# Urban Structures and Travel Behaviour. Experiences from Empirical Research in Norway and Denmark

Petter Naess
Aalborg University
Aalborg
Denmark
E-mail: petter@plan.auc.dk

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*In line with theoretical considerations, a number of empirical studies reviewed in this paper show that urban structural variables influence the inhabitantsí amount of transport and their choice of means of conveyance. This appears to be true across city sizes. The location of the residence relative to the city centre is the urban structural characteristic which, according to our analyses, exerts the strongest influence on travelling distances, modal split between car and non-motorized transport, and energy use for transport. The distance from the residence to the downtown area is a key factor influencing the accessibility to a number of facility types. Population densities at a local scale as well as for the city as a whole are also important to the amount of travel and the use of cars. In addition, a high road capacity contributes to the increase of the proportion of commuters travelling by car in the peak period.*

## Introduction

Reducing the consumption of fossil fuels (oil, coal and gas) is a key issue in the efforts to promote a *sustainable development,* as conceived by the UN World Commission on Environment and Development (the Brundtland Commission) in its report ìOur Common Futureî (WCED, 1987). The United Nations Climate Panel (IPCC) has suggested that the global-level carbon dioxide emissions should be reduced by at least 60 per cent as soon as possible. If at the same time an increase in the material standard of living is going to take place in developing countries, this will most likely imply substantial increases in the energy consumption of these countries. For such an increase to be possible within the frames of a total level of emissions that does not aggravate the greenhouse effect, industrial countries

1 Reviewed version of a paper prepared for the international conference on land use and modal choice, Amsterdam, 20 June, 2000

must reduce their emissions by considerably more than the 60 per cent suggested by the UN Climate Panel for the planet as a whole (cf. also WCED, 1987:171).

Transportation is probably one of the sectors of society where policies aiming to reduce greenhouse gas emissions will be most controversial. But transportation is also the sector showing the steepest increase in greenhouse gas emissions, thus the need for policies in order to "break the curve" is strong within this sector. Transportation in urban areas has a number of other negative environmental and social impacts too, including local air pollution, noise, loss of valuable buildings and recreational areas due to road construction, replacement of public urban space by parked cars, the barrier effects of major roads, and traffic accidents. After a period of traffic safety improvements and reduced number of deaths on the roads, the number of traffic fatalities is again rising in Denmark, following the general increase in traffic.

A number of imaginable measures exist in order to influence the amount of transport, the modal split between different means of conveyance, and the energy use and related emissions from transportation. Improving the energy efficiency of vehicles could bring about considerable reduction of the emissions from the transportation sector, but unfortunately, increased weight and motor power have so far tended to outweigh what is gained by ìlean-burnî motors. A shift to electric cars would solve many of the local pollution problems of car traffic, but in terms of greenhouse gases an electrification of the car fleet would only move the emissions from the streets to the power plant. Other measures (e.g., radical increases in gasoline fees, road pricing with restrictively high rates per kilometre, or the establishment of maximum quota for each personís purchase of fuel) could potentially change transportation patterns significantly in the course of a short time. However, it has proved to be extremely difficult to gain political backing for such measures. Part of the reason for this is probably the fact that the very mobility that has given most people in modern societies increased freedom to reach a wide range of destinations and activities, has also given us a society where a high mobility is increasingly becoming a requirement. The location of built-up areas and activities in urban regions is an obvious example. During the last half of the 20th century, it became not only possible, but also necessary for people to transport themselves considerably longer distances to reach daily and weekly activities.

In order to break the self-perpetuating interaction between increased mobility and a transport-generating land use, there will be a call for specific transport policy measures as well as a location and structuring of future urban development aiming to limit the needs for transportation. In the following, I will outline the state of knowledge about the influences of key urban structural characteristics on travelling distances, modal split and energy use. Such knowledge is a basic condition for land use policies aiming to reduce the need for transport ñ and in particular car driving ñ in urban areas. I will first provide a brief overview of the conclusions from research carried out in the Nordic countries (mainly in Denmark and Norway) about the influence of several urban form variables on travel behaviour and energy use for transport. Next, I will go more deeply into a recent study of residential location and transportation in the small Danish town of Frederikshavn. In this study, a broader range of research issues related to the topic were addressed than in most previous studies, and the relationships between urban structural factors and travel behaviour were checked for a larger number of control variables. The Frederikshavn study also combined travel survey analyses with qualitative interviews of some of the households, thus opening for a more in-depth understanding of the mechanisms by which land use affects daily travelling patterns. At the end of the paper, I will briefly point at some main strategies by which urban development might contribute to reach the goals of reducing the environmental load from urban transport.

## Theoretical point of departure

By creating proximity as well as distance between activities, and by facilitating various modes of traveling, the urban structure makes up a set of incentives facilitating some kinds of travel behavior and discouraging other types of travel behavior. People are assumed, *ceteris paribus,* to minimize their efforts to reach their daily activities. The efforts may include money, time, inconvenience, etc. In order to estimate a personís total efforts associated with making a trip, transport economists have introduced the concept of generalized travelling costs. The closer a destination is to the place where you are, and the faster, cheaper and more convenient ways of transportation are at hand, the lower will be your generalized travelling costs of going to this destination, and the higher will be its accessibility. In addition to the accessibility of a location, the trips to a destination depend on the reasons people may have for going there. Here, factors like the number and diversity of jobs and service facilities in the area, or the number of residents, will be important for the extent to which trips are attracted to a certain location.

The causes of travel behaviour of course also include personal characteristics of the travellers, such as age, sex, income, professional status, as well as their values, norms, lifestyles and acquaintances. Human behaviour is influenced by structural constraints and incentives (among which the material urban structure is only one category), as well as by the resources, preferences and aspirations of individuals. Also symbolic and cultural features attributed to an area may affect the number of visitors attracted. The emerging transportation pattern is a result of peopleís resources, needs and wishes, as modified by the constraints and opportunities given by the structural conditions of society (see Figure 1).

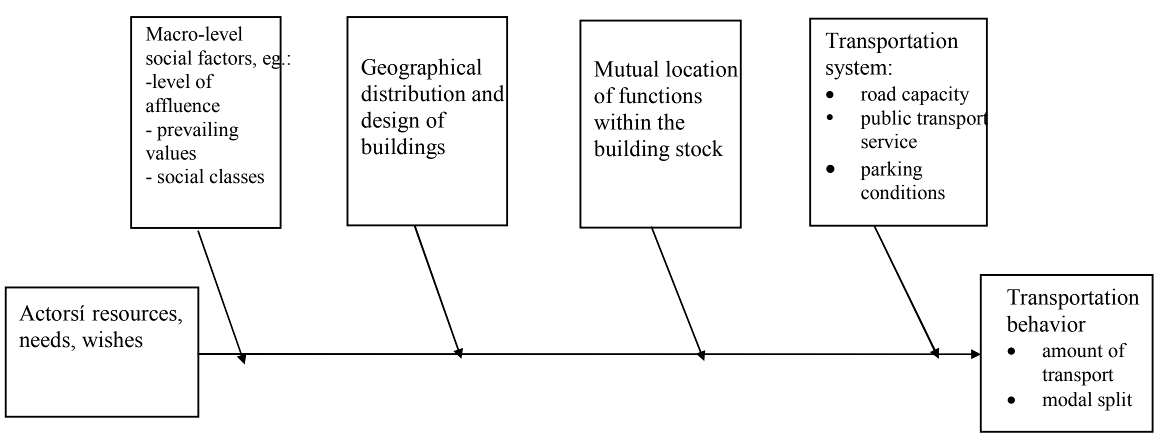


*Figure 1. Transportation behaviour as a function of land use characteristics as well as individual characteristics of the travellers.*

