BUILT ENVIRONMENT AND ACTIVE TRAVEL BEHAVIOUR OF CHILDREN: RESULTS OF A BAYESIAN BELIEF NETWORK

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ABSTRACT

In this study the participation of children in walking and bicycling activities for all purposes, and the relation with socio-demographic and environmental characteristics is examined. Specifically, a Bayesian belief network is proposed that derives and represents all direct and indirect relationships between the variables. Detailed individual travel data, including all walking and bicycling trips from a random sample of 4293 children in the primary school age category in the Netherlands are investigated. The participation in active travel behaviour has a direct relationship with all trip characteristics such as travel time and distance, and trip purpose. Furthermore active travel behaviour is related to the age of the child and the car possession of the household. The degree of urbanization has a strong direct influence on mode choice and therefore is an important explanatory variable for walking and bicycling of children. All the other environmental characteristics have an indirect influence on travel mode choice; they are directly related to the urban density level.

Keywords: children, physical activity, walking and bicycling, Bayesian belief network

INTRODUCTION

Each day children should accumulate at least 60 minutes of physical activity to provide them with important physical, mental and social health benefits (e.g., Salmon

& Timperio, 2007; World Health Organization, 2009). Despite this, physical activity levels are decreasing among children in countries around the world, due to increasingly common sedentary ways of life (e.g., Godbey, 1997; Thompson, Rehman & Humbert, 2005; World Health Organization, 2009). For example, fewer children walk or cycle to school and excessive time is devoted to watching television, playing computer games and other sedentary activities.

Active transportation modes as walking and bicycling have been suggested as an important source of physical activity for young people (e.g., Babey, Hastert, Huang & Brown, 2009; Handy, Boarnet, Ewing & Killingsworth, 2002; Frank, Kerr, Chapman & Sallis, 2007; McMillan, 2007; Timperio et al., 2006; Tudor-Locke, Ainsworth & Popkin, 2001). It is believed that early physical activity experiences are important factors for influencing adult physical activity (e.g., Sylvia-Bobiak & Caldwell, 2006; Thompson, Rehman & Humbert, 2005). Importantly, when patterns of physical activity and healthy lifestyles are acquired during childhood and adolescence they are more likely to be maintained throughout the life-span. Consequently, improving physical activity levels in young people is imperative for the future health of all populations (Ulfarsson & Shankar, 2008; World Health Organization, 2009).

Increasingly, links are being identified between various elements of the built environment and physical activity such as walking and bicycling (e.g., Brownson, Hoehner, Day, Forsyth & Sallis, 2009; Humpel, Owen & Leslie, 2002; Lenthe van, Brug & Mackenbach, 2005; Owen, Leslie, Salmon & Fotheringham, 2000; Sallis, 2009; Transportation Research Board, 2005). These studies stated that understanding the neighbourhood context is important for developing effective interventions that promote physical activity. Therefore, an objective set by the World Health Organization (2007) is to increase the percentage of communities that have passed urban design plans that facilitate physical activity, and ascertain commitments from local councils or governments to increase the amount of parks and recreational facilities for physical activity.

However, it is concluded that children are still an understudied group, while children are among the most intensive users of the living environment (e.g., Sallis, Cervero, Ascher, Henderson, Kraft, & Kerr, 2006; Schilling, Giles-Corti and Sallis, 2009). In designing and planning the environment their role is often not specifically taken into account. Moreover, studies investigating children specifically focused on walking and cycling to and from school, and did not include walking and bicycling activities for other purposes such as shopping, social contacts and recreational activities (e.g., McMillan, 2007; Timperio, et al, 2006).

The aim of this study is to examine the participation of children in the primary school age category in walking and bicycling activities for all purposes, and the relation with socio-demographic and environmental characteristics. A Bayesian belief network (BN) was used to derive and represent the causal relationships between all variables included. A major advantage of a BN is that the network structure takes direct and indirect relationships between the variables into account (e.g., Keuleers, Wets, Arentze & Timmermans, 2001; Arentze & Timmermans, 2007). After construction of a BN, it may be applied to a particular case. For each or some variables values can be entered into the network as a finding. Subsequently, probabilistic changes in other variables can be predicted and changes under certain conditions can be simulated.

