the arterial tissue, or vascular remodelling that can result in impaired flow-mediated dilation. Particle pollution exposure is associated with reductions in both flow-mediated and nitroglycerin-mediated dilation among the individuals with diabetes; the mechanism for its effects could lie in endothelial dysfunction, smooth muscle dysfunction, or both. Flow-mediated response depends on both the endothelium and smooth muscle. The acute response to an environmental exposure can be reduced because of endothelial factors, including less endothelial production of nitric oxide (NO) or more quenching of NO by an excess of oxidative radicals (superoxide anions) resulting from particle-associated inflammation and subsequent oxidative stress. Both the flow-mediated and nitroglycerin-mediated responses may be attenuated if the smooth muscle response to NO is reduced. People with T2DM may be more vulnerable to the acute effects of particles for many reasons, including chronic inflammation/oxidative stress quenching NO, imbalances in vasoactive mediators in arterial tissue or vascular remodelling that can result in impaired flow-mediated dilation. Reduced flow-mediated dilation has been associated with increased CRP concentrations. (O'Neill et al., 2005).

4.2 Obesity
First of all, obesity is associated with diabetes. Besides, geometric mean concentrations of C-reactive protein are lowest among individuals with a body mass index (BMI) of 18.5 kg/m$^2$ and increases with increasing BMI$_{10}$ categories. As shown earlier in this chapter, CRP is linked to increased cardiovascular risk and elevated when exposed to PM$_{10}$. Restricting the analysis to participants without various medical conditions did not change the relation. Elevated CRP concentrations are noticed among individuals who are obese or have diabetes. (Ford, 1999). CRP levels are even higher when both diseases are present. (Dubowsky et al., 2006).

4.3 Metabolic Syndrome
The prevalence of obesity increases the incidence of metabolic syndrome (MetSyn). The prevalence of MetSyn increases the risk for diabetes (doubles). (Olijhoek et al., 2005). MetSyn is a clustering of atherosclerotic cardiovascular disease risk factors characterized by visceral adiposity, insulin resistance, low HDL cholesterol and a systemic proinflammatory state. Furthermore, chronic inflammation, procoagulation and impaired fibrinolysis are components of MetSyn. Adipose tissue is an active secretory organ that elaborates a variety of molecules known as adipocytokines, including
TNF-α, IL-6, leptin, adiponectin and resistin. (Reilly et al., 2003). Levels of TNF-α and IL-6 also increase by exposure to PM$_{10}$.

Recent evidence suggests that innate immunity and inflammation play a role in the development of diabetes type 2. Thus, the pathophysiology of insulin resistance, the MetSyn cluster, and atherosclerotic cardiovascular events may have a common proximal inflammatory basis. (Reilly et al., 2003).
5. MOBILITY IN DUTCH CITIES

The previous chapters show the increasing incidence of diabetes mellitus type 2 and obesity due to a lack of physical activity. Travel is a major potential source of physical activity. Approximately 83% of all ‘trips’ are short, for non-work purpose and occur relatively close to home. The majority of non-work trips are within walking and cycling distance and are therefore of interest to physical activity, air quality and transportation planning fields. (Saelens et al., 2003).

Researchers in transportation, urban design and planning have long understood that neighbourhood design and the way land is developed and used may affect transport choice (auto, transit, walking/cycling). (Handy et al., 2002; Saelens et al., 2003). Therefore, recent research has begun to focus on the link between public health and the built environment in an effort to combat increasing rates of overweight and obesity found in many Westernized nations. An increasing body of evidence shows that the physical design of the places where people live and work affects their overall travel choices and how much they walk or bike for utilitarian travel. Time spent in the car as a passenger or driver and sedentary lifestyles are positively associated with obesity. To increase levels of physical activity to a point where the great majority of the population meets public health standards requires a rethinking of urban form. Certain transport and land-use policies protect the environment and promote public health, like biking and walking. (WHO Regional Office for Europe, 2000; Frank et al., 2004). The reduction of automobile traffic and substitution of alternative modes of transport are essential policies for health promotion. (Granados, 1998). It will improve air quality and road safety, reduce body weight and reduce cardiovascular disease and pulmonary diseases. (Frank et al., 2001; Ogilvie et al., 2004).

However, although vehicle ownership is approaching market saturation, time behind the wheel is still on the rise, as is miles of travel per capita, albeit to a lesser extent. (Frank et al., 2001; Statistics Netherlands, 2004a). The amount of other transport modes used available in cities is unclear. The motor vehicle density in the Netherlands is, with an average of 151 cars per km$^2$, the highest in the world. (Wijnen et al., 1995). This indicates the potential problems regarding air pollution.

This chapter will therefore give an overview of the modes of transport chosen by the Dutch, the reasons for their choices and the emissions/environmental damage per transport mode. Since motor vehicle density is so high and the impact regarding health and environmental damage so large, a separate paragraph is devoted to car ownership. Furthermore the influence of the built environment on transport choices is explained and how certain urban design can benefit health by promoting walking and cycling.

5.1 Transport modes in cities

Different transport modes are available in Dutch cities. Cars (either as passenger or driver), trains, buses, trams, subways, mopeds, bikes and walking are used as means of transport. The most common transport mode has been and still is the car. Its ownership has been increasing. The car is used in three quarters of the travelled distances and this has not changed over the last ten years. The largest daily distances are made next by bike and by train, having a share of 15% each.

From 1980 to 2004 passenger car ownership has increased with more than 50%. Currently, 7 million passenger cars exist and then there are still 1.1 million business cars present. (Netherlands Environmental Assessment Agency, 2005b). This implies that currently 429 passenger cars are present per 1000 inhabitants. In 1990 this was 367 compared to 320 in 1980 and 195 in 1970. (Directorate-General for Energy and Transport & Eurostat, 2005). Over the years, from 1994 to 2003, the percentage of households with one car in cities remains generally stable with 55%. However, more families now own two cars (from 8.6% in 1994 to 13.2% in 2003) or more than two cars (from 0.5% in 1994 to 1.1% in 2003). Therefore, the percentage of households in cities not owning a car decreased slightly, from 36.6% in 1994 to 32.2% in 2003. The number of families owning a bike decreased (from 26.4% to 20.9%) though this seems to be a national trend. The percentage of households owning a bike in cities is still larger than in rural areas. In rural areas, the percentage of households possessing two or more cars is larger than in urban areas although the percentage with one car is the same. (Statistics Netherlands, 2006b).
When urbanisation increases, bicycle ownership decreases. This is probably due to better quality of public transport, limited storing possibilities in older city parts and the larger risk for theft. Besides, the amount of kilometres travelled by car over the years has also increased, therefore the bike seems to be substituted by the car and seems less necessary to have. Furthermore the share of allochtones in cities is larger than on average and some categories of allochtones hardly use bicycles due to the low status it has in their cultures. Although the bicycle ownership in cities is less, the amount of biking is the same which means per capita bicycle use in cities is more than on average. (Wee van & Nijland, 2006).

In cities, people travel daily on average 35 km, this has not changed over the years. A third of the distance, around 11 km, is used to get to work. (Statistics Netherlands, 2006c). Different modes of transport are used for different activities. Figures 5.1 and 5.2 show the daily modes of transport chosen for different activities (in kilometres per day) within cities and the kilometres made daily for different activities and the modes of transport used. The car is the most used mode of transport with 25 kilometres a day in 2003, followed by bike (3.7 km) and train (3.6 km). The car is mainly used for going to work, recreative purposes and visiting while the bike is mostly used for shopping/groceries, going to work and recreative purposes compared to the train that is used for going to work and visiting. (Statistics Netherlands, 2006a).

Figure 5.1 Daily travel distance (km) in cities per person by mode of transport for certain activities in the Netherlands in 2003 (Statistics Netherlands, 2006a)

The mean distance travelled daily has not changed over the least 10 years. However, the distances per mode have changed. Car and train travel have increased from 1994 to 2003, with 6 and 15% respectively. Bus/tram/subway travel decreased with 7%, moped with 6% and walking even with 15%. The kilometres daily travelled by bike have remained the same. The largest distance, about 8 km, is daily covered to go to work and for visiting. Not surprisingly, this is done mostly by car. Furthermore, the train and bus/tram/subway are used for those purposes. The car is the predominant mode of transport for all activities, except for educational purposes and courses, then train, bus/tram/subway and bike are equally used as well. (Statistics Netherlands, 2006a).
5.1.1 The built environment and transport choice

The built environment comprises urban design, land use and the transportation system. Urban design is the design of the city and the physical elements within it, including both their arrangement and their appearance and is concerned with the function and appeal of public places. Land use refers to the distribution activities across space, including the location and density of different activities, where activities are grouped into relatively coarse categories such as residential, commercial, office, industrial, and other activities. Land use patterns therefore impacts the proximity between trip origins and destinations. Transportation system includes the physical infrastructure of roads, sidewalks, bike paths, railroad tracks, bridges, and so on, as well as the level of service provided as determined by traffic levels, bus frequencies, and the like. (Frank et al., 2001; Handy et al., 2002).

Transport choice is influenced by proximity (distance) and connectivity (directness of travel) and this thus depends on the built environment. (Berrigan et al., 2002; Saelens et al., 2003). Both the proximity and connectivity influence the travel time. Travel time is the most significant predictor of mode choice which depends on both proximity and connectivity. These models thus explain the relatively low amount of kilometres that are made by walking as seen in the previous paragraph since walking is the slowest mode of transport and thus generally has the longest travel time. Furthermore, out-of-vehicle travel time—walking and waiting for a bus—is considered more costly than in-vehicle travel time. (Handy et al., 2002).

The larger the distance, the more likely the car will be the mode of transport. Distances travelled up to 10 km are taken 1 out of 5 (20%) times by bike with the exception of distances shorter than 500 m, those are done by foot. The car share is already large at short travel distances; at 2.5-3.7 km the car is dominant with a share of 50%. (Wee van et al., 2006). The car is probably chosen because it is most of the time the fastest and there is no waiting for buses or trains. Furthermore, travelling by car is convenient for transporting children and groceries and with bad weather. Moreover it's considered to be a safe mode of transport. Data regarding motives, modes and distances of travel of the Dutch (Statistics Netherlands, 2006d) support this reasoning. The bike is used up to 5 km of travel. Trips daily done by bus/tram/subway cover an average distance of 12 km which takes 40 minutes. However, the car as a mode of transport covers daily on average 20 km which takes 20 minutes; a larger distance covered in a smaller amount of time compared to travelling by bus/tram/subway. But then the car does not have to stop at all bus stops and probably tries to avoid congestion. When the train is the mode of transport, the daily distant covered is 45 km, taking 65 minutes, comparable to the

Figure 5.2 Daily travel distance (km) in cities per person by activity and the modes of transport used for those activities in the Netherlands in 2003 (Statistics Netherlands, 2006a).
car. However, the train normally does not take you from door to door which means additional transport is required, which will lengthen the travel distance and time.

Within urban centres and communities, the layout of the street network and the distribution of space for different modes of travel within a given right of way impact the directness and quality of travel. It is at this scale that the ability to walk and bike between places of residence, commerce, employment. Research shows that areas that are highly walkable and cyclable have a good mixture of land use, high (street) connectivity, are dense and have an adequate walk/bike design. Urban sprawl, characterised by poor accessibility, thus decreases walking possibilities and frequency. (Handy et al., 2002; Ewing et al., 2003; Saelens et al., 2003). Bringing origins and destinations closer together is therefore related to increased walking. (Frank et al., 2005; Rodriguez et al., 2006). The greater connectivity in cities compared to suburban areas, leads to pedestrian volumes that are about three times higher. (Frank et al., 2001). Therefore, the presence of side walks encourages walking. The pedestrian and cyclist are more sensitive to urban design features of the built environment than the motorist. If the built environment is not structured to encourage pedestrian and bicycle travel, people will opt for the automobile. An increase in the use of non-auto transportation is seen when people move from more to less auto-dependent neighbourhoods. (Frank et al., 2001; Berrigan et al., 2002).

Another body of literature has attempted to assess the before-and-after impact of transportation investments on mode choice. Case studies of the effects of traffic calming techniques on pedestrian and bicycle travel in northern Europe, have repeatedly shown that traffic calming increases bicycling and walking levels, decreases automobile/pedestrian accidents, and slows vehicular traffic (Frank et al., 2001).

5.1.2 Built environment and safety
Fear of accidents and street violence and the barrier effect created by congested roads deter people from cycling and walking. (WHO Regional Office for Europe, 2000). Research shows that parents are withholding permission for their children to travel by themselves because of increased fears of traffic dangers, resulting in fewer trips by children on foot or by bicycle and more trips as passengers in cars. As a result, more and more children are relying on the car for mobility rather than walking and biking, translating into travel habits carried into adulthood. (Frank et al., 2001).

Road design is very important and effective for increasing bikers’ and pedestrians’ safety. Features that are effective are appropriately placed roundabouts, traffic calming in residential areas and cycling paths and side walks help in reducing accident rates. (WHO Regional Office for Europe, 2000). However, even in countries were biking is a lot more dangerous compared to the Netherlands, health benefits of biking are larger then the loss of life due to incidents. If biking frequency increases, so does safety since safety is both a cause and a consequence of less motorised mobility. (WHO Regional Office for Europe, 2000; Wee van et al., 2006). Nevertheless, when trying to stimulate biking and walking, safety and neighbourhood safety should also be considered in policy, otherwise the plan will be ineffective on forehand. (Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006; Wee van et al., 2006).