The situation is further complicated by the fact that increased accessibility may create new needs. For example, the increased accessibility facilitated by the shorter average distances between different functions (residences, jobs, service facilities etc.) in dense and concentrated cities, might be utilized by increasing the radius of action to include a wider range of opportunities, rather than by reducing the amount of travel. The multitude of structural and individual factors likely to influence transportation behaviour makes the study of relationship between land use and transportation a challenging exercise. (For a more thorough discussion of ontological and epistemological issues related to studies of the influences of land use on travel, see Naess and Saglie, 2000; Naess and Jensen, 2002.)

Most studies within the field of land use and transport have taken into consideration only a few factors influencing travel behaviour. The first generation of studies was dominated by model simulations of hypothetical patterns of development. The obvious constraint of this approach is the fact that the results of model computations depend entirely on the modelís assumptions about the influences between its variables. Model simulations can illustrate and synthesize already existing knowledge about transportation consequences of alternative urban structures, but cannot be used to investigate whether the assumptions on which the model is based are correct. Gradually, the number of empirical studies into the land use ñ transport relationship has increased. The first of these studies (among others, Keyes, 1976; Newman and Kenworthy, 1989) were comparisons of transportation activity at an aggregate level (typically between cities or metropolitan areas). Later on, an increasing number of studies have been carried out at a disaggregate level, with households or individuals as units of analysis. At first, few of these studies took into account other factors of influence than the urban structural variables the studies were focused on. Gradually, several empirical investigations have been carried out, incorporating urban form variables as well as demographic and socio-economic factors in the analyses. The latest development of the field of research implies a widening of the scope also to include several attitudinal or ìlifestyleî factors, e.g. residentsí attitudes to travelling and different means of conveyance (cf., among others, Handy, 1996). The findings presented in the next section stem mainly from projects where demographic and socio-economic variables have been included in the analyses, but not lifestyle factors. I will return to the influence of the travellersí attitudes later in the article.

## Urban form variables influencing energy use for transport

### Density

By sheer geometry it is easy to show that, other things being equal, the distances between the various functions of a city will be lower in dense and concentrated cities than in cities characterized by sprawling developmental patterns. In Figure 2, this has been symbolized by means of dots within circles of different sizes. Both circles include the same number of dots. We immediately grasp the fact that the average distance between the dots is shorter in the circle to the right than to the left.

A high population density implies shorter average distances between residences, workplaces and service facilities than in a city with a dispersed pattern of development. The gain in the form of travelling distances includes shorter trips from home to work and service facilities, better opportunities for linking different trip purposes, and shorter trips when visiting friends and relatives living in the same city. Furthermore, a high population density facilitates more

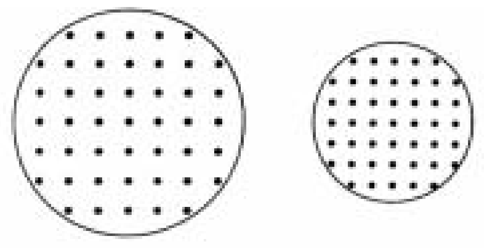

*Figure 2 The relationship between density and average distance between functions, symbolized with dots within circles of different sizes*

frequent departures and shorter walking distances to public transport stops. Because distances between activities are shorter in dense cities, a higher proportion of the destinations will also be within walking or cycling distances. Furthermore, in dense urban areas, streets are usually narrower and there is less space available for parking than in less densely developed areas. In summary, a high urban population density facilitates shorter travelling distances as well as a higher use of public and non-motorized transport.

Admittedly, increased accessibility may create new needs. The shorter distances between functions facilitated by dense cities could be utilized by opting for a wider range of workplaces, shops and residences and by increasing the frequency of trips, rather than reducing the amount of travel. Still, the empirical research carried out so far shows that even though some of the energy benefits resulting from shorter distances between functions are offset by this mechanism, dense and concentrated cities do indeed contribute to a lower energy use for transportation than in dispersed, low-density cities. The absence of any such influence would also have been quite sensational. If density and concentration were to have no effect at all on energy use for transportation, the entire benefit from shorter distances between functions must have been utilized by opting for a wider range of opportunities instead of reducing the volume of transportation. Such an imbalance in the trade-off between the benefits of an increased radius of action and the time and monetary benefits from reduced travelling does not appear to be very likely.

Figure 3 shows the relationship between urban area per capita and energy use per capita for transport found in a study of 22 Nordic cities (Naess, Sandberg and R□e, 1996). This relationship is still present when controlling for a number of other urban form and socio-economic variables. Similar results have been found in a number of other studies (Newman and Kenworthy, 1989; Fouchier, 1998; Naess, 1993), although few of these studies have controlled for other potential explanatory factors affecting energy use. Newman and Kenworthyís 1989 study as well as their updated study including 46 cities at a world-wide scale concluded that density still matters after controlling for some other variables, notably fuel price and income.

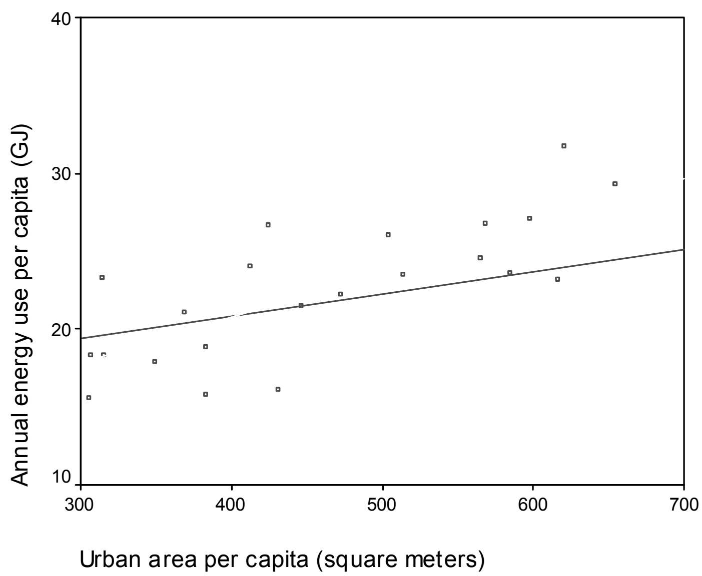


*Figure 3. Annual energy use per capita for transport (GJ) in Nordic cities with differences in urban area (square meters) per inhabitant. The regression line shows the relationship when controlling for a number of demographic, socio-economic and other urban form factors[2]. Level of significance for the controlled relationship: 0.032.*
Source: Naess, Sandberg and R□e (1996)

## Location of residences

Similar to Figure 2, Figure 4 illustrates how the average distance between dots is reduced when a large proportion of the dots is concentrated close to the centre of the circle. By analogy, a city with a concentration of activities towards the centre would yield a shorter average distance between functions.