Detailed individual travel data, including all walking and bicycling trips from a random sample of 4293 children in the primary school age category in the Netherlands are investigated. In the Netherlands children in general start primary school at the age of 4 and go to secondary school at the age of 12. The findings may provide urban planners and local government information about how to improve the planning and design of neighbourhoods that contribute to the stimulation of active transportation by children.

DATA

For this study several types of data were used. Firstly, individual travel diary data (Mon-data, Mobility Research Netherlands) collected by the Ministry of Transport, Public Works, and Water Management in 2006 was used. The aim of the MON data is to describe and predict daily mobility of inhabitants of the Netherlands. A random sample of 34,603 households in the Netherlands received a letter explaining the goal of the research, a household questionnaire, travel diaries for each household member for designated days, and a return envelope. In total 53,545 respondents in 23,695 households returned the questionnaires and diaries and provided useful data representing a response rate of 68.4%. For this study, all children, a total of 4293, in the age-category 4-11 years old were selected. Note that for young children parents/caregivers filled out the diaries.

The travel diary included all trips made by a respondent during one day. For each trip, information was collected on mode choice, purpose of the trip, start and end times of the trip, the geographic location where the trip started and ended, and the accompanying persons in the trip. In addition, individual and household socio-demographics such as gender, age, education, and income level were collected. The number of travel diaries filled out by the respondents was equally divided across all days of the year.

Secondly, data on land use at the neighborhood level were derived from Statistics Netherlands (CBS) to describe the built environment. Specifically, for every neighborhood in the Netherlands, percentages of a particular type of land use were calculated:

- Infrastructure (land used for rail, road, and air traffic)
- Agricultural areas (land used for greenhouse farming, land for grass, orchards, and farming)
- Recreation areas (land used for recreational purposes)

- Forests and nature areas (land used for forests, and dry or wet open natural areas)

The degree of urbanization was measured based on the ‘surrounding address density’, which was the average number of addresses per 500 meter square within a kilometer radius from the address. This indicator has been widely used in the Netherlands (e.g., Maas, Verheij, Groenewegen, De Vries & Spreeuwenberg, 2006) and consists of five categories:

- Very strongly urbanized (surrounding address density of 2500 and over per km^2)
- Strongly urbanized (surrounding address density between 1500 and 2500 per km^2)
- Moderately urbanized (surrounding address density between 1000 and 1500 per km^2)
- Little urbanized (surrounding address density between 500 and 1000 per km^2)
- Not urbanized (surrounding address density below 500 per km^2)

Furthermore, to describe the facilities available in a particular neighborhood an index with four categories was used:

- Level 1: All basic facilities, such as a shop, a general practitioner, a primary school and some other facilities such as a library, social-cultural centre, and sporting facilities are available.
- Level 2: One or two basic facilities are available in the area and one or more other facilities
- Level 3: There is one basic facility available in the area, or none, and in this latter case there is only one, or more other facilities available
- Level 4: There are no facilities available in the neighborhood

Specifically, the postal code (with four digits) served as the variable to fuse the various types of data. On average 4070 residents from on average 1765 households live in a four digit postal code area. If there were more postal codes in a neighborhood, the postal code with the largest number of addresses was taken.

METHODOLOGY

A Bayesian belief network (BN) was used to formulate and estimate the direct and indirect relations between the variables (see previous paragraph) (Arentze & Timmermans, 2009; Heckerman, Mandani & Wellman, 1995; Pearl, 1988). Formally, a BN is a directed acyclic graph were nodes are used for each variable, and the causal or temporal relations between the variables are represented by arcs. If there is an arc from node A to node B, then node A is called the parent and note B the child. For each node a conditional probability table (CP table) is provided, which expresses the probabilities for that variable, conditioned on the values of its parents nodes (if any). The CP tables are referred to as the parameters of the network.

After construction of a BN, it may be applied to a particular case. For each or some variables values can be entered into the nodes as a finding. Subsequently, probabilistic changes in other variables can be predicted and changes under certain conditions can be simulated. Every time new findings are entered into the network the parameters of all nodes can be updated based on probabilistic reasoning methods that are based on the Bayesian method of belief updating.

Estimating a BN from data involves firstly learning the network structure and secondly finding the parameters (CP tables). The BN-learning is based on the three-phase dependency method that develops the network based on tests of conditional independencies between pairs of nodes (Cheng, Bell & Liu, 2002). For the second step in estimating a BN, parameters (CP tables) are estimated based on the same data set using the EM-learning algorithm (Lauritzen, 1995). This algorithm uses maximum likelihood estimation of condition probabilities to deal adequately with possible missing data.