5.2 Transport choice and health
Transport choice influences environmental and human health. Motorized traffic emits pollutants although the number and kind of pollutants are different per mode of transport and therefore motorized traffic contributes to air pollution. This air pollution has an impact on human health, but human health is also affected by physical (in)activity because of the mode of transport chosen. Furthermore the amount of fatal accidents is described by mode of transport.

5.2.1 Environmental health
Most emissions from traffic can be found in cities. Of all particulate matter deposited, 40% is deposited in the cities, 25% in rural areas and 35% on highways. The reason most pollutants are emitted within city boundaries is because of the way of driving (a lot of braking and accelerating) and because the motor is still cold. Particulate matter emissions from traffic have decreased over the year because of measures taken; the motortchnical optimisation has increased. Therefore the particulate matter emissions from traffic have since 1990 yearly decreased despite the fact that the kilometres driven by passenger cars has increased with 35% between 1990 and 2004. Passenger cars are
responsible for three quarters of all PM$_{10}$ emitted by traffic. (Netherlands Environmental Assessment Agency, 2005c).

Different modes of transport emit different kind and amount of emissions. Focusing on particulate matter emitted by vehicles built in 2004, looking at the emissions within cities, a bus emits the largest amount of PM$_{10}$ per driven km, namely 0.309 gram. However, it should be taken into account that many people can travel on one bus. The delivery van driving on diesel emits next the largest amount of PM$_{10}$, 0.091 gram/km. A car driving on gasoline emits more PM$_{10}$ than a car driving on LPG and the same as a delivery van on gasoline, 0.011 versus 0.008 km/gram respectively. Driving on LPG is cleanest and on diesel dirtiest with emissions of PM$_{10}$ of 0.008 and 0.062 gram per kilometre driven respectively. (Statistics Netherlands, 2006d). Three quarters of the passenger cars in the Netherlands drive on gasoline, 20% on diesel and the remaining 5% on LPG. (Netherlands Environmental Assessment Agency, 2005b). Emissions for trains, trams and subways were not available, except for the fact that 3 gram PM$_{10}$ is emitted per kg fuel used in trains. According to the same data file, passenger cars emit 0.7 gram per kg fuel used. When the same use is assumed, only 5 people have to be on the train to emit less PM$_{10}$ then in cars, if the train at least consumes relatively per person the same amount of fuel. For buses this can be said as well. (Statistics Netherlands, 2006e). Therefore, PM$_{10}$ emissions from buses and trains are fewest.

In contrast to private automobiles, public transportation, bicycles and walking produce relatively little environmental contamination or injury-related morbidity and mortality. Besides, four times more energy per capita is consumed in “car” cities compared to “public transport” cities and almost 15 times as much as in “pedestrian” cities. (Granados, 1998).

The connectivity associated with the built environment influences the distances to travel and thus the mode of transport and the environment. Bringing origins and destinations closer together is related to increased walking and biking and reduces air pollution. (Frank et al., 2005; Rodriguez et al., 2006). Both biking and walking is energy efficient and space efficient. Furthermore, increased biking and walking is associated with reduced use of motorized transport which reduces noise and air pollution. (WHO Regional Office for Europe, 2000; Rodriguez et al., 2006; Wee van et al., 2006).

Mixed use and more compact community design show significant promise for the reduction of regional air pollution levels. Opportunities exist to improve regional air quality through more compact development. However, increased compactness or density often exacerbates traffic congestion and can increase exposure of harmful emissions within central areas. Therefore, strategies to reduce localized air pollution in existing and developing centres are required to enable larger environmental health benefits from smart growth to be realized. (Frank et al., 2005).

5.2.2 Human health

City planning and public health share common roots. Historically, many major planning initiatives grew out of health-related concerns. The current lack of emphasis on the interdependencies between built form and overall quality of life, as measured by health, safety, and welfare considerations, suggests the need for a rethinking of public policy approaches to transportation investment and land development. (Frank et al., 2001). Understanding associations between urban form and transportation choices influencing physical activity levels is important for public health because of the possibility that planning decisions could influence physical activity and therefore health. The presence of side walks and cycling paths can encourage physical activity. (Berrigan et al., 2002). Cycling and walking are forms of physical exercise accessible to the vast majority of the population, regardless of income, age and location. It is estimated that over 96% of citizens can walk and over 75% can ride a bicycle and therefore it should be promoted. (WHO Regional Office for Europe, 2000).

Increased auto dependence and limited opportunities to walk for utilitarian purposes has contributed to the emerging obesity epidemic. (Frank et al., 2005). Exclusive reliance on the automobile thus sharply reduces physical exercise and leads to obesity and poor physical conditioning. (Granados, 1998). Those who are overweight are also more likely to live in a street with no sidewalks and to perceive there was no walking or cycle paths within walking distance. (Giles-Corti, Macintyre, Clarkson, Pikora, & Donovan, 2003). Walkable environments influence exercise and weight in a positive way. (Doyle et al., 2006). Walkable environments are characterised by high density, mixed land use and a large street connectivity. Those characteristics of the built environment thus increase physical activity and can be as high as 50% compared to physical activity levels maintained before.
It was found that the country sprawl index has small but significant associations with minutes walked, obesity and hypertension. Those living in sprawling counties were likely to walk less, weigh more and have greater prevalence of hypertension than those living in compact countries. (Ewing et al., 2003)

Furthermore, in contrast to private automobiles, public transportation, bicycles and walking produce little injury-related morbidity and mortality. Walking and bicycling are minimally dangerous in themselves, but carry a very high risk of injury when they are done on streets or high-ways shared with automobiles. These modes of transport involve more physical activity, with its positive health effects. (Granados, 1998; Frank et al., 2001; Frank et al., 2004). The reduction of automobile traffic and substitution of alternative modes of transport are essential policies for health promotion. (Granados, 1998). Walking and cycling to work have been shown to meet metabolic criteria for achieving health benefits for exercise. Besides, daily physical activity is more beneficial than peak activity. Furthermore, activities with a medium exercise level can be done longer and result in a relative higher fat oxidation. The health benefits of regular sustained physical activity include a 50% reduction in the risk of developing coronary heart disease, a 50% reduction in the risk of developing adult diabetes and a 50% reduction in the risk of becoming obese. (WHO Regional Office for Europe, 2000; Wee van et al., 2006)

Therefore, from a physical activity perspective, environments that contribute to the development of obesity include those with poor access to recreational facilities and infrastructure that discourages incidental activity, walking and cycling. (WHO Regional Office for Europe, 2000; Giles-Corti et al., 2003). An awareness of pedestrians and bikers in urban planning and design can lead to healthier societies at two levels. Firstly at the individual level, better-designed walking and biking networks encourages physical exercise- the medical benefits of this have been repeatedly highlighted. Secondly, with a central focus and promotion on walking, dependency on motor vehicles is likely to become discouraged, thereby assisting in the reduction of traffic pollutant concentrations in the urban environment, automatically reducing pedestrian exposure and consequently contributing to the development of sustainable cities. (Kaur, Nieuwenhuijsen, & Colvile, 2005).

Although high street connectivity, mixed land use, high density and the presence of side walks and biking paths encourages physical activity, safety should not be underestimated in the process of deciding for or against walking or cycling. One out of every three people that die in a traffic accident is a pedestrian or a biker! Walking and bicycling are minimally dangerous in themselves, but carry a very high risk of injury when they are done on streets or high-ways shared with automobiles. (Granados, 1998). However, still most people get killed when driving a car but here it must be considered that the distance travelled and the frequency is also higher.

Although the number of people involved in traffic accidents declines yearly, still a large number of people die or get injured in traffic. In 2004, 9486 people got injured and 881 people died in traffic. (Statistics Netherlands, 2005a). Figure 4.3 shows the traffic deaths by mode of transport in 2005. Most of the victims are passengers or drivers of cars; they account for nearly 50% of the victims. A good second are bikers with 181 fatal accidents a year (22%). Furthermore, pedestrians were involved in 11% of the fatal traffic accidents accounting for 89 deaths. Also motorcycles and mopeds are often involved in fatal accidents (both 10%, 78 victims). Interestingly, people killed while on a bus, train, subway or tram are not mentioned separately so it is assumed that that those are under the heading ‘other participants’. (Statistics Netherlands, 2005b).

Most accidents happens in built areas as traffic is most dense there. On average, around 65% of road accidents happen in built-up areas, 30% outside built-up areas and around 4–5% on motorways. (WHO Regional Office for Europe, 2000). However, most traffic victims are likely to be found outside of built-up areas since the traffic speed is much higher there.
Figure 5.3 Traffic victims died in 2005 by mode of transport, in absolute numbers (in figure) and in percentage (around figure) (Statistics Netherlands, 2005b).

**Key findings:**
- in the Netherlands, daily 35 km is traveled, most of which is done by car (25 km), followed by bike (3.7 km) and train (3.6 km)
- built environment, in the form of connectivity and proximity, determines the transport mode chosen and therefore environmental and human health
- walking and biking are promoted by high connectivity, mixed land use, low proximity and the right infrastructure i.e. presence of sidewalks and biking paths as well as a general feeling of safety
- walking and biking in cities should be promoted, as it decreases air pollution (when it is a substitution for car travel) and increases physical activity

**Additional findings:**
- travel is a major potential source of physical activity in modern life, but is currently not completely utilized
- visiting, work and recreative purposes are the most important motives for mobility
- car ownership is increasing, though ownership decreases with increasing urbanisation
6. TOWARDS A HEALTHY CITY ENVIRONMENT: THE CASE OF THE CITY OF GRONINGEN

The previous chapters show how decreasing physical activity levels in the Netherlands lead to an increased incidence of diabetes type 2 and overweight and obesity. Summarizing, more than half a million people in the Netherlands (16 million now) are diagnosed with T2DM. Another estimated 250,000 are undiagnosed. This means that 5% of the Dutch population has T2DM. Half of the Dutch population (aged over 12) is overweight (25<BMI>30 kg/m²) and 10% obese (BMI>30 kg/m²) and the percentage is increasing. Since obesity is a risk factor for metabolic syndrome, and metabolic syndrome itself a pre-stage of diabetes, the incidence of metabolic syndrome is also increasing. One fifth of population has metabolic syndrome.

At the same time the energy use associated with passenger cars is high and increasing as well. Worldwide, 15.2% of the energy use is associated with passenger cars! In the Netherlands, energy use associated with passenger cars rose by 30% between 1980 and 1995 which makes passenger transport the largest contributor to the current energy consumption. (Bouwman, 2000). Yearly 111 GJ energy per person is used in the Netherlands, from which nearly 20% is used for transport. (Falkena, Moll, Noorman, Kok, & Benders, 2003).

Considering that physical inactivity is increasing as well as car ownership and car kilometres, and assuming that the emitted particulate matter causes inflammation in the same way as diabetes, obesity and metabolic syndrome, the health burden is expected to increase significantly. Currently, 53% of the population meets the healthy exercise norm. Meeting the healthy exercise norm requires 30 minutes of medium exercise for at least 5 days a week. A logical approach therefore will be to reduce PM_{10} emissions by substituting car travel by public transport, biking or walking. Increasing biking and walking will increase physical activity and this activity will take place in a cleaner environment.

In this chapter the model introduced in chapter 1 is used to assess the order of magnitude of the problem as well as the effect on PM_{10} levels and human health of substituting part of the car travel by public transport, walking or biking by using scenarios. For this case study data from the city of Groningen will be used regarding demographics, car ownership and health. Data not available or too difficult to obtain, will be extrapolated from existing national data. The model used is presented below as figure 6.1.

![Figure 6.1 Model representing influence of urban design on development of T2DM, MetSyn and obesity via motorised traffic, particulate matter (PM_{10}) and physical inactivity.](image)

Furthermore PM_{10} levels in the city of Groningen are assessed and compared to the PM_{10} norms. Urban form as an important factor determining transport used in the city is studied in various aspects. Proximity, connectivity and land use in the city of Groningen is examined to assess if the city of Groningen is bikable and/or walkable. Finally, data regarding car ownership, urbanisation grade, demographics, BMI, physical activity and the incidence of T2DM is acquired at a smaller scale (quarter level) and compared.
6.1 Groningen in numbers
In this paragraph the data necessary for the model is described as well as the data available. First the amount of kilometres travelled daily is investigated. Next, the demographics of the city of Groningen are studied since it is uncertain if Groningen is an average Dutch city and this influences the mobility pattern. Further the population size is needed for an estimation of PM$_{10}$ emissions. Finally, local health data are required.

6.1.1 Demographics
On January 1st 2003 the city of Groningen had on January 1st a population of 179,185. (Statistics Netherlands, 2004b). The population size at this date is chosen because the data about travel distances and modes of transport was from 2003. Since older people are less mobile and more likely to have health problems, demographic information is important. If many young people (age < 15) are present, then car ownership tends to be lower; this also influences mobility patterns and (environmental) health. Figure 6.2 below shows the demographics of strongly urbanised Dutch cities in general, and Groningen as a strongly urbanised city specifically for the year 2006 as this is the most recent year for which data are available.