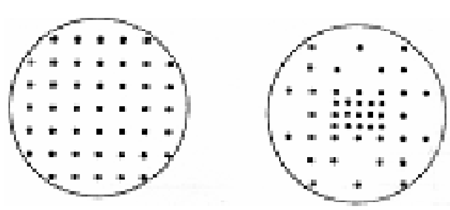

*Figure 4. The relationship between centralization within the urban area and average distance between functions, symbolized with dots within circles of different sizes*

Traditionally, many European cities have had a concentration of workplaces and service functions in the downtown area. In particular, this applies to public offices, cultural facilities, restaurants, entertainment and specialized stores. In many cities, a wide range of facilities

2 Composition of trades, gross commuting frequency, degree of population concentration within the urban area, population size, income level, fuel price, education level, car ownership rate, public transport supply, intra-urban road provision, degree of fragmented urban area demarcation, geometric shape of the town (linear vs. non-linear).

covering the city as a whole or the city region are located in this area. The historical urban core is often the geographical centre of gravity of the housing stock, and also the main node of the public transport system. Because of this high accessibility, downtown areas have attracted stores and other service facilities requiring a large population base (Christaller, 1933/1966:49-70). For the same reason, public authorities and agencies are often located in the city centre. This concentration of facilities also increases the possibility for visitors to carry out several errands within a small geographic area, which in itself increases the competitiveness of the urban core as a location for retail and other services (Christaller, ibid:43, 105). Moreover, for many types of businesses, a location in the city centre may offer so-called agglomeration benefits (Vatne, 1993). The advantages of being located close to other businesses in the same branch include the cost reductions of utilizing each other's competencies, as well as more qualitative relations in the form of informal contact between the companies.

The closer to downtown the residences of such cities are located, the more workplaces and service facilities are likely to be available in the proximity of the dwelling. Therefore, inner-city residents could be expected to make shorter daily trips than their outer-area counterparts, and a high proportion of destinations might as well be easily reached by foot.

The location of a residence within an urban area also affects the likelihood of being surrounded by either a high-density or low-density local community. Usually, there is neither tradition nor demand for the same densities in peripheral parts of a city as in the inner and central areas (Mogridge, 1985:482-484; Holsen, 1995). With a higher density of residences and/or workplaces in the local area, the population base for various types of local service facilities will also increase (Christaller, 1933/1966:45, 53)[3]. Hence, the average distance from residences to local service will also be shorter, possibly encouraging some of the residents to make their trips to these facilities by non-motorized modes.

Figure 5 shows schematically how the location of residences relative to the centre of the city could be expected to affect the amount of transportation as well as the distribution between different modes of conveyance. By influencing the distances to the downtown facilities as well as to the local facilities, the location of the residence relative to the city centre could, according to the above line of reasoning, be expected to influence both the residentsí travelling distances and their modal choices. A central location of residences could be expected to contribute to shorter average travelling distances and a lower proportion travelled by car. Both would contribute to limiting the use of energy for everyday travelling purposes.

Investigations in a number of towns confirm that those living in the outer parts travel considerably longer by motorized means of transportation, compared to the residents of inner and central parts of the town. The same main pattern has been found in cities as different as Paris (Mogridge 1985a, Fouchier 1998), London (Mogridge, ibid.), New York and Melbourne (Newman and Kenworthy 1989), San Francisco (Schipper *et al.* 1994), Greater Copenhagen (Hartoft-Nielsen 2001, Naess 2002), Greater Oslo (Naess, R□e and Larsen 1995; R□e 1999), ≈rhus (Hartoft-Nielsen, ibid.), Bergen (Duun 1994), Trondheim (Synnes 1990) and Frederikshavn (Naess, 2001).

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[3] Of course, local area density is not the only factor influencing the supply of service facilities. Other factors, among others, the purchasing power of those living or working in the area, will also be important. Nevertheless, other things equal a high density in the local area increases the likelihood of a high number of facilities per area unit.

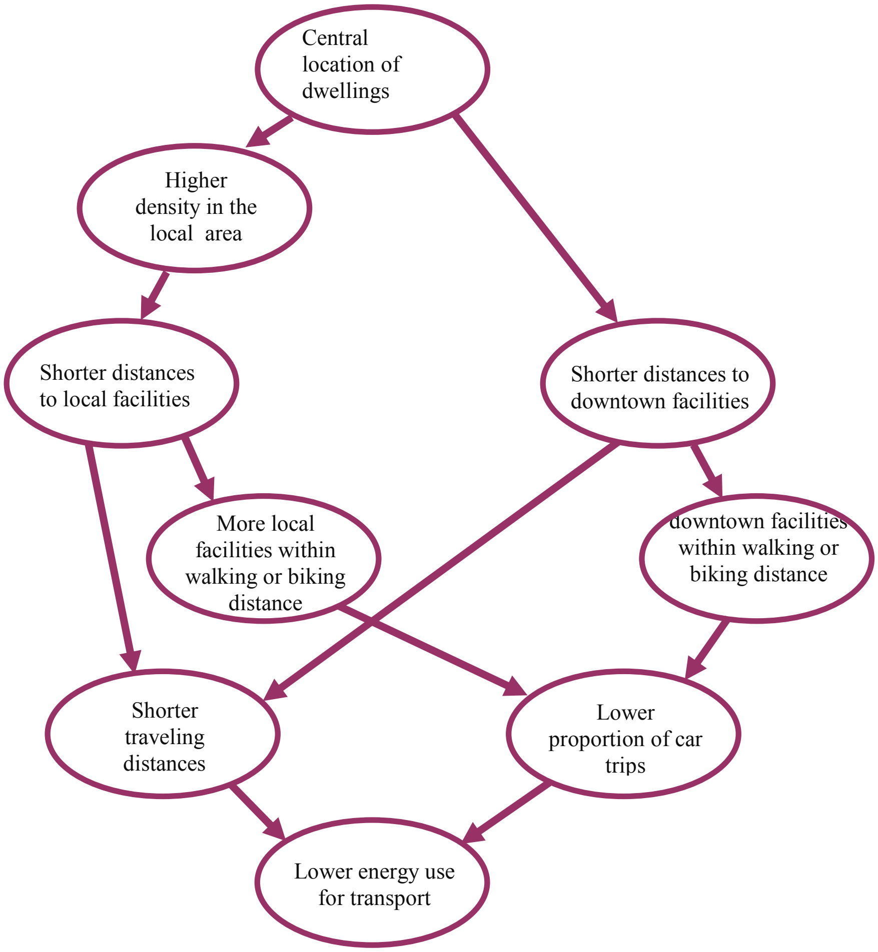


*Figure 5. Schematical illustration of how the location of residences relative to the centre of the city could be expected to influence energy use by affecting the amount of transportation as well as the distribution between different modes of conveyance.*

Admittedly, most of these studies have not controlled for the influence from socio-economic factors. Because, among others, income level, household structure and age of the inhabitants often vary between inner and outer parts of the city, there is a risk that differences in the transportation pattern actually caused by such factors are being explained with differences in the location. However, in a few of the examinations mentioned, socio-economic factors have been controlled for. This includes the investigation of the transportation pattern among households living in different areas within Greater Oslo, (Naess, Røe and Larsen, *ibid*.). As can be seen from the regression line in Figure 6, the correlation between the distance of the dwelling from the city centre and the motorized travelling distance per capita is still present when controlling for income, household composition, car ownership and a number of other potential factors of influence. The central and peripheral residential areas do not differ much regarding the modal split between car and public transport. Thus, the energy use for transportation varies approximately according to the same pattern as the travel distances. Keeping other variables constant, energy use among residents living in the most peripheral of the investigated areas (18 km from downtown Oslo) is on average nearly two and a half times as high as the per capita energy use of residents living in the most central area (1.2 km from downtown).