Both network structure and parameter learning is supported by the software PowerConstructor (Cheng, Bell & Liu, 2002; the software is freely available on the internet). The resulting network was visualized and compiled by using the software program Netica (Norsys Software Corp., 2006).

RESULTS

Profile of respondents

The profile of the respondents is presented in Table 1. The results show that slightly more boys than girls participated in the study. They are almost equally divided over the age categories from 4 to 11. Most of them, over 96%, own a bike.
The households the children are a member of are equally divided over the three levels, in a range from low to high, that indicate the socioeconomic status of the household. Most of the households, 51 %, possess one car, while 44% own two or more cars, and 5% of the households do not have a car. Finally, most children live in a four person household, while 14% is from a two or three persons household, almost 26% of the households has 5 members, while 9% consists of six or more persons.

Table I – Sample characteristics (*N*=4293)

Variables	*Levels*	*%*
Gender	Male	50.9
	Female	49.1
Age	4 + 5 years	25.9
	6 + 7 years	26.3
	8 + 9 years	23.7
	10 + 11 years	24.0
Bike owner	No	3.9
	Yes	96.1
Household, socio-economic status	Low	30.8
	Middle	33.8
	High	35.4
Household, size	2 + 3 persons	13.5
	4 persons	51.5
	5 persons	25.9
	6 or more persons	9.0
Household, car possession	No car	4.7
	1 car	50.7
	2 or more cars	44.6

Travel behaviour

Descriptive results in Table 2 indicate that the children made 15743 trips during the 4293 days (each child filled out a one-day dairy) and participated in 8649 out-of-home activities. Most of the trips, 36%, were made by bike, followed by 35% of the trips made as a passenger in a car, and 27% involved walking. Public transport accounts for only a marginal share (.9%) of the trips, and in 1.3% of the trips other transportation modes were used.

Table 2 – Trip travel modes and travel time

Travel modes	*Average travel time per trip (minutes)*	*Standard deviation*	*Number of trips (4293days)*	*Average travel time per day (minutes)*	*Average number of trips per day*
Car passenger	15.45	17.20	5515 (35.0%)	19.84	1.28
Public Transport	43.40	28.89	139 (.9%)	1.41	.003
Biking	9.53	8.73	5588 (35.5%)	12.41	1.30
Walking	8.18	10.41	4295 (27.3%)	8.18	1.00
Other	33.91	35.29	206 (1.3%)	1.63	0.05
Total	11.85	14.46	15743	43.46	3.67

(*N*=4293)

Table 3 – Trip travel modes and travel distance

Travel modes	*Average travel distance per trip (kilometres)*	*Standard deviation*
Car passenger	10.28	21.00
Public Transport	16.11	21.86
Biking	1.72	1.72
Walking	.59	.71
Other	13.40	19.21
Total	4.69	13.62

(N=4293)

The travel time for the bicycle trips was on average almost 10 minutes and for the walking trips over 8 minutes. The average travel time per trip shows that specifically the trips made by public transport take some time. This is also indicated by the travel distance per mode presented in Table 3. The travel distance for a trip by public transport is on average 16 kilometres, while the distance travelled by car is on average 10 kilometres. The results also show that specifically walking involves small travel distance, on average 600 meters per trip, while the distance travelled by bike is on average 1720 meters. This indicates that most of the activities the children participated in took place in their direct living environment.

Looking at the travel time per day, the results show that the children on average spend well over 43 minutes per day on travelling. The total time spend on walking and biking per day is 21 minutes, while they spend almost 20 minutes per day in a car.

Table 4 – Trip travel modes and trip purpose

Purposes / *Travel modes*	*Education (%)*	*Shopping (%)*	*Bring get act (%)*	*Social contacts (%)*	*Sport club act. (%)*	*Gen LA (%)*	*Touring walking (%)*	*Service related act.*
Car passenger	18.8	59.9	69.7	52.0	53.6	47.7	25.0	64.7
Public Transport	.8	1.0	.4	.5	.4	1.6	1.6	2.9
Biking	45.0	26.0	24.1	24.2	38.3	25.0	23.7	22.5
Walking	33.7	12.7	5.5	22.4	7.1	23.6	47.8	9.8
Other	1.6	.4	.4	.9	.6	2.1	1.8	0
	100	100	100	100	100	100	100	100
Number of trips	7575	1358	568	2392	1281	1000	1365	204
% of Total	48.1	8.6	3.6	15.2	8.1	6.4	8.7	1.3

(N=4293)

Table 4 presents the main reasons mentioned for making the trips. By far most trips are education related (48%), followed by social contacts (15%), touring/walking (9%), shopping (9%), and sport/club activities (8%). The respondents use their bike significantly more for travel to school, and also for sport and club activities. Walking is an important transport mode for school trips, and, not surprisingly, for touring/walking activities. The children tend to travel as a car passenger significantly more for shopping trips, bringing/getting, and service related activities.