![Figure 6.2 Demographics strongly urbanised areas and Groningen, the Netherlands in 2006 (Statistics Netherlands, 2004B; Statistics Netherlands, 2006F).](image)

The city of Groningen demographics differs substantially from average strongly urbanised areas in the Netherlands. The share of people below age of 15 in the city of Groningen is much lower than on the average in strongly urbanised areas (4 versus 6 percent respectively). On the contrary, the share of people in the age groups 20 to 25 and 25 to 45 is higher in the city of Groningen. The age group 20 to 25 is with a share of 15% of the population nearly three times as large as in average strongly urbanised areas in the Netherlands. (Statistics Netherlands, 2004b; Statistics Netherlands, 2006f). The number of students in the city of Groningen is very large, namely 36,000 which is nearly a fifth of the total population size! (Gemeente Groningen, 2006). The age groups 45 to 65 and 65 to 80 in turn are smaller again in the city of Groningen. It seems that people move out of the city when children are born and/or when retirement is reached; the share of children is after all also lower.

6.1.2 Mobility & car ownership
The large number of students in the city of Groningen is also reflected in mobility, car ownership and money spent on transport. In general, car ownership decreases as urbanisation increases although the amount of kilometres travelled daily is about the same no matter where people live. Car ownership per
household in very strongly urbanised areas is 0.69 and gradually increases to 1.12 in rural areas. Using the categories ‘very strongly urbanised’, ‘strongly urbanised’, ‘urbanised’, ‘mildly urbanised’ and ‘not urbanised’, the percentage of households not owning a car decreases accordingly. Successively, the percentage of households in 2003 without a car is 40.1; 24.2; 18; 14.5 and 12%. (Bouwman, 2000; Statistics Netherlands, 2006b). Those numbers hardly differ from the situation in 1993 (39.9; 25; 17.5; 15.3 and 12.9%) as mentioned by Bouwman (2000). However, the city of Groningen has one of the lowest rates of car ownership and one of the highest rates of bicycle possession. (Falkena, Moll, & Noorman, 2002). This is also depicted in the money spent in different transport categories in 2002. Compared to the average of the Netherlands, that is both urban and non-urban people, expenditure in the category car is with 45% for the city of Groningen significantly lower than the 60% in the Netherlands. Also the budget for public transport is higher, 34% in Groningen versus 13% in the rest of the Netherlands. (Falkena et al., 2003). It should be taken into account that in the household metabolism study, from which this data is taken, the city of Groningen is compared with the rest of the Netherlands and it may well be that urban people in general have a different expenditure pattern for transport compared to rural people. However, according to the Fietsersbond (Bicycle Association) which investigates and assesses the bicycle climate in 125 Dutch municipalities, the city of Groningen is very bike friendly compared to other cities. Not only is biking very comfortable (smooth asphalt), the bike is also 30% faster than the car (concurrent position) and 47% of the trips shorter than 7 km are made by bike, compared to 35% in other large cities. (Fietsersbond, 2005). Those aspects resulted in the Netherlands in becoming ‘Biking city of the year’ in 2002 and already Groningen was ‘World bike city’ in 1993. The assessment for Groningen, which resulted in becoming biking city of the year 2002, compared to average large cities in the Netherlands as well how the biking climate should be, are presented in figure 6.3.

Figure 6.3 Groningen assessment biking climate 2000-2004, compared to average large cities in the Netherlands as well as the situation required (norm) (Fietsersbond, 2005)

As the amount of kilometres as well as the kilometres made per mode of transportation in the city of Groningen is similar to average cities, the data representing transport in Dutch cities (chapter 5) is used. This implies that daily around 35 kilometres is travelled, from which 25 kilometres by car. Car travel consists of kilometres travelled as a driver and as a passenger. Passenger kilometres do not show up in the PM_{10} emissions in the model as to prevent double counting. Car travel as a driver is 15.7 kilometres per day. From these data, the relevant emissions can be calculated. Since the data is based
on the total population; people not being able to drive a car yet are included too, but those just lower the average and this should not pose significant problems. It is not possible to filter them out anyways, since Netherlands Statistics only allows selecting the ‘total population’ or ‘population older than 12’. Furthermore, there are also people entering the city to work, also those are not included in the calculation. Then again, people also travel from Groningen to work somewhere else and those kilometres are included so this might compensate for the ones travelling in the city.

On average, those people all travel 15.7 km daily by car as a driver. Taking into account that 75% drives a car on gasoline, 20% on diesel and 5% on LPG with emissions accordingly (see chapter 4), daily 59 kg \( \text{PM}_{10} \) is emitted from the city of Groningen. This could be more since emissions from the construction year of a car are chosen to be from the year 2004, although emissions from cars driving on LPG and gasoline have not improved in the last 10 years. The amount of non-motorized daily kilometres consists of kilometres by bike and by foot. This is daily 4.7 kilometres, 3.7 of which are made biking and 1 kilometre walking. Including those activities, 53% of the people meet the healthy exercise norm, which means that 53% of the people exercise at least 30 minutes 5 days a week at a medium level. Those are also taken from the data at city level as used before, meaning that those represent ‘very strongly urbanised’ and ‘strongly urbanised’ areas. This corresponds to nearly 95,000 people meeting the healthy exercise norm in the city of Groningen.

6.1.3 Weight-related health indicators

Extrapolating the Dutch data regarding incidence of obesity, overweight, metabolic syndrome and diabetes mellitus type 2, results in an estimation of the health burden. If 5% of the population has T2DM, this will correspond to nearly 9000 people in the city of Groningen. Metabolic syndrome is diagnosed in 20% of the population, in Groningen amounting to 36,000 people with metabolic syndrome. Of the population over 12 years of age, 50% is overweight and 10% is obese. In the city of Groningen, around 160,000 people are over 12 years of age. This can not be more specific, since the age categories maintained by Netherlands Statistics is > 10 years of age. In the city of Groningen 162,676 people are over 10 years of age. Extrapolating the data indicates that around 80,000 people are overweight and 8000 people obese.

Some recent local data regarding overweight and obesity and diabetes are available as well. The Health Service of the Municipality of Groningen (GGD) asked 1430 adults (aged 15 and older) from the city of Groningen to fill in the ‘Health Survey 2006’. From those 1430 people, 32% is overweight and 9.4% obese. Comparing this to the national data, less people are overweight and the amount of people being obese is about equal. The healthy exercise norm was also used in this questionnaire; 67% of the people meet the healthy exercise norm (HEN) exceeding the national average of 53%. About 4.4% has diabetes mellitus type 2, which is much lower than the average 7% in the Netherlands. (Broer, 2006). Data regarding the incidence of metabolic syndrome are not present, therefore no estimation and comparison is made. Using the same schedule as before, figure 6.4 shows the kilometres driven, \( \text{PM}_{10} \) emitted and incidences of the diseases in the city of Groningen in 2003.

Figure 6.4 Urban health and transportation model filled out for the city of Groningen
6.2 PM$_{10}$-levels Groningen

Levels of particulate matter vary per location and time of the day and change daily. Weather and season also influence PM$_{10}$ levels. Part of the PM$_{10}$ is also natural (about 7-9 $\mu$g) or coming from abroad (10-15 $\mu$g). (Visser, Buringh, & Breugel van, 2001). In the previous chapters is shown that the mode of transport as well as ventilation rates give different exposures to and inhalation of PM$_{10}$. It is therefore hard to determine the influence of a reduction in PM$_{10}$ on human health in terms of numbers since inhalation depends on the dose but also on the length of exposure. However, it is known that there is no effect level for PM$_{10}$; hence PM$_{10}$ levels should be as low as possible and reductions can only have positive results.

Guidelines for PM$_{10}$ are made at the European level and implemented on the national level. In the Netherlands, the daily average PM$_{10}$ level should not be above 50 $\mu$g/m$^3$. This daily average may be exceeded 35 times a year. The yearly average PM$_{10}$ levels should not exceed 40 $\mu$g/m$^3$. PM$_{10}$ levels are monitored continuously on 48 locations in the Netherlands. Monitoring is done by the National Monitoring Net Air Quality (LML) which is part of the Ministry of Housing, Spatial Planning and the Environment (RIVM). The monitoring location for Groningen exists since May 7th 2003. From this point to 2005 hourly data were collected. Data for 2005 and 2006 give a daily summary. To indicate the variability of the PM$_{10}$ levels, graphs were created from some of the data representing monthly, daily and hourly averages.

Figure 6.5 shows the monthly average PM$_{10}$ levels in the city of Groningen in 2005. Values vary from 26 $\mu$g/m$^3$ to 45 $\mu$g/m$^3$. The months with the highest average PM$_{10}$ values (February, March, September and October) also have the highest variations; standard deviations (not shown) are highest for those months. In the months with the highest PM$_{10}$ values the standard deviation is 20 while in the other months it is on average 10. The yearly average PM$_{10}$ concentration was 35 $\mu$g/m$^3$ and therefore below the guidelines. However, the number of exceedings was not: 48 times the guideline was exceeded while only 35 are allowed. For the year 2006 as of August 12$^{th}$, the daily average norm has already been exceeded 43 times.

![Figure 6.5 Monthly PM$_{10}$ levels Groningen (Europaweg), 2005 (Landelijk Meetnet Luchtkwaliteit, 2006)](image)

To put the PM$_{10}$ guidelines into perspective, one can calculate the emission in kilogram for the city of Groningen, which in turn can be compared to the car emissions calculated earlier. The city of Groningen roughly has a size of 10 kilometre by 10 kilometre. It is assumed that most of the pollution gets up to a height of 100 m. With a guideline of 35 $\mu$g/m$^3$ this implies that 350 kg PM$_{10}$ can be emitted. However, there is still the natural background of 7-9 $\mu$g/m$^3$ and the PM$_{10}$ coming from abroad...
Together this is 24 \( \mu g/m^3 \) already coming from natural and foreign, which leaves 9 \( \mu g/m^3 \) to be emitted anthropogenically, amounting to 90 kg.

Figure 6.6 shows the daily PM\(_{10}\) levels in the city of Groningen (Europaweg, location 937) for the year 2005. PM\(_{10}\) levels vary daily and no regular pattern can be distinguished. Earlier research done by IVEM by Van der Weide (2005) examined, among others, PM\(_{10}\) levels on five locations (1 city, 1 town and 3 villages) in the northern of the Netherlands for 28 weeks in 2003. On all five locations the fluctuations are also high, just like in the city of Groningen. Furthermore the concentrations were not significantly different.

![Figure 6.6 Daily variation in PM\(_{10}\) levels in the city of Groningen (Europaweg), 2005 (Landelijk Meetnet Luchtkwaliteit, 2006)](image)

To examine the PM\(_{10}\) variation pattern in a day, 4 days were chosen, one in every season, 3 months apart from each other. The results are shown in table 6.7. Also here the variation in PM\(_{10}\) concentration is very high and no pattern can be distinguished. Some measurements are very high (April 18\(^{th}\) 0:00) or very low (number of measurements on January 18\(^{th}\), April 18\(^{th}\) and July 19\(^{th}\)) and it may be questioned if those measurements are valid. Generally, however, the measurements give a good overview of the daily fluctuations of PM\(_{10}\) levels. The PM\(_{10}\) concentration on average is higher in spring and fall as is the fluctuation since the standard deviation is higher. PM\(_{10}\) concentrations are also on average lower in the morning compared to the evening; traffic at night is close to zero which results in lower PM\(_{10}\) levels in the morning before rush hour starts.
### Hourly PM$_{10}$ levels (µg/m$^3$) on 4 selected days in the city of Groningen (Europaweg), 2004

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### 6.3 Scenarios

Substituting car travel by walking and biking is the best option to increase daily physical activity and decreasing the physical inactivity related diseases T2DM, MetSyn and obesity. This paragraph presents different scenarios in which different amounts of car travel is substituted by walking and/or biking. This will have an effect on the daily PM$_{10}$ emitted and also on the amount of physical activity. Decreasing the amount of PM$_{10}$ emitted and increasing the amount of physical activity will decrease the development of T2DM, MetSyn and overweight. However, it is uncertain with which amount this corresponds and therefore calculations regarding a decrease in development of T2DM, MetSyn and overweight and obesity will not be made.

To get an idea of the daily movements that can be substituted, first the travelled distance per car movement by motive is calculated as well as the frequency this transport mode is used. Previously the amount of car kilometres per motive was already calculated but this was the sum of all trips by car for a particular motive and this bears no relationship with the distance per trip. Furthermore, the amount of car kilometres travelled consisted of car kilometres made as a driver and as a passenger. In the scenarios, kilometres made as a passenger are left out for a reason. In order to have an influence on PM$_{10}$ levels, beside the passenger, also the driver has to choose for another mode of transport. The kilometres made as a passenger are not included in the PM$_{10}$ emission calculations. However, the distances that are travelled as a passenger are small and infrequent and therefore offer the perfect opportunities for alternative transport.

Figure 6.8 shows the kilometres travelled by car per movement by motive as a driver and as a passenger as well as the relative frequency of this movement. The distances per movement are very small, either as a driver or passenger, and therefore they are suitable for alternative transport. Distances per movement are larger for car drivers compared to car passengers. Since the frequency of movement is relative within section ‘driver’ or ‘passenger’, frequencies can not be compared between the sectors. Car drivers use the car the most (0.225) for work and the distance per movement for work...
is largest as well, 4.4 kilometres. Visiting next requires the most kilometres, namely 3.3 kilometres although it is not as frequently done. The next largest distance done by car is 1.9 kilometre for businesslike visit (frequency 0.055) and 1.6 kilometres for recreative purposes (frequency 0.105). Shopping is the second most frequent car consuming motive as a car driver, followed closely by recreative, remaining and social recreative.