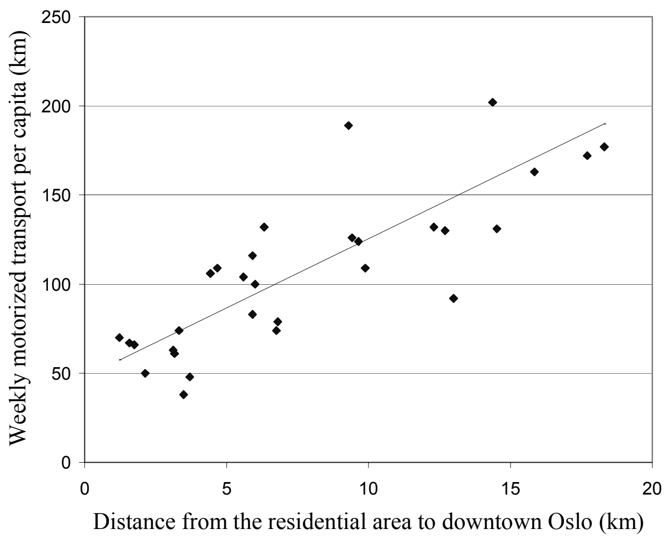


*Figure 6. Average weekly motorized transport within the Greater Oslo region among respondents from residential areas located in different distances from downtown Oslo.*
Official trips not included. The regression line shows the relationship when controlling for a number of demographic, socio-economic and other urban structural factors[4]. Level of significance for the controlled relationship: 0.000. N = 321 households in 30 residential areas. Source: Naess, R□e and Larsen (1995)

**Location of workplaces**

A central location of workplaces could also be expected to contribute to a lower energy use for transport. The accessibility by public transport is usually highest in the central parts of the city. In addition, congestion and scarcity of parking space in downtown areas may cause a number of potential car commuters to leave their car in the garage at home.
Several studies have shown that the number of people travelling to work by car is considerably lower among employees of workplaces in the town centre than among those working at the outskirts of the town (Hanssen 1993, Dasgupta 1994, Naess and Sandberg 1996, Hartoft-Nielsen 1997). Peter Hartoft-Nielsenís research in the Copenhagen area shows that 10-25% of the employees at offices in the inner town travel to work by car, whereas the proportion of car travelling is 70-85% among employees at offices located far from commuter train stations in the outer town areas. The difference in car driving between inner and outer

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[4] Cars per adult household member, number of children in the household, income per household member, average age among household members, proportion of women among adult household members, local area density, provision of local service functions near the residence, public transport provision near the residence.

parts of the city is, however, considerably less in the provincial towns than in the capital area, due to the lower congestion level, more ample parking provision and lower quality of the public transport services in the provincial towns.

Few studies of relationships between workplace location and transportation have also included socio-economic factors in their analyses. This was, however, done in Naess and Sandbergís above-mentioned investigation, focusing on the employeesí journeys to six workplaces in Greater Oslo (cf. Figure 7). The relationship between the distance of the workplaces from downtown and the modal split was still strong when controlling for a number of other factors that may influence the commuting pattern, among others car ownership, sex and income (Naess and Sandberg 1996).

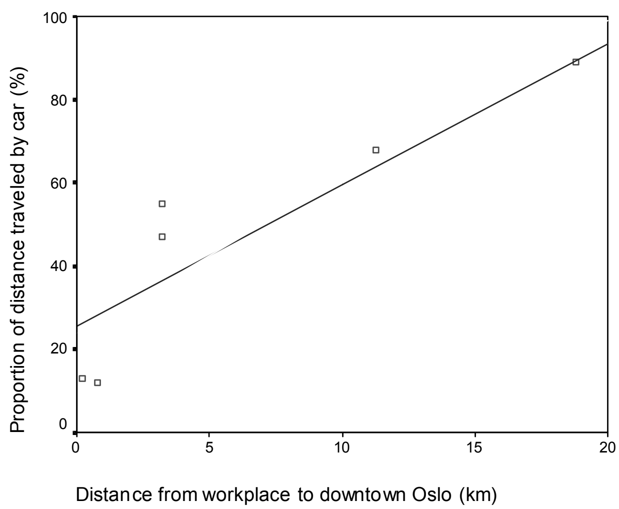


*Figure 7. Average proportions of commuting distance travelled by car among employees at workplaces located in different distances from downtown Oslo. Per cent. N = 465 employees at 6 workplaces.*

The regression line shows the relationship when controlled for a number of demographic and socio-economic factors[5] (with the individual employees as units of analysis, N = 405) Level of significance for the controlled relationship: 0.000. Source: Naess and Sandberg (1996).

Data from Nordic cities do not show any tendency that the employees of workplaces at the outskirts have a shorter average travelling distance to work, as many planners have believed. The investigations made in Oslo, Copenhagen and the Danish provincial towns, as well as a study in Helsinki (Martamo, 1995) rather show a tendency for employees at the outskirts to have somewhat longer travelling distances to work than people working in the inner parts of the city. Together with the strong increase in the proportion of car drivers the farther from downtown the workplace is located, this gives a very clear correlation between workplace location and the employeesí energy use for journeys to work.

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[5] Age, sex, income per household member, cars per adult household member, driverís license, disposing a company-owned car, number of children in the household, occupational grade, proportion of working days when errands were carried out in connection with the commuting trip, number of workforce participants in the household.

Exceptions from the conclusion that a central workplace location gives the least use of energy, are functions clearly directed towards the local neighbourhood ñ for example grocery stores, post offices, elementary schools, secondary schools and kindergartens. For such functions, short distances for pupils and visitors are more important than the employeesí journeys to work. Thus, these sorts of functions will create least traffic if located close to residential areas, for instance in local centres[6].

**Public transport, road system and parking possibilities**

Except for the rush hours, public transport in cities has difficulties in competing with the travel time of cars. In the peak periods, cars lose time on congestion (distinct from transit running on a separate lane), whereas the public transportís more frequent departures make the average waiting periods shorter. Thus, it is primarily for journeys to and from work that public transport is able to compete with cars. For such journeys, measures reducing travel time by car can make some public transport passengers change their means of transport. Conversely, an improvement of the competitiveness of the public transport regarding travel time can make some car travellers leave their cars at home. Theoretical considerations by, among others, Downs (1962), Thomson (1977) and Mogridge (1985b) indicate that increased road capacity in urban areas may turn out to be an inefficient or even counter-productive measure to reduce door-to-door travel times.