Bayesian belief network

Table 5 presents the variables that are included in the BN model analysis. By setting a threshold the number of links in the network can be controlled: a lower threshold results in more links and a higher one in less links (Keuleers et al, 2001). The threshold for establishing links between the variables was set at the standard norm of 1.0. The database is taken as input and the belief network structure is constructed as output. Network learning algorithms require that all variables used in the analysis have discrete values. For the categories defined per variable see also Table 5.

Table 5 – Variables used in the Bayesian network model analysis

Variable	*Label*	*Categories*
Person, age	P_age	1=4+5 years, 2=6+7 years, 3=8+9 years, 4=10+11 years
Person, gender	P_gen	1=male, 2=female
Person, bike owner	P_bike	0=no, 1=yes
Household, car possession	H_car	0=no car, 1=one car, 2=two or more cars
Household, size	H_size	1=2-3 persons, 2=4 persons, 3=5 persons, 4=6 or more persons
Household, socio-economic status	H_sec	1=low, 2=middle, 3=high
Activity, type	A_type	1=education, 2=shopping, 3=bringing/getting activities, 4=social contacts, 5=sport_club activities, 6=general leisure activities, 7=touring/walking, 9=service related activities
Activity, duration	A_dur	1=≤15 min., 2=15≤30 min., 3=30≤60 min., 4=1≤2 hrs, 5=2≤3 hrs, 6=3≤4 hrs, 7=>4 hrs
Travel mode	T_mod	1=car passenger, 2=public transport, 3=biking, 4=walking, 5=other
Travel distance	T_dis	1=≤0.5km, 2=0.5≤1km, 3=1.0≤2.5km, 4=2.5≤5km, 5=5.0≤10km,6=>10km
Travel time	T_time	1=≤5 min., 2=5≤10 min., 3=10≤15 min., 4=15≤30 min., 5=>30 min.
Travel day	T_day	1=weekend, 2=weekday
Neighborhood, urban density	N_urbden	1=very strongly urb., 2=strongly urb., 3=moderately urb., 4=little urb., 5=not urb.
Neighborhood, facilities available	N_fac	1=all basic fac. and some other, 2=one or two basic fac. and some other, 3=one or less basic fac. and one/some other, 4=no fac. available
Neighborhood, agricultural areas	N_agri	1=very low%, 2=low%, 3=middle%, 4=high%, 5=very high%
Neighborhood, nature areas	N_nat	1=very low%, 2=low%, 3=middle%, 4=high%, 5=very high%
Neighborhood, recreation areas	N_recr	1=very low%, 2=low%, 3=middle%, 4=high%, 5=very high%
Neighborhood, infrastructure	N_infr	1=very low%, 2=low%, 3=middle%, 4=high%, 5=very high%

The resulting network is presented in Figure 1. The bar diagrams at each node show the probability distribution across the categories of the variables. The arrows represent the causal relationships between two variables. First of all it can be noticed that all variables except gender are included in the network model. This shows that gender has no relation with the participation in active travel behavior and with all the other variables included in the analysis.

The resulting BN shows that travel behaviour has a direct relationship with all trip characteristics such as travel time, distance, and day, and activity purpose and duration. Furthermore active travel behaviour is related to the age of the child and the car possession of the household. The degree of urbanization also has a direct influence on mode choice and therefore is an explanatory variable for walking and bicycling activities of children. All the other environmental characteristics and the level of facilities do not have a direct influence on travel mode choice; however, they directly influence the urban density level.