As a car passenger the largest distance is travelled for visiting, daily 3.0 kilometres. With a relative daily frequency of 0.12 this is also the most frequent motive. The second largest distance is for recreative purposes (1.8 km) followed by social recreative (1.2 km) and remaining (1.0 km). After visiting, travelling by car as a passenger occurs most frequently for recreative purposes (0.095) and social recreative and shopping purposes (both 0.085).

The scenarios will focus on car travel done as a driver. As the car is very convenient and considered safe, it will be hard to get people out of the car. Therefore, scenarios are made for 10 and 20% switching as well as all distances under 2 kilometres since those distances can easily be biked. Those three scenarios are worked out in the paragraphs below and show the effect on PM$_{10}$ emissions and physical activity levels.

6.3.1 The 10%-scenario

In the 10% scenario, 10% of the daily car kilometres made as a passenger are replaced by biking or walking. This corresponds to 1.5 kilometres that will be travelled extra by non-motorized modes of transport. For the city of Groningen, reducing 10% of the driver car kilometres reduces PM$_{10}$ emissions daily with 5.9 kg. By biking or walking this 1.5 km, physical activity is increasing. This then can be added to the healthy activity norm, so more people are going to meet it. The fastest mode of transport, the bike, will give the lowest contribution to the healthy exercise norm and the slowest mode of transport, walking, gives the highest contribution. Substituting the car travel by walking or biking is given as part of the healthy exercise norm met by comparing the minutes exercised when walking or biking weekly with the healthy exercise norm of 150 minutes (five days a week 30 minutes of exercise). When it is chosen to combine the modes of transport when substituting, the value will be typically between those two. Therefore, calculating the share of the healthy exercise norm using only walking or only biking gives a minimum and a maximum share of the healthy exercise norm that is accomplished when substituting 10% of the daily driver car travel by walking or biking.

Assuming an average walking speed of 5 km/hour, calculated from the Netherlands Statistics data regarding travel distance and time in cities, walking the 1.5 km will add 18 minutes of medium physical activity per person per day amounts to 126 minutes per week. The healthy exercise norm advises 5 days of exercise of at least 30 minutes; in a week this amounts to 150 minutes per person.
Therefore, substituting 10% of the daily car kilometres by walking results in 84% of the physical activity required for meeting the healthy exercise norm since 126 minutes of exercise is added in a week.

The average biking speed in Dutch cities is, according to Netherlands Statistics, 13 kilometres per hour. Substituting the 1.5 kilometres of car travel by biking therefore means 7 minutes of biking. In a week this will add 49 minutes of physical activity which is about a third of the healthy exercise norm.

6.3.2 The 20%-scenario
In the 20% scenario, 3 kilometres of car kilometres made as a driver are substituted by biking or walking. \( \text{PM}_{10} \) emissions are then reduced with 11.8 kg daily and the resulting load of \( \text{PM}_{10} \) emissions will be down to 47 kg for the city of Groningen.

Walking daily an extra 3 kilometres results in 36 minutes of physical activity. In a week this adds up to 252 minutes and this exceeds the healthy exercise norm. Walking daily an extra 3 kilometres results in 168% of the healthy exercise norm. However, it is not likely that people walk an extra 36 minutes every day since already 1 kilometre is walked everyday. Biking daily an extra 3 kilometres results in 14 minutes of physical activity. In a week this is then 98 minutes, which is 65% of the healthy exercise norm.

6.3.3 The <2 km-scenario
All movements made with a distance of 2 kilometres or less can either be walked or biked. Daily, in total 8 km of trips are made with each 2 kilometre or less. When choosing alternative non-motorized transport for those 8 kilometres, this daily reduces 29 kg of \( \text{PM}_{10} \) emissions. The previous paragraph showed, taking into account foreign emissions and natural background, 90 kg of \( \text{PM}_{10} \) is emitted daily which results in a concentration increase of 9 \( \mu \text{g/m}^3 \). Measurements by the National Monitoring Network showed that the yearly average \( \text{PM}_{10} \) concentration is 35 \( \mu \text{g/m}^3 \). A reduction of 29 kg of \( \text{PM}_{10} \) emissions therefore reduces \( \text{PM}_{10} \) concentration by 3 \( \mu \text{g/m}^3 \). Substituting half of the car driver kilometres therefore results in a \( \text{PM}_{10} \) reduction of 10% (3/35).

It can not be expected that those 8 kilometres will be walked; therefore the extra exercise when walking is not calculated. Part of this distance however may be walked, the rest biked. When the total 8 km is biked, this adds daily 37 minutes of physical activity. In a week this amounts to 259 minutes, which is far above the healthy exercise norm.

The 59 kilograms calculated from the model therefore already make up two thirds of the allowed amount and buses, cabs and trucks are not included in this amount.

Considering the motives the car is used for, one may expect that not all of the trips fewer than 2 km are substitutable for walking or biking. When getting many groceries, a car may be handy. Although it should be considered this are the daily distances; if daily groceries are done, the amounts will be much smaller then when this is only done once a week. When visiting people or going on business trips, the car may be preferred as it can be a status symbol and furthermore people do not want to get wet by rain or physical activity when reaching those destinations.

However, substituting some of the trips is certainly possible. Table 6.9 gives an overview of the reduction of \( \text{PM}_{10} \) and part of the healthy exercise norm met with the different scenarios.

Table 6.9 Car driver substituting scenarios and the impact on \( \text{PM}_{10} \) emissions and healthy exercise norm

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Daily ( \text{PM}_{10} ) reduction (kg), city of Groningen</th>
<th>Part of healthy exercise norm* by biking or walking p.p.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% (1.5 km)</td>
<td>5.9</td>
<td>33%-84%</td>
</tr>
<tr>
<td>20% (3 km)</td>
<td>11.8</td>
<td>65%-168%</td>
</tr>
<tr>
<td>&lt; 2 km</td>
<td>29</td>
<td>at least 173%</td>
</tr>
</tbody>
</table>

* healthy exercise norm: performing physical activity at least 5 days a week for 30 minutes
6.4 Urban form

Urban form influences physical activity; urban form measures to increase physical activity have been discussed in the previous chapters. In this paragraph, urban design indicators that are known to increase physical activity are assessed for the city of Groningen to indicate walkability and bikeability.

Two indicators of transportation-related activity levels are ‘time spent in a car’ and ‘distance walked’. (Frank et al., 2004). Frank et al (2004) have investigated the effects of time spent driving and distance walked on the probability of being obese in a group of 10,878 Americans. The results were shown graphically and are shown below in figure 6.10.

Those graphs can be used to assess the situation in Groningen. The people in Groningen daily walk one kilometre. According to the probability of the obesity graph, assuming all people being white, the changes for obesity lay between 0.12 (for females) and 0.28 (for males). Data present regarding obesity in Groningen, show that 9.4% is obese. Dutch citizens in cities drive daily 25 kilometres (not all of them in the city) resulting in 29.71 minutes spending in a car as either a driver or passenger. (Statistics Netherlands, 2006a). This gives them a risk of 0.09 (for females) to 0.18 (for males) of getting obese. However, this risk is already present even if no minutes are spent in a car; figure 6.10 shows hardly any difference in risk for obesity between 0 minutes spent in a car a day and 29.7 minutes. Therefore, reducing car kilometres in the city of Groningen as such does not result in a reduced risk for obesity; the amount of time spent in a car is already relatively small.

![Figure 6.10 Probability of obesity and distance daily walked and minutes daily spent in a car (Frank et al., 2004).](image)

6.4.1 Proximity

Factors that influence the choice to use motorized or non-motorised transport are based primarily on two fundamental aspects of the way land is used: proximity and connectivity. Proximity is determined by two land use variables, density and land use mix. Population density is among the most consistent positive correlates of walking trips. (Saelens et al., 2003). Granados (1998) classified cities by population density and the predominant mode of transport into car, public transport or pedestrian cities, as seen in table 6.11.

<table>
<thead>
<tr>
<th>Type of city</th>
<th>Population per hectare (average)</th>
<th>Automobiles per 1000 population</th>
<th>Annual consumption of gasoline</th>
<th>Use of public transport (trips per capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car cities</td>
<td>10 to 30 (20)</td>
<td>400</td>
<td>870</td>
<td>90 (low)</td>
</tr>
<tr>
<td>Public transport cities</td>
<td>30 to 130 (90)</td>
<td>170</td>
<td>220</td>
<td>310 (high)</td>
</tr>
<tr>
<td>Pedestrian cities</td>
<td>130-400 (170)</td>
<td>20</td>
<td>60</td>
<td>180 (moderate)</td>
</tr>
</tbody>
</table>

Based on the data available, three of the four indicators characterising the type of city Groningen is, are determined. Population density is 2.269 per square kilometre, which is 23 persons per hectare.
(Giesbers, 2005). Based on this single indicator, Groningen falls within the category ‘car city’ as the population per hectare is between 10 to 30. However, the city of Groningen also includes parks, industrial areas, schools and others. When only taking into account residences in the city of Groningen, the surface is 2319 hectares. With a population of around 180 000 the number of people living on one hectare is 78, which means the city of Groningen is a public transport city. (Genk van, 2006). The number of automobiles per 1000 people is 429 (see previous chapter); therefore based on this indicator Groningen is a ‘car city’ as the number of automobiles per 1000 people is 400 or more. Public transport is also not used very much. The average number of trips daily made by public transport by people in cities is 0.143, which results in 53 trips a year. This is far lower than the 90 trips required for it to be a car city. Based on those the three indicators of Granados, Groningen is a car city.

Netherlands Statistics uses the environmental address density (OAD) to reflect the extent of human concentrated activities like living, working, education, shopping. This is done by calculating the average number of addresses per square kilometre in a circle within the radius of one kilometre. For the city of Groningen, the environmental address density is 2824 per square kilometre. Although no reference is present, it seems like a high value. Considering that 20% of the Groningen population is a student, this may not be surprising.

The second component of proximity is land use mix (LUM), or the distance between or intermingling among different types of land uses. The measure of land-use mix follows:

\[
LUM = - \sum_{i=1}^{n} p_i \ln p_i / \ln n,
\]

In which \( p_i \) is the proportion of estimated square hectares attributed to land use \( i \), and \( n \) is the number of land uses. The measure represents the evenness of distribution of square hectares of development; evenness is maximum when the LUM is 1. Frank et al (2004) also used this formula which resulted in the graph shown in figure 6.12. Depending on the LUM, the risk for obesity varies between 2% and 32% depending on sex and race.

![Figure 6.12 Probability of obesity in relation to land-use mix (Frank et al., 2004).](image)

The land use mix in the city of Groningen was calculated, using the formula above. Land use mix categories needed to be distinguished, formed from the Standard Company Classification (SBI = Standaard Bedrijfsindeling) which is a classification of economic activities. The Spatial Science Department of the Municipality of Groningen uses this classification to keep track of land use in the Settlement Register (Vestigingenregister). This wide range of economic activities was sorted out and brought down to the categories ‘sports, game and leisure’ (land use 1), ‘stores and retail’ (land use 2), ‘services, government and health care’ (land use 3), ‘industry and business’ (land use 4), ‘wholesale business’ (land use 5) and ‘education and research’ (land use 6) as this reflected best the trips people take in their daily life to go to work, to shop, to sport, to go to school and in their spare time. By doing so, 3.5% (26 hectare) of the economic activities in the city of Groningen is not included. A summary of the list is given in Attachment 1 and includes the selection for each category. The land use for
residences in Groningen is kept in another register, called VOLIS. Land use 7 therefore is ‘residences’. Table 6.13 gives the areas in hectares in the city of Groningen for each land use with the share of total land use in 2005.

Table 6.13 Land use city of Groningen and share of total land use, 2005 (Vestigingenregister, 2005; VOLIS, 2005)

<table>
<thead>
<tr>
<th>Land use and amount</th>
<th>Area (hectares)</th>
<th>Share of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Sports, game and leisure (1398)</td>
<td>116,05</td>
<td>0.037</td>
</tr>
<tr>
<td>2: Stores and retail (4242)</td>
<td>319,99</td>
<td>0.103</td>
</tr>
<tr>
<td>3: Services, government and health care (965)</td>
<td>127,01</td>
<td>0.041</td>
</tr>
<tr>
<td>4: Industry and business (844)</td>
<td>83,40</td>
<td>0.027</td>
</tr>
<tr>
<td>5: Wholesale business (579)</td>
<td>59,21</td>
<td>0.019</td>
</tr>
<tr>
<td>6: Education and research (399)</td>
<td>88,84</td>
<td>0.029</td>
</tr>
<tr>
<td>7: Residence (81,587)</td>
<td>2318.53</td>
<td>0.745</td>
</tr>
<tr>
<td>Total</td>
<td>3113.03</td>
<td>1</td>
</tr>
</tbody>
</table>

Residence is the dominant land use in the city of Groningen which has with 2319 hectares a share of 75%. Many stores and retail are present as well, as they have a share of nearly 11%. The other land uses have about an equal share. Knowing all this, the land use mix can be calculated. The shares (ρ) are taken from table 6.10 and the number of land uses ‘n’ equals 7. The LUM for the city of Groningen therefore is 0.50 which corresponds with a risk for obesity of 5% for white women and 11% for white men according to figure 6.9. However, although the share of land use is known and this says something about the evenness of distribution of land uses, it does not say anything about division of land use. The land uses can still be concentrated together within the city which can make distances between different land uses still high. This is however not the case, as can be seen in figure 6.14. Figure 6.14 shows all the locations with the different land uses on the map of Groningen, per land use except for residence as those are found all over the city.