Several professionals have claimed, however, that a field of competition between car and public transport hardly exists (cf., among others, Bly, Johnston and Webster (1987), KlÊboe (1994) and Solheim (1994). According to these authors, increased road capacity in urban areas will lead to better-flowing traffic, but it would not influence, to a degree worth mentioning, the distribution between car travellers and public transport passengers.

Recent investigations in the Oslo region, however, clearly show that a field of competition between car and public transport does exist for journeys to work in the rush hours (Engebretsen 1996, Naess, Mogridge and Sandberg 2001). The number of travellers sensitive to changes in travel time of the respective modes seems to be considerable. A number of factors influence the travellersí choice of conveyance, but both the travel time ratio between car and public transport and the parking conditions at the workplace turn out to be important. Figure 8 shows how the likelihood of commuting by car varies with varying ratios of door-to-door travel times by car and transit (Naess, Mogridge and Sandberg, ibid.). The figure applies to male car-owning commuters holding a driverís license, living in the western suburbs of Oslo, working in the downtown area and having easy parking facilities at the workplace. A number of other variables influencing the modal choice were also controlled for. When car and transit were equally fast, the probability of commuting by car was 40 per cent. When car

[6] The influence of the distance from residences to service facilities on traveling distances was demonstrated in the above-mentioned study of residents in Greater Oslo, where a service accessibility index based on the distances to grocery stores, post offices, elementary schools, secondary schools and kindergartens was the second urban form variable (in addition to the distance from residence to downtown) with a significant effect on traveling distances.

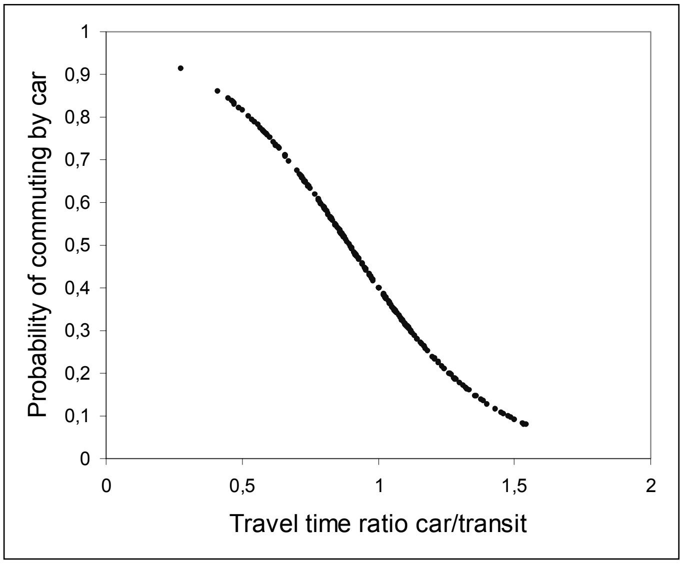


*Figure 8. Probability of commuting by car at varying ratios of door-to-door travel times by car and transit. N=261 commuters living in western suburbs of Oslo and working in the downtown area. The probability levels apply to male respondents holding a driverís license, with a high car-ownership level and good parking conditions at the workplace. The following variables have been kept constant at mean values: income level, education level, age, travel expenses paid by the employer, and errands on the way home from work. Sig. = 0.0000.*
Source: Naess, Sandberg and Mogridge (2001)

was 20 per cent faster than transit, the probability of going by car was 59 per cent. Increased road capacity leading in a short term to better-flowing traffic is therefore likely to change the modal split in favour of the least energy-efficient mode. In a longer term, congestion is likely to occur again (Mogridge, 1997). The low average probability of commuting by car among the respondents must be seen in the light of the fact that the workplaces were all located in the downtown area of Oslo, cf. also Figure 7.

### The case of Frederikshavn: a closer look into the relationship between residential location and travel behaviour

Most previous studies into the relationship between location of dwellings within cities and the residentsí travel behaviour have focused on large and medium-sized cities. Few studies have examined the situation in small towns, although a considerable proportion of the inhabitants of European countries live in settlements with less than 50,000 inhabitants. Frederikshavn, comprising 35,000 inhabitants within the municipality and 26,000 within the continuous built-up area around the municipal centre, belongs to a settlement size where the relationship between land use and transport has hardly been investigated before. The town is located in Northern Jutland in Denmark, about 60 km to the north of the regional centre of Aalborg. Distinct from many larger cities, where multinuclear or hierarchical centre structures are more common, Frederikshavn is a typical monocentric town.

In addition to gaining experience from a small Danish town[7] about the relationship between land use and transport, we also wanted to go beyond the scope of most previous studies and investigate a broader and more detailed range of urban form characteristics, as well as controlling for a higher number of other factors of influence. In particular, we were curious to see whether the relationships found between urban form variables and travel behaviour were altered when the residentsí attitudes and activity preferences were taken into consideration. Some debaters (among others, Kitamura et al., 1997) have hypothesized that the values and attitudes of the inhabitants of different parts of a town, for instance regarding car use, may be different, creating a possible source of error in the research carried out till now.

Seen in a wider energy use and greenhouse gas emissions perspective, an important question arising is whether a modest extent of local transportation will result in extended transportation in other places, as long as the total purchasing power does not change. Is it so ñ given a certain level of income ñ that the sum of "environmental vices" is constant, and that households managing on a small everyday amount of transportation, create even heavier environmental strain through for instance weekend trips to a cottage or long-distance holiday trips by plane? In the professional debate, some parties (e. g. Kennedy, 1995) have claimed that people living in high-density, inner-city areas, to a larger extent than their low-density counterparts, will seek out of town in the weekends, for instance to cottages etc., in order to compensate the lack of access to a private garden. In addition to this ìhypothesis of compensationî others, including the Swedish mobility researcher Vilhelmson (1990), have launched a ìhypothesis of opportunityî implying that the time and money people save due to shorter distances to daily destinations, probably will be utilized by increasing the length of their leisure journeys.

In line with the above, the study in Frederikshavn focused on the following research questions:

- What relationships exist between the urban structural situation of residential areas and the residentsí travel behaviour (amount, modal split and energy use), when taking into consideration demographic, socio-economic as well as attitudinal factors?
- Are the relationships between the urban structural situation of dwelling and the residentsí travel behaviour the same across population groups, or do the location and structure of residential areas influence travel behaviour differently among different subgroups of the population?
- Is the effect of a residential situation where the need for everyday transportation is low, offset by a tendency to compensate this by making more frequent and longer trips during vacations and weekends?
- Does the location of the residence within the urban structure put constraints on the range of activities in which people engage?

## How the study was conducted

The Frederikshavn study included a questionnaire survey as well as qualitative interviews with a limited number of residents. The questionnaire survey was carried out in June 1999 among households living in 11 residential areas, nine in the main urban settlement and two in

[7] A study with a similar methodology has recently been carried out in the Copenhagen metropolitan area, thus covering a considerably larger city size (Naess, 2002).

smaller, peripheral settlements. Our gross sample included all residents within the delimited residential areas. Each household member of at least 15 years old was asked to answer a range of questions about her/his travel activities, as well as about employment and education, leisure interests and shopping preferences, and attitudes to mobility, means of transportation, and environmental issues[8]. For each day during a week, the respondents noted how long they had been travelling by different means of transport. We also asked about the personal income of the respondent. In addition to these questions concerning characteristics of the individual respondent, one person per household was asked to answer a few questions about the household. The focus of these questions was on the householdís vehicles and their driving distances (which were to be registered by noting the mileage at the beginning of the period and again at the end of the period a week later). In addition, we asked about the number of household members, their sex and age, and the total household income.