The model can be used to predict the effect of one variable on one or more other variables in the network. Specific data for one variable can be entered as evidence in the network structure and next the probabilities of the other variables can be updated. For an example see Figures 2 and 3. In Figure 2 a very strongly urbanized density level is entered while in Figure 3 for a not urbanized density level is chosen. Subsequently, the probabilities of the other variables in the network can be updated. Specifically, Table 6 shows the probabilities for the travel modes for all urban density levels. Then, the travel mode choices can be compared based on the various levels. The results show that children tend to walk more in strongly urbanized neighbourhoods compared to little urbanized neighbourhoods. In contrast, children tend to bike more often in less urbanized neighbourhoods compared to strongly urbanized neighbourhoods. Furthermore, children travel more frequently by public transport in very strongly urbanized neighbourhoods. The probability that children travel as a car passenger is not related to the urban density level.

Table 6 – Updated probabilities for trip travel modes based on urban density level

	Neighbourhood, urban density level					
Travel modes	*no evidence*	*very strongly urbanized*	*Strongly urbanized*	*Moderately urbanized*	*Little. urbanized*	*Not urbanized*
Car passenger	20.1	20.1	20.0	20.1	19.7	20.1
Public Transport	17.1	18.4	17.0	17.2	17.1	17.1
Biking	23.7	21.1	23.5	23.8	24.3	23.7
Walking	21.9	21.9	22.4	21.6	21.7	21.9
Other	17.2	18.4	17.1	17.3	17.3	17.2

The relations between the other variables and travel mode indicate that when the age of a child increases the more often (s)he walks or uses a bike as transport mode instead of travelling by car. As households own two or more cars they more often use their car for taking their child to an activity than when they own one or less cars. The relations between travel time and travel distance with travel mode show similar results. Within a distance of 500 meters from their home or 5 minutes travelling the children typically tend to walk. For distances between 500-2500 meters or a travel time in between 5 to 15 minutes they are more likely to use their bike. For longer distances with a longer duration they tend to travel as car passengers. However, also for the smaller distances there is still a significant amount of children that travel by car. Furthermore, children are significantly more active during weekdays; they are more likely to participate in active travel behaviour by walking or biking. In the weekend they travel more by public transport or as a passenger in a car.