![Figure 6.14: Map of the city of Groningen with land uses and their locations in 2005 (Genk van, 2006).](image)

The different land uses are distributed all over the city of Groningen, although the density differences are present. People living in the less dense areas regarding the different land uses will have to travel a larger distance compared to those in the more dense areas.
6.4.2 Connectivity

The second aspect that influences the choice of transport mode is connectivity. According to Saelens et al. (2003), two community designs can be distinguished; a low-connectivity and a high-connectivity community design, shown in figure 6.15.

Connectivity is high when streets are laid out in a grid pattern and there are few barriers (walls, freeways) to direct travel between origins and destinations. With high connectivity, route distance is similar to straight-line distance and different land uses are integrated within small areas. A map of the city of Groningen can assess the community design present based on the pattern of the street network. The map of Groningen is shown in figure 6.16. The street pattern is very similar to the high-connectivity design seen in figure 6.15 and thus is the connectivity very high.

Although the population density and the use of public transport as well as the number of automobiles per 1000 people indicate Groningen is a car city, the land-use mix, connectivity, environmental address density and proximity assessment for the city of Groningen show that all the factors are present to encourage biking and walking.

Figure 6.15 Low-connectivity community design (top) and high-connectivity community design (bottom) (Saelens et al., 2003).
6.5 Urban form, mobility and health on a smaller scale
Based on the information collected in this chapter so far, it would be interesting if data could be acquired at a smaller scale. Therefore, this final paragraph aims to collect information regarding urban design, car ownership, demographics and health in the city of Groningen at quarter level and put the information beside each other.

6.6.1 Urban form quarters of Groningen
Although it is known that the land-use mix is good and so is connectivity in the city of Groningen in general, it is interesting to know if this is the case for each quarter of the city. If distances to work, school, shops, sports are too large, people will not opt for walking or biking. Therefore, a GIS-expert of the municipality of Groningen, Jozef Genk, calculated for a random sample of 100 households of the city of Groningen (population around 180,000) the distances (minimum, maximum, average) to all the locations within the land uses 1 to 6 defined before. This was done using Pythagoras’ assertion \(a^2 + b^2 = c^2\) to determine the distance between two coordinates, in this case the coordinate of the residence and the location of a certain land use type. The skewed side was used (so \(c^2\)) although this may lead to slight incorrectness as the city of Groningen is grid-like composed, hence the shortest distance from one place to another is not \(c\), but \(a + b\) and therefore distances should be multiplied by the square root of two. Since distances are already very small this incorrectness will not lead to significant differences.

The locations of those 100 households are given on the map of Groningen as figure 6.18. The result is a large matrix with the distance of every location defined as a certain land use to sample of households, 100 in total. Since already 1232 locations were destined to land use 1, this matrix is too large to be included in this report. A table is created that shows a summary of the data. Table 6.19 shows for each land use for 100 random addresses in the city of Groningen the minimum and maximum distance from all addresses to a certain land use and the average, average minimum and average maximum distances of the sample to a certain land use.
Figure 6.18 Random sample of 100 households in the city of Groningen (Genk van, 2006)

The closest someone can live to a certain land use location is zero, since people live above stores or for example beside a sport accommodation. The average minimum, which is the average of all minimum distances of the sample (100 in total) to a location with a certain land use (1 to 6), is low and varies from 59 m (for stores and retail) to 199 m (wholesale business).

On average, people have to travel around 3 kilometre to the nearest sports centre, store, doctor, wholesale business or school. The average maximum of all those households varies from 7056 m (for education and research) to 8056 m (industry and business) to reach certain land use location. The furthest anyone of those hundred people had to travel was 11436 m, which probably equals crossing the city diagonally as from northeast to southwest. (Genk van, 2006).

Table 6.19 Distance statistics of 100 households in the city of Groningen (Genk van, 2006)

<table>
<thead>
<tr>
<th>Land use (LU) and number of locations with assigned land use</th>
<th>Distances to locations (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU 1: Sports, game and leisure (1232)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 10712</td>
</tr>
<tr>
<td>LU 2: Stores and retail (3556)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 10235</td>
</tr>
<tr>
<td>LU 3: Services, government and health care (773)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 10102</td>
</tr>
<tr>
<td>LU 4: Industry and business (762)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 11436</td>
</tr>
<tr>
<td>LU 5: Wholesale business (522)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 10664</td>
</tr>
<tr>
<td>LU 6: Education and research (355)</td>
<td>Minimum: 0</td>
</tr>
<tr>
<td></td>
<td>Maximum: 9880</td>
</tr>
</tbody>
</table>

Since the distances to the locations of different land use for this sample are quite similar, spread of different land uses is good, indifferent of where in the city of Groningen people live. It is important to know how many people (percentage) have to travel what distance to reach a certain land use, as this determines the mode of transport. Therefore, figure 6.20 below gives the distances the households of the sample had to travel to reach each destination categorized as land use 1, 2, 3, 4, 5 and 6. This takes into account all the possible locations of the land use. Regarding land use 1, this means 123200 trips (100 households to 1232 locations, see table 6.20) are categorized and counted (frequency) and then recalculated as ‘share of households’.

Although the curve shifts slightly depending on the land use, the shape remains the same. In other words, around 85% of the people has to travel up to 5 kilometre to reach the destination of its choice. Since all locations with a certain land use are taken into account, distances will in reality be shorter since people often search for work close to their house or the other way around. The same can be
applied to schools, sport facilities etc. That decreases travel distances. Table 6.19 shows that some people have to travel 10 kilometres; this is very incidental as it does not show up in the graph.

Figure 6.20 Share of household versus distance to different land use locations (Genk van, 2006)

Assuming that people want to make the distance to do groceries, sports etc as short as possible, it is interesting to know how close people live to those locations. Taking only into account the shortest distances to land uses 1-6 (100 trips per land use), graph 6.21 was made to show the result.

Figure 6.21 Minimum distances of 100 households to certain land uses (Genk van, 2006)

As the spread in distances is larger as for the total of locations, those could not be put into one graph. The shape of each of the graphs in figure 6.21 is generally the same which indicates that the largest part of the population lives very close to different land uses. In the category ‘sports, game and leisure’ more than 50% of the people lives within 100 m of such a location and no one has to travel more than 400 m. Regarding ‘stores and retail’, 88% of the people finds this within 100 m of their residence and all within 200 m. ‘Services, government and health care’ can for 85% of the population be found
within 200 m which can also be said for ‘industry and business’. Nearly for all wholesale business is within 500 m and so is education and research. The closest locations of land uses may not for all be the one preferred however and thus trips further than this may be required. It should also be taken into account that the number of people in the sample from the dense neighbourhoods, as for example the city centre, is relatively high and therefore the distances to the different land uses as shown may give a distorted image. People from other, less dense, quarters probably have to travel longer distances to different land uses. However, all are that small that biking and in most cases even walking, should not be a problem.

6.6.2 Car ownership in the quarters
The city of Groningen has one of the lowest rates of car ownership although differences may be present per quarter. It is known that with increasing urbanisation and thus increasing population density, car ownership rate decreases although the total number of cars increases. Data regarding car ownership, population density and urbanisation grade is present via Netherlands Statistics on quarter and neighbourhood level. The full list can be viewed in attachment 2.

Generally, the city of Groningen owns one car per household and the urbanisation grade is 1 which indicates it is very strongly urbanised. Urbanisation grade is judged on a level 1-5; 1 meaning very strongly urbanised, 2 strongly urbanised, 3 mildly urbanised, 4 little urbanised and 5 not urbanised. In the city of Groningen in 2005 62,970 cars are present for a population of 180,000. Population density is 2269 people per square kilometre.

The city of Groningen is divided into 10 quarters with each a number of neighbourhoods. The total number of neighbourhoods is 59. Naturally the city centre is very strongly urbanised; the urbanisation grade is 1 and population density around 10,000 people per square kilometre. At the same time car ownership is on average zero per household. Other very strongly urbanised quarters or neighbourhoods (which is most of Groningen) also nearly all have on average no car per household. Furthermore the population density of those very strongly urbanised neighbourhoods is at least 6000 people per square kilometre. Interesting, those are also nearly the only neighbourhoods that get rid of their cars; the year mutation of cars is negative and can be as high as -15% in the city centre. Quarters and neighbourhoods that are less urbanised (level 2 to 5) all have 1 car per household except for the neighbourhood ‘university’ (urbanisation level 4, no cars) but very few people live there and the people that live there are all students. Households that own 2 cars is very rare; only 2 neighbourhoods exist were this occurs out of the 59 neighbourhoods. In those neighbourhoods few people live (150 and 360) and the population density is low (324 and 860 people per square kilometre). However, other neighbourhoods exist with those characteristics where car ownership is 1. (Statistics Netherlands, 2004b; Statistics Netherlands, 2006g).

6.6.3 Demographics of quarters/neighbourhoods
The demographics of the city of Groningen deviate from average cities in the Netherlands, as discussed before. Now a closer look is taken on demographics in the quarters and neighbourhoods of Groningen since this influences mobility and health. The age-categories when information is required at quarter level are different then before, therefore the demographics of the city of Groningen is given again but then with the other age-categories. The age-category < 15 years contains 13% of the population, 21% is between 15 and 25 years of age, 33% between 25 and 45, 21% between 45 and 65 and 12% is over 65%.

The city centre is significantly different from average Groningen. Most of the population (75%) is between 15 and 45 years old. Hardly and people are below 15 or above 65 and clearly many students. The city centre was also almost without cars. Wondering about urbanisation level, demographics and car ownership, statistics are compared.

Previously it was shown that very strongly urbanised quarters and/or neighbourhoods (level 1) possess no cars on average. The demographics of those quarters/neighbourhoods is sometimes different from the average demographics of Groningen but not in the same way. For example, neighbourhood Selwerd in quarter Oranjewijk has significantly more elder people than normal (22 versus 12%) and less people in the age category 25-45 (25 versus 33%) which is a different composition than the city centre. Therefore, now the less urbanised quarters and/or neighbourhoods are analysed.
Neighbourhoods/quarters with urbanisation level 2 nearly always have on average a higher share of 65+ and a lower share of students (category 15-25), except for Beijum-West and Helpman-Oost. A level 3 urbanisation grade goes together with a significantly higher share of people aged below 15 (around 20% versus 13% on average), a lower share of people between 15 and 25 years, a higher share of people between 25 and 45 and mostly a lower share of people above 65. It seems that more families live in quarters/neighbourhoods with level 3 urbanisation. The same can be said for level 4 and 5 quarters/neighbourhoods where also the share of students and elderly is lower and the share of people below 15 and between 45 and 65 is much higher. Level 4 and 5 urbanisation is very rare, only 7 neighbourhoods are characterised like this (of the 59). (Statistics Netherlands, 2006g; Statistics Netherlands, 2004b; Statistics Netherlands, 2006h). The complete list of demographics of quarters and neighbourhoods is shown in attachment 2.

6.6.4 Health of quarters in the city of Groningen

The recently performed ‘Health Survey 2006’ (Gezondheidsenquête) by the Health Service of the Municipality (GGD) Groningen is of use when determining the health situation in the quarters. This survey was filled in by 1430 people in the city of Groningen. From this survey the incidence of T2DM, BMI and the healthy exercise norm were derived. Another classification of quarters (the so-called GSBG-classification) is used; neighbourhoods falling within this classification are mentioned later. The incidence of diabetes mellitus type 2, percentage of people meeting the healthy exercise norm and the BMI in the quarters of Groningen as indicated by this sample are shown in table 6.22.