The questionnaires were quite extensive, with one set per household member and a requirement to record the travelling distances by different modes for each day of the week, as well as the vehicle mileage at two times. The respondents were also asked to differentiate between trips within and outside the municipality, and between private and official trips. Not surprisingly, then, the overall response rate was only 24%. In total, we received completed questionnaires from 381 households and 628 individuals aged 15 or more. Sample characteristics were compared with statistical data for the municipality as a whole as well as for the census zones among which the residential areas were chosen. This comparison shows that our respondents do not differ much from the municipal population in terms of household size, sex, employment or income. Persons over 45 years of age make up a larger part of our sample (63%) than in the municipality (52% of residents over 15 years of age). Our respondents also include a higher proportion of persons with a higher education than in the population at large (on average 12.8 years of education including primary school, compared to 11.2 years among the inhabitants of Frederikshavn). In general, still, the sample must be considered fairly well representative for the inhabitants. Anyway, because the questionnaire included a number of questions about socio-economic as well as attitudinal characteristics of the respondents, a statistical control for the influence of these factors can be made in the analyses of the relationship between the urban structural situation of dwelling and the residentsí travel behaviour.

The qualitative interviews included six households, two of which living close to the city centre and two living in a residential area about 7 kilometres to the west of the downtown area. Each interview lasted for about one hour and a half and was carried out in the home of the interviewees. Except for one household, two adult persons from each household participated in all of the interviews. The persons participating in the qualitative interviews had on average a higher education level than the sample of respondents, thus differing even more from the municipal average. However, they represented a broad variation of occupations, including an assistant social worker, a clerical assistant, a nursing assistant, a trainee teacher, a shipyard workman, two carpenters, two teachers, a chief archivist and a chief secondary school administrator.

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[8] Additive indices for environmental and transport attitudes as well as leisure and shopping prefereces were constructed, based on four, ten and seven questions, resepctively, within each category. For each individual question, respondents were requested to express their attitude to a statement using a five-level Likert scale, ranging from totally agree to totally disagree.

## Results from the study

Below, only a brief summary of the main results of the study will be presented[9]. In accordance with our theoretical considerations, we find that those who live furthest away from the centre of Frederikshavn travel longer distances and have a lower share of non-motorized transport than their inner-city counterparts. Figure 9 shows arithmetic means and median values for total travel distance (to the left) and the proportion of distance travelled by non-motorized modes (to the right), with the investigated areas placed along the horizontal axis according to their distance from the centre of Frederikshavn. In all these averages, respondents without a driverís license and respondents using their car for official trips more than 10 times a month have been excluded.

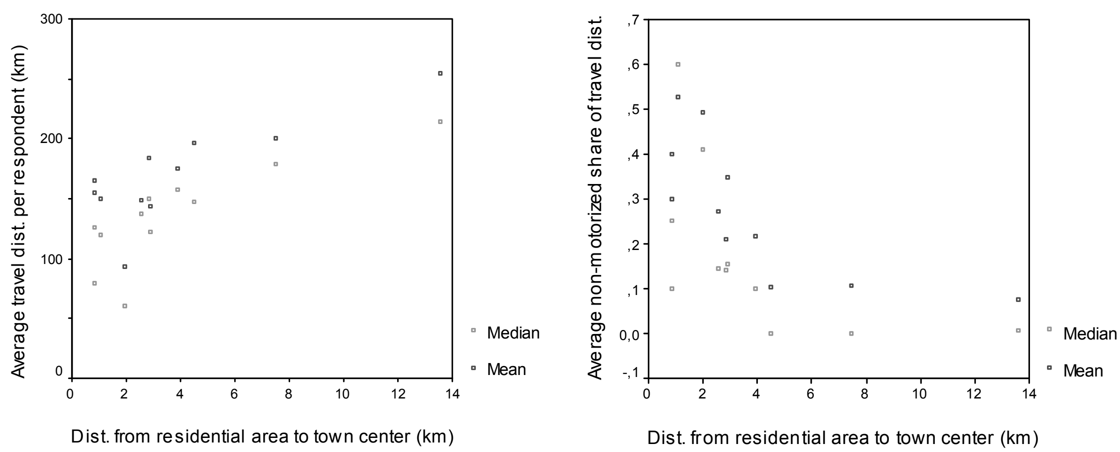


*Figure 9. Mean and median values for total travel distance (to the left) and the proportion of distance travelled by non-motorized modes (to the right) among respondents from residential areas located in varying distances from the centre of Frederikshavn. Respondents without a driverís license and respondents using their car for official trips more than 10 times a month have not been included. N = 11 residential areas including 375 counting respondents, min. 21 and max. 70 in the separate areas.*

As can be seen from Figure 9, the relationship between the distance from the town centre and travel behaviour does not appear to be linear. A curved or S-shaped graph seems to represent the relationship in a better way than a straight line. In the analyses, the distance from the residence to the urban centre has been transformed by means of a hyperbolic tangential function with its turning point at a distance of 3 km from the centre. Such a curve might mirror a situation where the accessibility to relevant facilities decreases from a high level in the central area to a low level in the outer suburbs, where only the most elementary facilities are available, with no further decrease when moving further away from downtown.

Although respondents with outlying travel distances have been excluded, respondents having travelled considerably longer than the average exert a strong influence on the results of the linear regressions analyses. Replacing the ordinary travel distances with the logarithms of the

[9] Readers who are interested in more details, might confer an English-language anthology article (Naess, 2001a), or the full-length, Scandinavian-language study report (Naess and Jensen, 2000).

distances travelled reduces the influence of the longest travel distances, which may to a high extent be a result of accidental circumstances.

Figure 10 shows the relationship between the logarithm[10] of the total distance travelled by the individual respondents during the week and the distance from their dwelling to the centre of Frederikshavn. In this analysis, as well as in the other analyses of factors influencing travel behaviour, the following independent variables were included in the regression: Hyperbolic tangent to the distance from the residence to the centre of Frederikshavn, public transport provision near the residence, sex, age, number of household members below 18 years, number of years of education, employment, whether the respondent is a student, personal income, driver's license, use of car for official trips, responsibility for regular transportation of children, number of days at the workplace or school during the investigated week, attitudes to transportation issues, attitudes to environmental issues, and preferences for leisure activities.