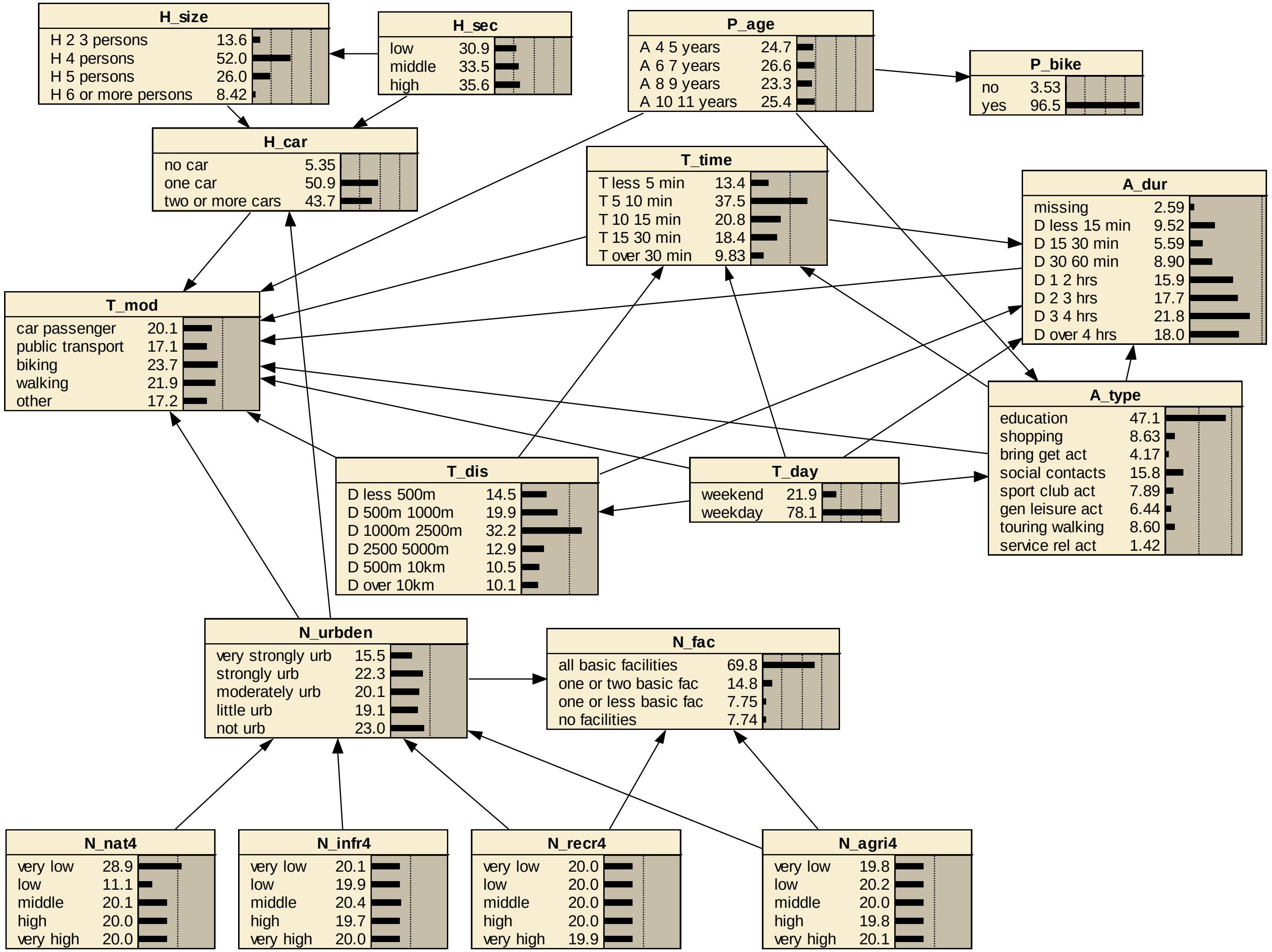

Figure 1 – The Bayesian belief network model

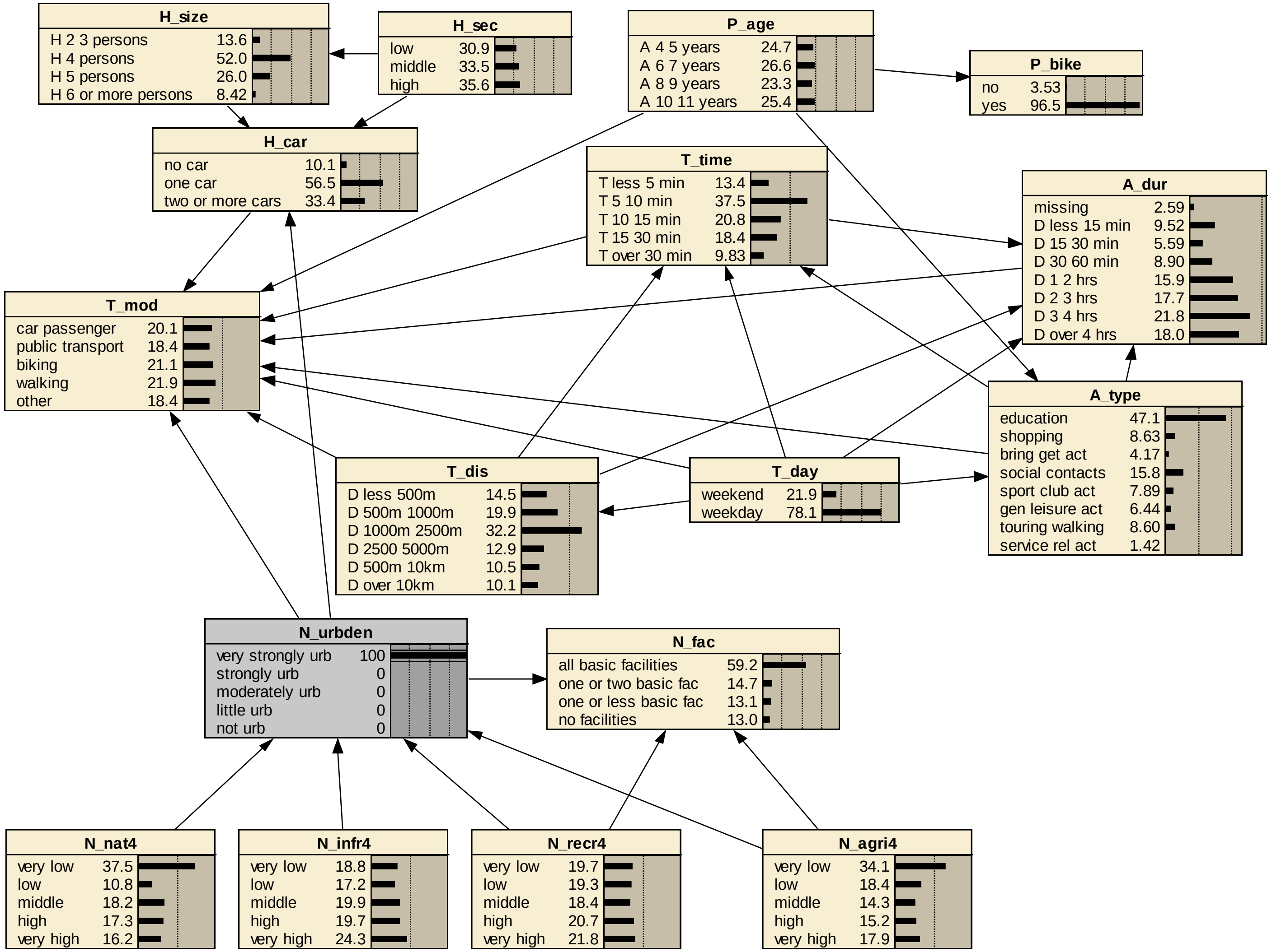

Figure 2 – Illustration of the network after entering the evidence of a case (very strongly urbanized density level)