<table>
<thead>
<tr>
<th>Quarter and number of people surveyed</th>
<th>Diabetes Mellitus Type 2 (%)</th>
<th>Healthy exercise norm met (%)</th>
<th>BMI &lt;18.5</th>
<th>18.5-25</th>
<th>25-30</th>
<th>&gt;30</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Centre (87)</td>
<td>2.4</td>
<td>55.1</td>
<td>2.3</td>
<td>67.8</td>
<td>28.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Oranjewijk/Schilderswijk (94)</td>
<td>1.1</td>
<td>73.5</td>
<td>4.3</td>
<td>62.8</td>
<td>27.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Oud-zuid (108)</td>
<td>1.0</td>
<td>65.7</td>
<td>1.9</td>
<td>66.7</td>
<td>22.2</td>
<td>9.3</td>
</tr>
<tr>
<td>Nieuw-zuid corporatief (95)</td>
<td>5.2</td>
<td>70.4</td>
<td>3.2</td>
<td>57.9</td>
<td>27.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Nieuw-zuid particulier (112)</td>
<td>2.8</td>
<td>67.8</td>
<td>1.8</td>
<td>58.9</td>
<td>33.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Oosterpark (113)</td>
<td>7.2</td>
<td>62.8</td>
<td>3.5</td>
<td>58.4</td>
<td>32.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Korrewegwijk/De Hoogte (85)</td>
<td>2.4</td>
<td>59.8</td>
<td>2.4</td>
<td>75.3</td>
<td>17.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Lewenborg (104)</td>
<td>8.3</td>
<td>75.0</td>
<td>3.8</td>
<td>46.2</td>
<td>37.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Beijum (99)</td>
<td>2.1</td>
<td>67.6</td>
<td>2.0</td>
<td>53.5</td>
<td>31.3</td>
<td>13.1</td>
</tr>
<tr>
<td>Nieuw-oost (118)</td>
<td>3.6</td>
<td>71.2</td>
<td>1.7</td>
<td>50.8</td>
<td>32.2</td>
<td>15.3</td>
</tr>
<tr>
<td>Paddepoel (103)</td>
<td>9.2</td>
<td>65.0</td>
<td>2.9</td>
<td>50.5</td>
<td>40.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Vinkhuizen (97)</td>
<td>5.3</td>
<td>62.7</td>
<td>4.1</td>
<td>49.5</td>
<td>32.0</td>
<td>14.4</td>
</tr>
<tr>
<td>Nieuw-west (101)</td>
<td>3.0</td>
<td>65.7</td>
<td>3.0</td>
<td>47.5</td>
<td>40.6</td>
<td>8.9</td>
</tr>
<tr>
<td>Hoogkerk/De Dorpen (114)</td>
<td>6.5</td>
<td>75.7</td>
<td>1.8</td>
<td>42.1</td>
<td>41.2</td>
<td>14.9</td>
</tr>
<tr>
<td>Total (1430)</td>
<td>4.4</td>
<td>67.3</td>
<td>2.7</td>
<td>55.8</td>
<td>32.1</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Earlier in this chapter was already established that people in the city in Groningen are healthier than the average Dutchmen, since levels of obesity and overweight are lower, incidence of T2DM is lower and more people meet the healthy exercise norm. Although the Health Survey is just a sample taken at random, differences between quarters can be determined. When looking at the incidence of T2DM, a number of quarters jump out. Paddepoel, Lewenborg and Oosterpark have a high incidence of T2DM (9.2, 8.3 and 7.2 % respectively). In Oosterpark and Paddepoel this high incidence of T2DM goes together with less people than average (62.8 and 65% respectively) meeting the healthy exercise norm. However, in Oosterpark more people have a healthy BMI (58.4% versus 55.8%) and less people are obese (5.3 versus 9.4%). In Paddepoel less people are obese (5.8% versus 9.4%) but more people are overweight (40.8% versus 32.1%) and less people have a healthy BMI (50.5% versus 55.8%). Although the incidence of T2DM in Lewenborg is high, so is the amount of people meeting the healthy exercise norm. However, less people have a healthy BMI and more people are overweight and obese (37.5 and 12.5% versus average 32.1 and 9.4%).

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Quarters with a very low incidence of T2DM are Oranjewijk/Schilderswijk (1.1%), Oud-Zuid (1.0%) and Beijum (2.1%). In Oranjewijk/Schilderswijk many people meet the healthy exercise norm (73.5%) and more people have a healthy BMI. At the same time less people are overweight and obese. Although people in Oud-Zuid do not exercise more than average, more people have a healthy BMI and therefore less people are overweight and obese. The people from Beijum do not exercise more than average and their BMI’s are comparable to the average with the exception that slightly more people are obese. The incidence of T2DM is surprisingly low considering the BMI and exercise pattern.

However, the largest share of population has a normal weight corresponding with a BMI between 18.5 and 25. Only a small share of the population has underweight, indicated by a BMI lower than 18.5. The share of people with underweight is quite low, around 3%, and quite the same in every quarter. The share of population with either overweight or obesity is much larger than the share of people with underweight. In some quarters nearly half of the population is overweight.

This table is represented in some graphs by making x, y plots of the different information collected on quarter level. Figure 6.23 shows per quarter the share of people with overweight (BMI between 25 and 30), obesity (BMI above 30), T2DM and meeting the healthy exercise norm in the city of Groningen in 2006. Since already overweight is a risk factor for the development of T2DM, an extra category is added representing the share of population with a BMI above 25. Therefore this category represents the overweight and obesity group together.

![Graph showing the percentage of people with overweight, obesity, T2DM, and meeting the healthy exercise norm in different quarters of Groningen.](image)

Figure 6.23 Share of people with overweight (BMI 25-30), obesity (BMI>30), T2DM and meeting the healthy exercise norm in quarters of the city of Groningen, 2006 (H/D= Hoogkerk, de Dorpen; L= Lewenborg; NW= Nieuw-west, NO= Nieuw-oost, P= Paddepoel, V= Vinkhuizen, B= Beijum, N-ZP= Nieuw-zuid particulier, N-ZC= Nieuw-zuid corporatief, O= Oosterpark, O/S= Oranjewijk/Schilderswijk, O-Z= Oud-zuid, C= Centre, K/H= Korreweg, de Hoogte) (Broer, 2006)

The percentage of people meeting the healthy exercise norm varies. No correlation can be found with the percentage of people being overweight or obese in a quarter. Quarters where the incidence of T2DM is high, Lewenborg, Paddepoel and Oosterpark, many people are overweight or obese and/or not meeting the healthy exercise norm. In the quarters where the incidence of T2DM is the lowest, Oranje/Schilderswijk and Oost-zuid, significantly less people are overweight or obese; the share of people meeting the healthy exercise norm is average for the Netherlands. The quarter with the lowest amount of overweight and obesity together, Korrewegwijk/De Hoogte, also has a low incidence of
T2DM; however, the share of people meeting the healthy exercise norm is among the lowest. Other factors, like age, ethnicity and social-economic status, should be taken into account as confounders.

Figure 6.24 shows the share of population with T2DM versus the share of population meeting the healthy exercise norm. No pattern can be distinguished in this graph. When the incidence of T2DM is low, there are quarters with low and high shares of population meeting the healthy exercise norm, but this is also the case when the incidence of T2DM is high. It is clear that the development of T2DM does not only depend on the amount of physical activity.

Next car ownership and demographic data is put beside it. Since in this health survey an other classification of quarters and neighbourhoods is used, the other data is rearranged to fit this one, otherwise the health data could not be compared to demographics and car ownership. The full data set is given in attachment 3. Car ownership and demographics are mainly studied for those quarters with a difference in T2DM incidence, healthy exercise norm and BMI.

High incidence quarters T2DM
Paddepoel has the highest incidence of T2DM. The quarter is highly urbanised (level 1) and on average people have no cars per household. Demographics are similar to the average except that a larger share is older than 65 years of age, namely 19% versus 12%. In some neighbourhoods within Paddepoel this share is even 35%. The risk for illnesses increases with age. Furthermore, the share of people with overweight is larger than average.

Oosterpark has a high incidence of T2DM too. In this level 1 urbanised quarter on average households own no car. Demographics are average. The share of people meeting the healthy exercise norm is too low.

Lewenborg with a high incidence of T2DM is mildly urbanised (level 3) and households have on average one car. Lewenborg is more a ‘family’ quarter as the share of people below 15 years of age and between 45 and 65 is significantly higher than average. Furthermore, the share of people older than 65 is lower than average.

The incidence of T2DM is with 6.5% also high in Hoogkerk/De Dorpen. This quarter is not totally representative as it also includes the villages around the city of Groningen beside Hoogkerk which is quarter of the city. Characterised as level 4 urbanisation, it is little urbanised. People own on average one car per household. Although many people meet the healthy exercise norm (75.7%), many people are overweight (41.2%) and obese (15%). Also here more families live, since the share of children and people in the age group 45 and 65 is higher. The share of people older than 65 is lower.
Low incidence quarters T2DM
Five quarters can be distinguished that have a very low incidence of T2DM; Oranjewijk/Schilderswijk (1%), Oud-Zuid (1%), Beijum (2.1%), City Centre (2.4%) and Korrewegwijk/DeHoogte (2.4%). Oranjewijk/Schilderswijk All those quarters, except for Beijum have on average no car per household and are very strongly urbanised (level 1, Beijum level 3). The share of people meeting the healthy exercise norm is not higher, sometimes even lower. Only 55% of the people in the city centre meet the healthy exercise norm but the share of students is very high and the share of overweight much lower and obese persons nearly zero which eliminates two risk factors: overweight and age. This same situation is occurring in Korrewegwijk/De Hoogte.

High share of elderly
Since the incidence of diseases is increasing with age, it may be expected that quarters with a high share of elderly have also more persons with diabetes. Four quarters have a high share of persons above 65 years of age: Nieuw-Zuid Corporatief (19%), Nieuw-Zuid Particulier (21%), Paddepoel (19%) and Vinkhuizen (19%). In all those quarters, except for Nieuw-Zuid particulier, the incidence of T2DM is above the average incidence of the city of Groningen. However, in all those quarters, except for Nieuw-Zuid particulier, the share of people with overweight and obesity is lower than average.

Large car ownership
Large car ownership is hardly present since average car ownership per household is one and already the highly urbanised quarters have on average no cars. Incidentally, neighbourhoods have two cars per household; this is only observed in two quarters in total which is in two different neighbourhoods. Since this is such a small part of the total quarter, no effect (if existing) can be distinguished.

Lack of physical activity
Two quarters can be distinguished with a significantly lower share of people meeting the healthy exercise norm: city centre (55.1%) and Korrewegwijk/De Hoogte (59.8%). The share of overweight and obese people in those quarters is however significantly lower than average as well as the incidence of T2DM. The share of people between 15 and 25 is significantly higher; health problems may still evolve.

BMI
It is only in the quarters where there is on average no car per household, that the share of overweight and obese persons is significantly lower. Paddepoel is an exception and has a larger share of overweight persons. However, it also has a larger share of elderly. In all the other quarters, except Nieuw-Zuid Particulier, the share of people with overweight and/or obesity is higher than average.

Key findings:
- the urban design of the city of Groningen is well suited for encouraging biking and walking; proximity and connectivity are excellent
- PM$_{10}$ levels in the city of Groningen strongly fluctuate but are on the average below the PM$_{10}$ norms although the maximum number of exceedings in a year is higher than allowed
- incidence of T2DM as well as the share of population being overweight or obese is in the city of Groningen lower than average
- high T2DM incidence corresponds with a high (> 25) BMI
- absence of cars within a household seems to correlate with less overweight and obesity
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**Additional findings**

- On average very strongly urbanised neighbourhoods possess on average no car daily trips in the city of Groningen are generally short and therefore bikable and/or walkable.
- Substituting part of car travel by biking and/or walking reduces PM$_{10}$ emissions and significantly increases daily physical activity.
- Demographics influence health: quarters with higher share of elderly have a higher incidence of T2DM.
- Favourable demographics healthwise (large share of students) may give a false positive health view; physical activity is poor but BMI and incidence of T2DM still good but frank illness may not have developed yet.
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7. DISCUSSION

Before discussing methods and data acquired, the explorative character of this study should be emphasized. This means that in depth aspects are taken into account in this research (cellular mechanisms \( \rightarrow \) internal environment) but broad ranging aspects as well (external environment).

This research aimed in general to develop research questions for further research based on the hypothesis that the mechanism by which diabetes mellitus type 2, metabolic syndrome and obesity brought about due to lack of physical activity is complementary to the mechanism that causes particulate matter to be damaging to human health and therefore may be additive. More specifically, the influence of urban design on transport choice and particulate matter levels, physical activity and the incidence of obesity and diabetes mellitus type 2 was examined. This chapter discusses the process and results found. Conclusions and recommendations finish this report.

7.1 Discussing data and method used

This research focuses on the relationship between physical (in)activity and the development of T2DM, obesity and metabolic syndrome. Other factors can also enhance and/or cause the development of T2DM, obesity and metabolic syndrome like the kind and amount of food or genetics and should also be considered.

The amount of physical activity performed among the Dutch was measured using the healthy exercise norm. Although it is not possible to determine the intensity of the exercise performed, this norm uses average activity and therefore all exercise (also household activities) will be included and people do not have to think about the kind of activity (light, medium, heavy) when filling out surveys about physical activity. The other strong point of the healthy exercise norm is the inclusion of household activities which makes the norm applicable to all layers and ages of society. This norm is used by a wide range of institutions and therefore up-to-date data was available.

Physical inactivity related diseases were studied regarding incidence and mechanisms. Although it is clear that the incidence is high and increasing, the exact incidence of T2DM is not clear because many hidden cases still exist and the diagnostic criteria of metabolic syndrome may differ. Those problems underestimate the real incidence of T2DM and metabolic syndrome although estimates about the number of undiagnosed T2DM cases do exist.

The exact mechanisms underlying T2DM, MetSyn and obesity remain unclear although this has been an intensive area of research for many years. The same can be said for the mechanisms that cause the effects of exposure and inhalation of PM\(_{10}\). Therefore it remains a hypothesis that the mechanisms that cause T2DM, obesity and diabetes are similar to the ones that cause the effects of PM\(_{10}\). Examined literature points to chronic inflammation and oxidative stress as causing those diseases and effects of PM\(_{10}\) but no single mechanism is decided on. More experimental research is needed to be able to draw firm conclusions regarding mechanisms.