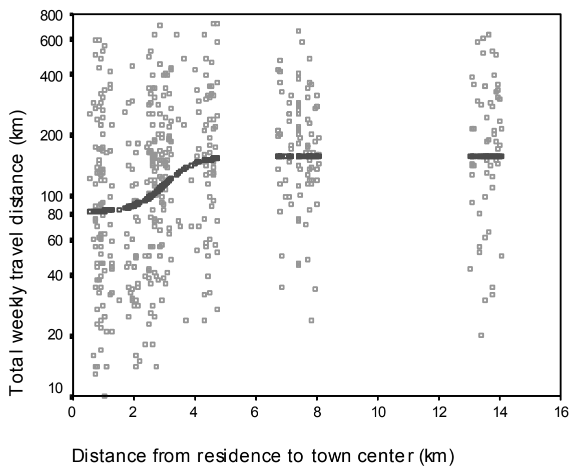


Figure 10. Total weekly travel distance (km) among respondents living at different distances from the centre of Frederikshavn (km).

*N = 453. The regression curve for the controlled relationship[11] between travel distance and the distance between the residence and the town centre is shown in red, based on a regression model where travel distances have been measured in logarithmic values, cf. Table 1. Sig. = 0.000. Ten respondents with travel distances less than 10 km are not shown in the diagram.*

When controlling for the above-mentioned factors, the average weekly travelling distance increases from 84 km in the areas closest to the centre, to 156 km when the distance from the centre exceeds 5 km. Not surprisingly, there is a large variation also among people living in the same distance from the centre. This reflects socio-economic and lifestyle differences, as well as sheer chance, such as the choice of a respondent to visit his aunt in ≈rhus (a city

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[10] Analyses were also carried out with the total travel distance, the distance traveled by car and the energy use for transport measured in ordinary kilometers and kWh as well as by logarithmic values. The absolute differences in travel distances and energy use between central and peripheral areas were slightly smaller when logarithmic values were used. However, the power of explanation of the investigated variables turned out to be higher in the analyses based on logarithmic values.

[11] Controlling for sex, age, number of household members below 18 years, number of years of education, employment, whether the respondent is a student, personal income, driver's license, use of car for official trips, responsibility for regular transportation of children, number of days at the workplace or school during the investigated week, attitudes to transportation issues, attitudes to environmental issues, preferences for leisure activities, and public transport provision near the residence.

located approx. 175 kilometres south of Frederikshavn) during the week of investigation instead of another week. However, the statistical relationship between residential location and travelling distance is very strong.

The distance from the residence to the downtown area is a key factor influencing the accessibility to a number of facility types. The proximity or remoteness of these facilities from the residence has a strong influence on the distances needed to reach daily or weekly destinations. The accessibility to service facilities is very different in the central and the peripheral areas. In addition, our material shows that the commuting distances of the workforce participants are strongly influenced by how far away from the town centre the residence is located.

Of all our investigated variables, the location of the residence relative to the town centre turned out to be the variable with the strongest effect on the weekly distance travelled. In addition, the amount of transport tends to increase if you hold a driverís license, have a preference for leisure activities away from home, belong to a household with a high car ownership, are not much concerned about environmental protection, are a male, and are not a student.

Our material also shows that the respondentsí choice of mode of transportation is affected by the location of the dwelling. Controlling for the same variables as in Figure 10, walking and biking could be expected to account for 38 per cent of the distance travelled by a dweller of the central area of Frederikshavn, as compared to only 15 per cent when the distance to downtown exceeds 5 kilometres[12]. Conversely, the proportion of distance travelled by car is higher among residents of the peripheral areas and lower among downtown dwellers.

Public transport plays a modest role for local transport in Frederikshavn. On average for the respondents, public transport (mainly bus, and in a few cases train) accounts for only 5 per cent of the travelling distance. Within the main urban settlement, distances are short enough, so that the bike most often appears to be a more relevant alternative to the car than going by bus. Thus, none of the urban structural factors, including the public transport provision near the residence, appear to exert any influence worth mentioning on the share of the public transport mode.

Consistent with our findings about the influence of residential location on the total travel distance and the proportion travelled by car, we see a clear effect of the location of the dwelling on energy use for transport. Controlling for the same variables as in Figure 10, energy use was on average 61 kWh per week among residents of the most central area, compared to 98 kWh when the distance to downtown exceeded 5 km.

Not surprisingly, car ownership turned out to influence the distance travelled by car, the modal split between car and other modes, as well as energy use. However, except for the modal split, the effects of this variable were weaker than the effects of the location of the dwelling relative to downtown. It should also be noted that car ownership itself is to some extent influenced by residential location (see below). Therefore, including car ownership as a control variable implies a conservative estimate of the effects of urban structure on travel. Among the attitudinal variables, both the extent of out-of-home leisure interests and environmental attitudes turned out with effects on the weekly travel distance. The less concerned the respondents were about environmental issues and the more their leisure

[12] As mentioned above, respondents with very long trips out of the county have been excluded. If these respondents had been included, the overall shares of walk/bike would have been lower, but the shape of the curve would have remained the same.

interests were directed towards out-of-home activities, the longer they tended to travel during the week. Transport attitudes were found to influence modal split as well as energy use in the expected directions (the more car-oriented attitudes, the higher the share of car travel and the higher the energy use).

With all urban structural variables (including the location of the dwelling relative to the town centre, local area density and variables measuring the accessibility from the residence to various facilities) included in the multivariate analysis, the former was the only urban structural variable showing significant effects on the travel activity variables. Thus, among the urban structural variables, the location of the dwelling relative to downtown proved to be the strongest. However, from theoretical considerations, it seems reasonable to assume that not only the distance to downtown, but also other locational characteristics of the dwelling (such as local area density and accessibility from the dwelling to shopping and other service facilities) might influence travel. However, in Frederikshavn, the latter urban characteristics were found to be closely correlated with the location of the dwelling relative to downtown. This high multicollinearity is probably part of the reason why local area density and variables measuring the accessibility from the residence to various facilities showed no effects on travel when controlling for the location of the dwelling relative to downtown. In order to trace the impacts of these "secondary" urban structural variables, separate analyses were carried out where the accessibility variables, or indices based on groups of such variables, were replacing the location of the dwelling relative to the town centre. With the location of the residence relative to downtown thus removed from the multivariate regression model, the accessibility indices were found to influence the transportation activity variables (except the share of public transport), but the effects were not as strong (Beta values of approx. 0.13) as the effect of location of the dwelling relative to the town centre (Beta = 0.23), and the power of explanation was lower. The same applies to the population density of the residential area (Beta = 0.16) when this variable was included in the regression instead of the location of the dwelling relative to the town centre.

The importance of the location for travel behaviour is confirmed by the qualitative interviews. Two of the families of the central area had previously lived in satellite settlements, 8 and 13 kilometres from the town centre. Asked about the main reason for moving to the town centre, both immediately pointed to the advantage of not having to depend on so much transportation to reach daily activities. One of the interviewees claimed that the family had saved 500 Danish Crowns a month in gasoline expenses when they moved in 1994 to the town centre from Jerup, 13 kilometres to the north. This corresponds to a monthly saving of about 60 Euros.

The location of the residence appears to influence car ownership to some extent. Our statistical analyses show that car ownership is higher in the peripheral than in the central residential areas, also when controlling for a number of the most plausible socio-economic and attitudinal factors that might influence car ownership. It is of course hard to tell whether people adapt their car ownership to the needs of transportation generated by the location of the residence, or choose residence according to the mobility level they have at the outset. However, the qualitative interviews show an example of a household who found it necessary to buy an additional car after having moved to a peripheral neighbourhood from a residence relatively close to the centre, because it became too troublesome to reach daily activities with only one car. In a time-geographical perspective (Hägerstrand, 1970) this implies that the car enabled this household to expand the time available for other activities than commuting the long distance between their peripheral residences and their workplaces.