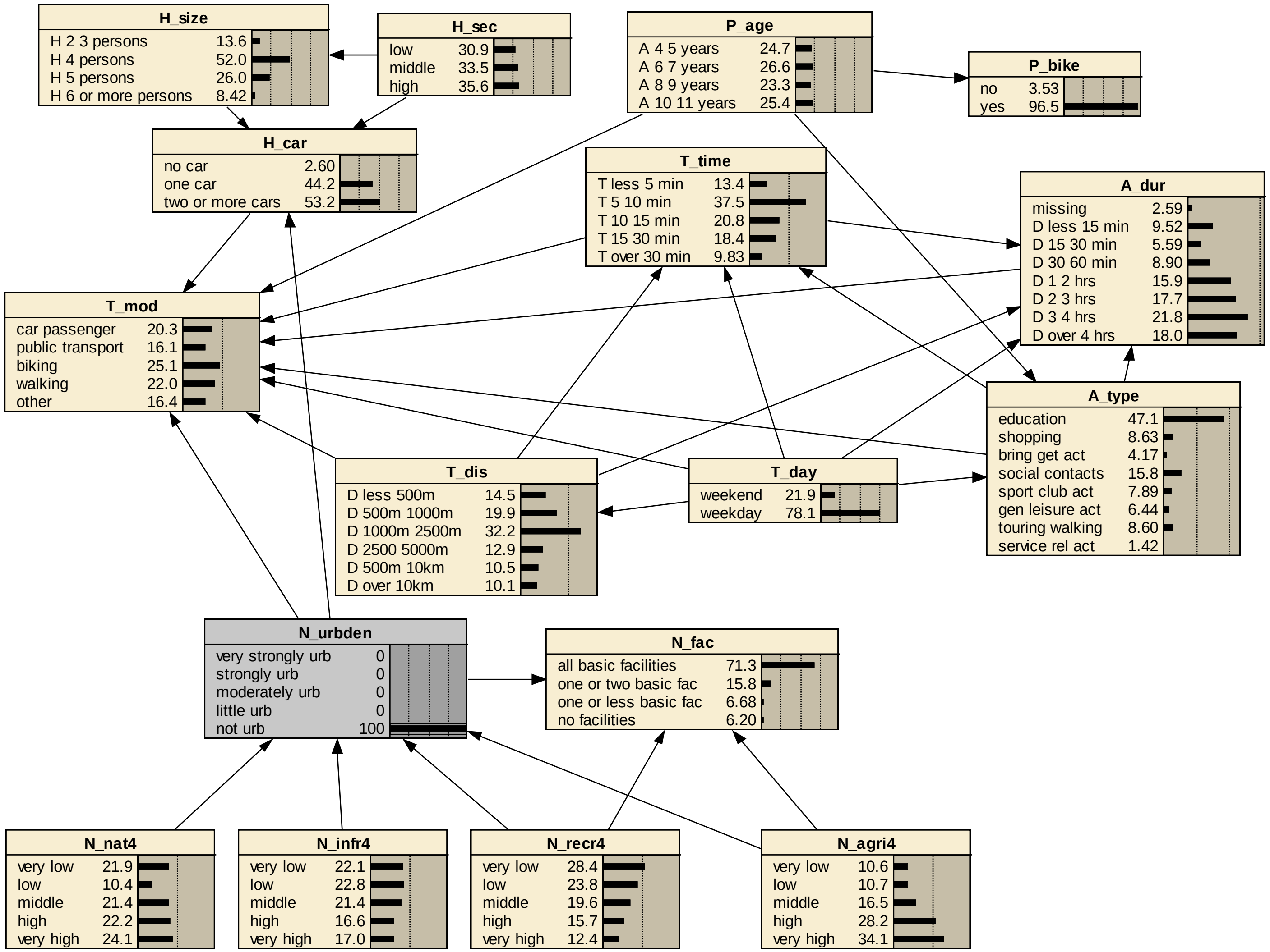

Figure 3 – Illustration of the network after entering the evidence of a case (not urbanized density level)

CONCLUSION AND DISCUSSION

In this study the relation between the participation in active travel behavior by children, individual and household socio-demographics, and objective measurements of the built environment was explored. Specifically, a Bayesian belief network (BN) was derived that represents the direct and indirect relationships between all these variables.

On average, children in the Netherlands spend over 20 minutes per day on active transportation, specifically for school trips, but also for sport, club and touring activities. This is one third of the recommended 60 minutes of physical activity per day (WHO, 2009). Of course, there are also other possibilities for children to be physically active such as physical education in school (e.g., Haug, Torsheim, Sallis & Samdal, 2008) and recreational activities such as playing outside, and sport activities (e.g., Sener, Copperman, Pendyala & Bhat, 2008). In future research, it might be interesting to see whether these types of physical activity complement or substitute each other.

Specifically for trips in the neighbourhood, walking and biking are popular transport modes. However, still over 17% of the trips within 1000 meters from a child's home are spend in a car as passenger. This might, for example, include a trip to school with a parent bringing his/her child by car to school and then continue the trip to work. However, these trips are of interest when promoting participation in active transportation, because these small trips are just right for walking and cycling for most children, also taking into account that almost all children own a bike.

Furthermore, the network showed that participation in the active transport modes walking and biking by children is directly influenced by the trip characteristics, travel time, distance, and day and activity purpose and duration. Related to trip purpose it was found that almost 79% of the trips from and to school are made by active transportation modes, 45% of the trips by bike and 34 % involve walking. This percentage is, compared to results from other countries, very high. For example, Sirard, Ainsworth, McIver and Pate (2005) found that only 5% of the children form eight randomly selected elementary schools in Columbia, SC, USA, actively commuted to or from schools across all observed trips. Other aspects influencing participation in active travel behavior are the age of the child and the car possession of the household.

Also the degree of urbanization has a direct influence on children's travel mode choices. Higher urban density levels have a positive effect on walking. In contrast, lower urban density levels are positively related to bicycling. Urban density is not significantly related to the number of trips a child travels as a car passenger. This indicates the importance that research should distinguish between walking and bicycling as separate transport modes and not for example focus on motorized/fast versus non-motorized/slow transport modes.

Finally, the results show that the objective environmental characteristics of the neighbourhood and the number of facilities available are indirectly related to active travel behaviour of children through the urban density level of the neighbourhood. A higher number of facilities promotes bicycling, just as a higher amount of agricultural and nature areas, and a lower amount of recreation areas and infrastructure. This latter finding might also be related to safety; a neighbourhood with a low infrastructure level might be perceived as safer and therefore might promote participation in bicycling trips.

That leads to the limitations of this study. First, the importance of safety and security, which might be important for children is not taken into account (e.g., Timperio et al., 2004). Also other aspects, such as detailed urban design features, which might affect participation in walking and bicycling, were not included in the study. However, in the Netherlands, compared to other countries, facilities for walking and cycling are quite convenient and safe (e.g., Pucher & Dijkstra, 2003; Susilo & Maat, 2007). It might be of interest to compare children's participation in active transport modes across countries.

It can be concluded that in planning and designing neighborhoods children should be given more attention. It is important that planners and designers find a good mix between various land uses as this might improve the planning and design of neighborhoods that contribute to the stimulation of active travel behavior of children. Furthermore, a combination of planning interventions with informational approaches such as a program to promote the health benefits of walking and cycling or behavioral and social approaches might be recommended.

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