The assessment of overweight and obesity by the BMI-index can be a matter of debate as it is only based on the weight and length of a person. People with many muscles will be heavier and may therefore be considered overweight while probably they have less fat than the average individual. Waist circumference is a therefore better assessor of metabolic risk than BMI because it is more directly proportional to total body fat and the amount of metabolically active visceral fat (Haslam, Sattar, & Lean, 2006). However, waist circumference measurements are not widely applied and therefore data is limited. Complete data existed when using the BMI-index and therefore was chosen for BMI.

The body burden of PM\(_{10}\) inhaled is difficult to determine. Although exposure can be measured, inhalation still depends on concentration of PM\(_{10}\), ventilation rate and the time spent in that area. Once inhaled, it depends on the size and composition of the particulate what the behaviour and thus the effects will be. Transport modes and exposure and inhalation of PM\(_{10}\) is therefore difficult to compare as so many factors are involved. Assuming a certain distance of travel, this distance will be travelled faster by car than when biking or walking. Although the exposure to PM\(_{10}\) for bikers and walkers is much less since they are not directly near the emissions, the increased ventilation due to exercising and the increased travel trip (compared to a car or bus) will result in inhaling more air. It is uncertain if eventually the inhaled PM\(_{10}\) is less than when driving a car since this depends on the
length of the trip, the inhalation and the concentration in the air which varies frequently changes. However, it is proven that the benefits of exercising (although inhaling potentially more PM$_{10}$) are much larger than not exercising at all. Further the concentration of PM$_{10}$ significantly decreases with distance from the road. Hence, sidewalks and biking paths should be as far as possible from the road, possible even be disconnected instead of parallel as currently the case. This could also be applied in rural areas.

Car ownership data was collected to reflect car use, but this does not necessarily have to correlate. However, when a car (or more) is available in the household, it is just a little step to use it. Indeed, it is shown that car ownership has increased over the years and so has the amount of kilometres travelled by car per person. The increase of car travel by day is small however. Furthermore, the daily car travel data is an average and therefore does not show by whom the increase in car travel was made: did households owning previously one car and now two increase their car travel or did households owning previously no car and now one start to travel by car, or is it a combination of those two?

The built environment influences transport choice and health. Giving the growing predominance of urban living, interventions that take into account features of the urban environment that have the potential to be widely applicable and to influence the health of vast numbers of people. (Vlahov et al., 2003). Although it is evident that close proximity and good connectivity increase the walking and biking possibilities, this does not necessarily mean that people will substitute their car trips by walking or biking. Many other factors are important. First of all, maybe most important, is the time spent on travelling. Here the “Law of Constant Travel” has to be taken into account; if the change of transport lengthens the travel time, it will not happen. Trips out of the city therefore are not likely to be substituted since most of the time the car is faster. Sometimes trains or buses when using special bus lanes are faster, but then those bus lanes have to be present. Within the city, research done by the Bicycle Association has shown that bikers travel 30% faster than cars. Besides, the price of travel also plays a role which of course also depends on the amount of kilometres travelled. Biking and walking will be cheaper than driving a car, but the bus or train not necessarily so. To consider as well, is the quality of travel of the chosen mode of transport. Although the car, bike and walking have in common that the freedom exists to go and leave as you please, weather and lack of space can be a disadvantage when opting for biking or walking. Further, pedestrian and biking facilities have to be present and adequate. This means people have to feel safe, be able to park their bike somewhere safely and not be limited by for example the opening hours or prices of biking store facilities. Psychological and social factors are more important for walking and biking than for driving. The influence of friends and peer groups, perceptions about crime rates and personal safety and the pleasure one gets from the aesthetic appeal of a streetscape are almost certainly more important determinants of walking behaviour than of driving behaviour. (Handy et al., 2002). Safety issues therefore may limit physical activity, especially among elderly.

Reducing car traffic is desirable. However, it is also possible that less cars decrease congestions which makes it possible for the remaining cars to increase their speed resulting in more accidents and pollution. Banning cars or limiting speeds is the only option to prevent this. Broadening biking paths adjacent to the road makes the lane for cars optically smaller and this also reduces their speed. Other policy measures like gasoline taxes and congestion prices may also be effective. (Frank et al., 2005) A decrease in cars on the road in urban areas should not result in an increase in accidents and pollution.

Data for the city of Groningen was acquired to estimate the impact of a reduction of car travel on PM$_{10}$ levels and physical activity as well as assessing the situation of the city of Groningen regarding meeting the healthy exercise norm, the incidence of T2DM, prevalence of overweight and obesity in relation to car ownership, demographics and urban form. Car ownership is lower in the city of Groningen than on average in the Netherlands. However, the share of students is large in the city of Groningen and since they generally do not possess a car they decrease the car ownership. In fact, the people not being students can probably have on average more cars and still the city of Groningen will have a low car ownership rate since 20% of the population is student. Although car ownership is lower, the amount of kilometre travelled daily by car is not lower than average. This indicates that the people that do own a car travel on average more by car. Overweight and obesity seems to occur more in households with a car. It is not known if this increased incidence is due to the ownership of a car or
that the ownership of the car is because of the overweight and obesity, which makes physical activity
harder.

The incidence of T2DM and overweight is lower in the city of Groningen compared to the
Dutch national data and the share of people meeting the healthy exercise norm is too. This information
is based on the data collected by the Health Service of the Municipality of Groningen (GGD) for the
Health Survey 2006. Although this is just a sample of 1430 from a population of nearly 180 000, it is
supposed to represent the population of the city of Groningen as this is aimed by the GGD.

The calculated emissions from the cars in the city of Groningen represent the current situation
as good as possible. It was not possible to calculate emissions according to all the different
construction years and therefore it was chosen to use the data from the most recent construction year
available. For some cars PM$_{10}$ emissions within urban areas have not or hardly declined over the
years. This is the case for gasoline and LPG cars and those cars represent 80% of the cars used.
Therefore the error due to not using different construction years will be small. Furthermore, it is
unknown how much is driven daily with what kind of car (fuel used) and construction year. It is for
example possible that people with diesel cars, emitting the largest amount of PM$_{10}$ per kilometre, also
drive daily the most kilometres and have the oldest cars and therefore contribute most to PM$_{10}$
emissions. Of the three kind of fuels, diesel emits the most PM$_{10}$ per kilometre and it also shows the
most reduction over the year. Therefore, if a diesel car is reasonably old, the PM$_{10}$ emission will be
significantly more. Translating these emissions to exposure of humans will not result in the correct
inhalation of people walking or biking. The weather influences PM$_{10}$ levels but also the distance
between the cars and bikers/walkers makes a difference. Besides, peak exposures were measured at
traffic lights and cultivation along the road traps PM$_{10}$ and thus reduces exposure. All those factors
could not be measured/taken into account.

Regarding all previous data, the time perspective should be taken into account. The data used
is a momentarily recording; the current situation. When looking at the incidence of T2DM and obesity,
itis should be realized that the development of T2DM and obesity is a gradual process; one does not
become a diabetic or obese from one day to the other. Physical inactivity and/or exposure to PM$_{10}$
leading to the development of T2DM or obesity could therefore have occurred a long time ago and this
is difficult to trace. It is not known if the exposure to PM$_{10}$ has to be long-term or that an incidental
peak exposure is enough to cause T2DM or obesity. Long-term experimental studies are necessary on
a non-migrating population to follow-up on PM$_{10}$ levels, mobility patterns and health. However,
although many things remain uncertain, it is essential to reduce the population burden of PM$_{10}$.

Urban form indicators were used to assess walkability and bikability, but also the risk for
obesity. Although a risk for obesity does not mean that people become obese, it does give a view on
how fast the risk for obesity increases when less is walked and more is driven as well as the difference
in genetics (black versus white) regarding this risk.

Although the urban design of the city of Groningen is well-suited to encourage walking and
biking, this does not necessarily mean people will walk and bike. A good urban design is a
prerequisite for biking and walking. Beside individual responsibility, government measures are
necessary to encourage people to walk or bike since the car has still too many advantages. This means
parking tariffs in the city should be higher. A restriction of cars in the city centre is also a good option.
Further, air pollution caused by driving a car, should be incorporated in the car or gasoline price.
Currently, the advantages of the car do not weigh up against the disadvantages. As long as this does
not change, even though the urban design is suitable for walking and biking, the car will still be the
dominant mode of transport.

Combining data regarding weight-related health indicators, demographics and car ownership
on quarter level in the city of Groningen had to provide new insights regarding possible relationships.
Information on the weight-related health indicators is based on the Health Survey and therefore a
sample which may not give a complete picture. Besides, the data used are just a momentarily
recording. The findings, although very preliminary, should be considered in further research. More
extensive, comparative, long-term data is required for future research but already now interesting
things show up although it is uncertain if those findings can be translated nationally. Car ownership is
zero when the urbanisation level of a quarter is zero. This did not show when the city of Groningen
was taken as a whole, therefore the smaller scale data is needed. Quarters not possessing a car also had
a lower incidence of T2DM and prevalence of overweight and obesity. However, those quarters have a
large share of students that may explain the low car ownership and low incidence of T2DM. The economic situation of most students does not allow them to own a car, beside the fact they have a public transportation pass which allows them to travel for free. Furthermore, they are probably still too young to develop T2DM. Therefore, socio-economic data could also be useful in future research.

The quarters with a larger share of students, City Centre and Korrewegwijk, also have a low share of people meeting the healthy exercise norm. Since those people are still young, the incidence of overweight and obesity is still low and so is the incidence of T2DM. However, they do form a risk group because of their low physical activity but also because of living near busy traffic. Demographics should be included when looking at physical activity and incidence of T2DM, otherwise a distorted image will evolve.

7.2 Conclusions
A lack of physical activity can lead to the development of T2DM, MetSyn, overweight and obesity that can result in CVD. T2DM, MetSyn and obesity are characterized by chronic inflammation and oxidative stress. Incidence of one of these disorders, increases the risk for developing the other. All three disorders tend to be difficult, if not impossible, to reverse. In the Netherlands, the incidence of T2DM, MetSyn, overweight and obesity is increasing and physical activity has declined due to a change in transportation modes. Only 53% of the Dutch population meets the healthy exercise norm of moderately exercising for half an hour on at least five days of the week; 10% is virtually inactive. Cardiovascular diseases are the most important cause of death currently.

Exposure to PM$_{10}$ causes respiratory, cardiovascular and cardiorespiratory morbidity and mortality; no apparent threshold level exists. This morbidity and mortality is caused by inflammation and oxidative stress as well as formation of free radicals. Body burden of PM$_{10}$ depends on length of exposure, concentration of PM$_{10}$ size of the particles, distance to the source of PM$_{10}$ emission and ventilation rate. Travelling by different modes of transport gives different PM$_{10}$ exposures; highest exposures are measured in buses and cars and lowest for walking and biking.

In urban areas 35 km is travelled daily, most of which is done by car (25 km), followed by bike (3.7 km) and train (3.6 km). Travel is a major potential source of physical activity in modern life, but is currently not completely utilized. Over the last 10 years, car travel has increased with 6% while biking has remained the same and walking has decreased with 15%.

Mixed use and more compact community (high connectivity and low proximity) designs show significant promise for the promotion of physical activity (walking and biking) and the reduction of regional air pollution levels. Opportunities exist to increase physical activity and improve regional air quality through more compact development. However, increased compactness, or density, often exacerbates traffic congestion and can increase exposure of harmful emissions within central areas. Therefore, strategies to reduce localized air pollution in existing and developing centres are required to enable larger health benefits from smart growth to be realized. Additional government measures to discourage car use are necessary to increase the amount of disadvantages of travelling by car.

The city of Groningen has an urban design that promotes biking and walking. A larger share meets the healthy exercise norm and the share of people with T2DM, overweight and obesity is significantly lower. Quarter level data for the city of Groningen show that T2DM incidence is higher in quarters with less physical activity and/or a high BMI (> 25). Absence of cars reduces overweight and obesity. Demographics should be taken into account as it has been shown that quarters with a higher share of elderly have a higher incidence of T2DM while the share of people being overweight and obese was lower. The quarters with a high share of students had poor physical activity levels but BMI and T2DM incidence was still good.

Based on the information above there seems to be a relation between use and exposure to emissions of motorised traffic, immobility and the development of diabetes mellitus type 2, metabolic syndrome and obesity. Mechanisms causing the effects of PM$_{10}$ and the development of T2DM, MetSyn and obesity can be similar. The hypothesis is neither rejected nor confirmed yet. Further research is needed, but the first step is made.

7.2.1 Policy recommendations
To decrease the incidence of T2DM, MetSyn, overweight and obesity, physical activity should be increased and PM$_{10}$ exposure decreased. Several measures can be taken to decrease exposure to PM$_{10}$. 

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First of all, PM$_{10}$ emissions from motorised vehicles have to be reduced. This can be done by reducing the car travel or by reducing emissions from cars. Cars on hydrogen for example do not emit PM$_{10}$. An other option is to make the distance from the source of PM$_{10}$ and walkers and bikers as large as possible. Sidewalks and biking paths should be built far from roads, if possible independent from main roads. Trees and bushes can be used to eliminate PM$_{10}$. Cars can be banned on routes most often taken by bikers and walkers, like the city centre. It is also an option for bikers and walkers to travel on other times than cars to avoid rush hour and peak exposure of PM$_{10}$.