Judged from the interviews, the location of the dwelling seldom prevents people from engaging in the activities in which they are really interested. At least, this is true for the majority of households who own at least one car. For those without a car, living far from relevant destinations is more troublesome. In particular, this is true if you are not physically fit. A woman of the peripheral area, whose vigour was reduced from disease, had her job at the nearby primary school. Still, she felt that she would be completely ìimprisonedî without her car. This statement reflects a residential location where it is very difficult to go to her desired destinations - except for the workplace - without a car.

The statistical relationships of residential location with total travelling distance, travelling distance by car, the proportions of distance travelled by car and by non-motorized modes, as well as with energy use for transport, are distinct also when splitting our sample into subgroups according to demography, socio-economic status or attitudes. Although the strengths of the relationships may vary, living close to downtown Frederikshavn contributes to less travel and less use of cars among all the investigated groups. The only exception found is among female employees with working-class occupations. Among this group, the travelling patterns appear to be less influenced by urban structural conditions than among the remaining respondents. A possible explanation could be that these women are, to a higher extent than other population groups, compelled to choose among the job opportunities available in the local area. At the same time, this group of women is often without a specialized education, and hence less dependent on finding other types of jobs than those available in the local community. (J□rgensen, 1992.)

We do not find any tendency that households managing on a small everyday amount of transportation create heavier environmental strain through long and polluting leisure trips. Also when controlling for other potential factors of influence, there are no indications that living close to the urban centre contributes to more frequent trips out of the county or a higher number of trips by airplane (significance levels of 0.80 and 0.66, respectively)[13]. On the contrary, there is a slight, but quite uncertain (sig. = 0.27) tendency of residents of the central areas travelling less to non-local destinations.

## Concluding remarks

The studies reviewed in this paper all show that urban structural variables influence the inhabitantsí amount of transport and their choice of means of conveyance. This appears to be true across city sizes. Although most of our examples are from the Nordic countries, the mechanisms through which urban structure affects travel behaviour are likely to be present in a wider European context[14] as well. As one might expect, socio-economic factors and the

[13] However, in the earlier mentioned study of Copenhagen metropolitan area, tendencies were found to more frequent trips to destinations outside the metropolitan area among people living in dense inner-city areas (Naess, 2002).

[14] Probably, this will also be the case at a global scale among cities where the mobility resources of the population are high. In cities where the population has a low access to fast modes of transportation a more decentralized urban structure might still be transport efficient, cf. the "Brotchie Triangle" (Brotchie, 1984). Admittedly, the influence of residential and workplace location relative to downtown is likely to be weaker in

respondentsí attitudes play an important role for the respondentsí travelling patterns. But also when controlling for such factors and a range of other potential explanatory variables, we find clear relationships between urban structural characteristics and travel activity. The location of the residence relative to the city centre is the urban structural characteristic which, according to our studies, exerts the strongest influence on travelling distances, modal split between car and non-motorized transport, and energy use for transport. The distance from the residence to the downtown area is a key factor affecting the accessibility to a number of facility types. The proximity or remoteness of these facilities from the residence has a strong influence on the distances needed to reach daily or weekly destinations.

Controlling for the location of the residence relative to the city centre, local area density does not show statistically significant influences on travel behaviour in any of the reported studies. However, this should not lead us to believe that local area density is unimportant to travel. Firstly, local area density influences the provision of local service. Secondly, local area densities add up to the overall density of the city. The higher the population density of the city as a whole, the lower will be the average distance between the residences and the downtown area. In this way, local area densities indirectly influence the urban structural variable that, according to our studies, exerts the strongest influence on the transportation of individuals and households, namely the location of the residence relative to the city centre.

In addition to the above land use characteristics, a high urban highway capacity affects energy use for transport by increasing the proportion of commuters travelling by car in the peak period. The same applies to ample parking facilities at the workplace.

Based on the studies presented in this paper, the following urban developmental policies could be recommended in order to help reduce the amount of travelling, and increase the share of the less polluting modes of transportation:

- avoid further urban sprawl
- increase the proportion of the population living in the inner and central areas of the city
- increase the proportion of workplaces located in the inner and central areas of the city
- ensure a sufficiently high density in new developmental areas to facilitate a good provision of local service and a good public transport provision
- reduce, or at least refrain from increasing, the road and parking capacity.

Such principles are also very well compatible with energy conservation in buildings, as the building types associated with low-density, suburban residential areas require considerably more energy per inhabitant for heating and cooling than the housing types characteristic of inner-city, medium or high-density living. Since the residential sector accounts for an even higher energy use than the transportation sector, the energy gains for space heating and cooling resulting from a transport-reducing urban developmental strategy should not be forgotten when discussing the possible contribution of urban planning in limiting $CO_2$ emissions. Furthermore, a less area-demanding urban development will contribute to the sustainability objectives of protecting soil for food production as well as natural areas and biodiversity in the surroundings of the city.[15]

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high-mobility cities without any clear CBD, like Phoenix and Houston in the USA. Yet, even in such cities a central location is likely to generate less travel, because of the role of the center as the point of gravity of the housing stock and the stock of workplaces. The average distance to all the other addresses of the city will even in a polycentric city be shorter from a central than from a peripheral location.

[15] See Naess (2001b) for a further discussion.

Seen in the light of current policies pursued in many European countries some people might find the recommendations above unrealistic and even naÔve. In particular, a reduction of urban road and parking capacity is far away from the current agenda of urban policies in most countries. In Denmark, for example, extensive urban motorway construction is underway in the Copenhagen region and some of the larger provincial towns, in spite of official goals of increasing the proportion of travel accounted for by public and non-motorized modes. Based on current transport policies, the emissions from the transportation sector will make up 32% of the internationally agreed limit for the total, national $CO_2$ emissions in Denmark in 2010, compared to 21% in 1997 (Jespersen, 2000:107). Hardly in any sector is the discrepancy between official political goals and the policies actually implemented larger than within the transportation sector. According to Jespersen (ibid.), these prospects could be characterized as follows:

> îOverall it can be observed that a realistic projection of traffic development is not at all realistic ñ business as usual will not be a sustainable strategy as regards traffic development."

If measures necessary for limiting transport-related environmental problems are considered unrealistic, then the reason might perhaps be that sustainable development - understood in the way the concept was used by the UN World Commission on Environment and development, with its emphasis on ecological carrying capacity as well as reducing the gap between developed and developing countries ñ itself is in lack of political support. However, there are indications from several European cities of a gradual change towards more sustainable developmental strategies, in particular as regards land use, but in some cases also concerning transport policy. Forerunners are cities like Freiburg, Stockholm, Zurich and Oslo, where many - albeit not all - of the policies recommended above have actually been implemented. The purpose of the present paper has been to provide planners and urban policy-makers with information about the likely impacts of land use and transport infrastructure changes to the amount of travel and the modal split between different means of transport. In cities where there is political willingness to take the sustainability challenges seriously the urban planning strategies listed above could make an important contribution.

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