The speed of cars can be reduced although this does not solve the problem of peak emissions at traffic lights. Speed reduction is also achieved when roads are made optically narrower; biking paths can be enlarged to achieve this effect.

The smaller distances travelled by car should be substituted by biking or walking to increase physical activity. Therefore, enough facilities for parking the bike (safely) have to be present. Shower facilities should be present at schools and work. People should feel safe when biking or walking, therefore adequate lighting should be present. Pollution caused by car travel should be incorporated in car or gasoline price. The latter is probably the most effective as owning a car does not say anything about the use of the car.

7.3 Recommendations
Considering the explorative character of this study, much further study is needed. In the first place regarding the mechanisms that cause T2DM, MetSyn and obesity in relation to physical inactivity and exposure to PM$_{10}$.

Research is needed in the form of case studies to quantify the relation between urban environment, transportation and human health. Regarding the empirical data collected for the city of Groningen, it would be interesting to interview people with obesity and/or diabetes mellitus type 2 that have not moved house in the last 5 or 10 years. On the questionnaire things like daily activity, transport mode to and from work and route (busy road, streets, time) and house location (busy road, street) should be included. Based on this information, streets/neighbourhoods at risk for high PM$_{10}$ levels can be determined. The next step is to determine if the obese people in those streets have a higher risk for developing T2DM compared to if they did not have this PM$_{10}$ exposure.

Comparative assessments need to be done regarding the incidence of obesity and diabetes mellitus type 2, PM$_{10}$ levels, physical activity and, built environment characteristics in other cities and quarters to quantify the before mentioned relationship.

Dietary patterns and genetics are important health determinants that need to be included in future research. Anti-oxidants for example are potential health determinants against the possible consequences PM$_{10}$ inhalation as it scavenges free radicals.
REFERENCES


VOLIS. (1-1-2005). Grondoppervlakte van woningen naar type in de gemeente Groningen. Groningen, Gemeente Groningen. Ref Type: Data File


Weide, L. van der (2005). *Air pollution and asthma in children: the relationship between air pollution and anti-asthma medication dispensing to children from 6 until 12 years old in the North of the Netherlands*. Groningen: CIO/IVEM.


ATTACHMENTS

Attachment 1: Summary Standard Company Classification (SBI = Standaard Bedrijfsindeling)

The SBI’93 consists of six levels; the highest two levels (sections and subsections) are indicated by letters and the lower levels (departments, groups, classes and subclasses) are indicated by numbers. Below a summary of the SBI’93 is given. The full list can be found on the website of Statistics Netherlands (http://www.cbs.nl/nl-NL/menu/methoden/classificaties/overzicht/sbi/default.htm)

<table>
<thead>
<tr>
<th>Level</th>
<th>Industry Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Landbouw, jacht en bosbouw</td>
</tr>
<tr>
<td>01</td>
<td>Landbouw, jacht en dienstverlening voor de landbouw en jacht</td>
</tr>
<tr>
<td>02</td>
<td>Bosbouw en dienstverlening voor de bosbouw</td>
</tr>
<tr>
<td>B</td>
<td>Visserij</td>
</tr>
<tr>
<td>05</td>
<td>Visserij, kweken van vis en schaaldieren</td>
</tr>
<tr>
<td>C</td>
<td>Winning van delfstoffen</td>
</tr>
<tr>
<td>CA</td>
<td>Winning van energiehoudende delfstoffen</td>
</tr>
<tr>
<td>10</td>
<td>Turfwinning</td>
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<td>11</td>
<td>Aardolie- en aardgaswinning en dienstverlening voor de aardolie- en aardgaswinning</td>
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<td>CB</td>
<td>Winning van niet-energiehoudende delfstoffen</td>
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<tr>
<td>14</td>
<td>Winning van zand, grind, klei, zout e.d.</td>
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<tr>
<td>D</td>
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<td>Vervaardiging van voedingsmiddelen en dranken</td>
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<td>Verwerking van tabak</td>
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<td>Vervaardiging van textiel en textielproducten</td>
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<td>17</td>
<td>Vervaardiging van textiel</td>
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<td>18</td>
<td>Vervaardiging van kleding; bereiden en verven van bont</td>
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<td>Vervaardiging van leer en lederwaren (geen kleding)</td>
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<td>Houtindustrie en vervaardiging van artikelen van hout, kurk, riet en vlechtwerk (geen meubels)</td>
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<td>Vervaardiging van papier, karton en papier- en kartonwaren</td>
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<td>22</td>
<td>Uitgeverijen, drukkerijen en reproductie van opgenomen media</td>
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<td>DF</td>
<td>Aardolie- en steenkoolverwerkende industrie; bewerking van splijt- en kweekstoffen</td>
</tr>
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<td>Aardolie- en steenkoolverwerkende industrie; bewerking van splijt- en kweekstoffen</td>
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<td>Vervaardiging van producten van rubber en kunststof</td>
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<td>DI</td>
<td>Vervaardiging van glas, aardewerk, cement-, kalk- en gipsproducten</td>
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<td>Vervaardiging van glas, aardewerk, cement-, kalk- en gipsproducten</td>
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<tr>
<td>DJ</td>
<td>Vervaardiging van metalen in primaire vorm en van producten van metaal</td>
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<td>Vervaardiging van metalen in primaire vorm</td>
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<td>28</td>
<td>Vervaardiging van producten van metaal (geen machines en transportmiddelen)</td>
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<td>Vervaardiging van machines en apparaten</td>
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<td>29</td>
<td>Vervaardiging van machines en apparaten</td>
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<tr>
<td>DL</td>
<td>Vervaardiging van elektrische en optische apparaten en instrumenten</td>
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<td>30</td>
<td>Vervaardiging van kantoormachines en computers</td>
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<td>31</td>
<td>Vervaardiging van overige elektrische machines, apparaten en benodigdheden</td>
</tr>
<tr>
<td>32</td>
<td>Vervaardiging van audio-, video- en telecommunicatieapparaten en -benodigdheden</td>
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</tbody>
</table>
33 Vervaardiging van medische apparaten en instrumenten, orthopedische artikelen e.d., precistie- en optische instrumenten en uurwerken
DM Vervaardiging van transportmiddelen
34 Vervaardiging van auto's, aanhangwagens en opleggers
DN Vervaardiging van meubels; vervaardiging van overige goederen n.e.g.
36 Vervaardiging van meubels; vervaardiging van overige goederen n.e.g.
37 Voorbereiding tot recycling
E Productie en distributie van en handel in elektriciteit, aardgas, stoom en water
40 Productie en distributie van en handel in elektriciteit, aardgas en warm water
41 Winning en distributie van water
F Bouwnijverheid
45 Bouwnijverheid
G Reparatie van consumentenartikelen en handel
50 Handel in en reparatie van auto's en motorfietsen; benzineservicestations
51 Groothandel en handelsbemiddeling (niet in auto's en motorfietsen)
52 Detailhandel en reparatie van consumentenartikelen (geen auto's, motorfietsen en motorbrandstoffen)
H Horeca
55 Logies-, maaltijden- en drankenverstrekking
I Vervoer, opslag en communicatie
60 Vervoer over land
61 Vervoer over water
62 Vervoer door de lucht
63 Dienstverlening voor het vervoer
64 Post en telecommunicatie
J Financiële instellingen
65 Financiële instellingen (uitgezonderd verzekeringswezen en pensioenfondsen)
66 Verzekeringswezen en pensioenfondsen (geen verplichte sociale verzekeringen)
67 Financiële beurzen, effectenmakelaars, assurantietussenpersonen, administratiekantoren voor aandelen, waarborgfondsen e.d.
K Verhuur van en handel in onroerend goed, verhuur van roerende goederen en zakelijke dienstverlening
70 Verhuur van en handel in onroerend goed
71 Verhuur van transportmiddelen, machines en werktuigen zonder bedienend personeel en van overige roerende goederen
72 Computerservice en informatietechnologie
73 Speur- en ontwikkelingswerk
74 Overige zakelijke dienstverlening
L Openbaar bestuur, overheidsdiensten en verplichte sociale verzekeringen
75 Openbaar bestuur, overheidsdiensten en verplichte sociale verzekeringen
M Onderwijs
80 Onderwijs
N Gezondheids- en welzijnzorg
85 Gezondheids- en welzijnzorg
O Milieudienstverlening, cultuur, recreatie en overige dienstverlening
90 Milieudienstverlening
91 Werkgevers-, werknemers- en beroepsorganisaties; levensbeschouwelijke en politieke organisaties; overige ideële organisaties e.d.
92 Cultuur, sport en recreatie
93 Overige dienstverlening
P Particuliere huishoudens met personeel in loondienst
Q Extra-territoriale lichamen en organisaties
99 Extra-territoriale lichamen en organisaties
From this list a selection was made to represent the land uses:
1) Sports, game and leisure
2) Stores and retail
3) Service, Government and health care
4) Industry and business
5) Wholesale business
6) Education and Research

Table 1 below shows the categories from the SBI’93 that are selected for each land use.

<table>
<thead>
<tr>
<th>Land use category</th>
<th>SBI content</th>
</tr>
</thead>
</table>
| 1: Sports, game and leisure | *H: Catering industry  
*O 913: Religious and political organisations; remaining idealistic organisations like hobby clubs  
*O 92: Culture, sports and recreations (except for O 924 and 925) |
| 2: Stores and retail | *G 52: Retail and reparation of consumer items  
* I 632: Remaining services for transportation  
* I 633: Travel organisation and arbitration; information regarding tourism  
* I 641: Mail and courier services  
* J: Financial institutions  
* K 71: Rental of vehicles, machines and equipment (except for K 712)  
* K 72: Computer service and information technology  
* K 74: Remaining businesslike services  
* O 911: Business-, employers- and professional organisations  
* O 912: Employee organisations  
* O 924: Press- and news agencies  
* O 93: Remaining services |
| 3: Service, government and health care | * L: Public management, government services and compulsory social insurances  
* N: Health- and well-being care  
* O 90: Environmental services  
* O 925: Cultural loaning centres, public archives, museums, zoos etc |
| 4: Industry and business | * D: Industry  
* F: Building Industry (except for F 4550)  
* I 6312: Storage |
| 5: Wholesale business | * F 4550: Rental of building- and destructing machinery with staff  
* G 50: Dealing and reparation of cars and motorcycles  
* G 51: Wholesale business and trade arbitration |
| 6: Education and research | * K 73: Tracing- and development work  
* M: Education |
### Attachment 2: Demographics and car ownership at quarter/neighbourhood level in Groningen

<table>
<thead>
<tr>
<th>Postcode</th>
<th>Stedelijk bevolking</th>
<th>Bevolking per km²</th>
<th>OAD</th>
<th>Pers. auto's per tot</th>
<th>Pers. auto's per jaar</th>
<th>Pers. auto's per per hh</th>
<th>Pers. auto's per per km²</th>
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</table>

Note: The table contains demographic and car ownership data for different quarters/neighbourhoods in Groningen, with columns for various age groups and car ownership statistics per km² and per household.
<table>
<thead>
<tr>
<th>Postcode</th>
<th>Bevolking</th>
<th>Bevolkingsdichtheid</th>
<th>OAD</th>
<th>Pers. auto's tot</th>
<th>Pers. auto's jaar mutatie</th>
<th>Pers. auto's per hh</th>
<th>Pers. auto's per km²</th>
</tr>
</thead>
</table>

**Wijk 05**
- **Oosterpoortwijk**
  - 9724: 1 4780
  - 9723: 1 360
- **Euvelgumme**
  - 9723: 5 100
- **Middelburg**
  - 9723: 5 170
- **Engelbert**
  - 9723: 5 890
- **Roodenhaan**
  - 9723: 5 30

**Woonschepenhaven**
- 9723: 4 130

**Wijk 06**
- **Herewegwijk en Helvaman**
  - 9725: 1 2302
  - 9721: 1 2740
- **Rivierbuurt**
  - 9725: 1 2320
- **Helpman-West**
  - 9725: 1 120

**Corpus Den Hoorn-Noord**
- 9728: 3 4040

**Wijk 07**
- **Stadsparkwijk**
  - 9728: 2 15270
  - 9721: 1 1430
- **Laanhuizen**
  - 9727: 1 1120
- **Grunobuurt**
  - 9727: 1 2220

**Corpus Den Hoorn-Zaam**
- 9728: 3 6170

**Wijk 08**
- **Vierverlatten**
  - 9744: 3 33620
- **De Held**
  - 9745: 3 1550

**Wijk 09**
- **Noordzijde-Oosterhof**
  - 9731: 3 3440
- **Lewenborg-Noord**
  - 9733: 3 3720

**Wijk 10**
- **Boven-streek**
  - 9735: 3 280
- **Beijum-Noord**
  - 9737: 2 6470

**Wijk 11**
- **Ulgersma-buurt**
  - 9731: 3 5610
- **Beijum-West**
  - 9737: 3 6470

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### Attachment 3: Demographics, car ownership and health at Groninger quarters

<table>
<thead>
<tr>
<th>stedelijk</th>
<th>bevolking</th>
<th>bev.dichtheid</th>
<th>Bevolking naar leeftijdsgroep</th>
<th>Pers. auto's tot</th>
<th>pers. auto's per hh</th>
<th>pers. auto's per km²</th>
<th>suiker/ziekte</th>
<th>NNGB</th>
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