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Exploring the relationship between the built environment, trip chain complexity, and auto mode choice, applying a large national data set

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ABSTRACT

In the completion of transport-based activities, some people save time by chaining trips with different purposes. Several studies have found that trip chaining encourages car use, while others find that features of the built environment can enable complex trip chains without the use of the car. Relatively few studies have presented analyses of trip chains and mode choice that also include built environment variables, although it is well established that urban density and urban structure influence on the transport mode distribution.

In this paper we explore the relationship between the built environment, trip chaining, and auto mode choice in Norway. We apply national travel survey data, deriving commuting and non-commuting home-to-home trip chains, terming trip chains with more than two legs "complex". We add built-environment measures, including the density of inhabitants plus employments, and their balance, the number of public parking lots and transit stops/stations, as well as the distance to the nearest urban centre. We run models splitting the travel survey data into two subsets, one more urban and the other more rural.

We find that higher minimum density at destinations is consistently associated with lower odds of a complex trip chain and of auto mode choice. Longer distance from the residence to the nearest centre increases the odds of car use, and reduces the odds of a complex trip chain. The association with other built-environment characteristics depends on area type and whether it is commuting or not. A higher maximum distance from a destination to an urban centre increases the odds of a complex trip chain and auto mode choice in the more urban subset of the data, but in the more rural subset of the data such association is only found for commuting trip chains. The job-population balance in the home area shows negative association with auto mode choice; and in the more urban subset also a negative association with complex commuting trip chains. The more urban subset comprised municipalities with registered numbers of public parking lots; a higher minimum parking lot number at destinations in the trip chain was associated with lower odds of a complex trip chain, as well as higher odds of choosing the car as the main mode in non-commuting trip chains.

1. Introduction

Governments around the world are developing policies aiming at a shift from car-based transport to public transport or active transport, as a main premise for improving urban sustainability (Banister, 2008). In Norway, "urban growth agreements" provide governmental financial support for development of urban transport systems, given that the local authorities – through their planning – achieve the national target that all growth in urban transport over the 12-year period 2018–2029 is to be undertaken by public transport, cycling, and walking (Ministry of Transport, 2017).[1] In practice (due to population growth) the focus is on reduction of the car share on single trips. One feature of individuals' transport behaviour, however, is to chain trips with different purposes, saving time in carrying out daily activities (Strathman et al., 1994). Various studies have found that trip chaining encourages car use (Strathman et al., 1994; Hensher and Reyes, 2000; Ye et al., 2007); although other studies have conditioned such findings, indicating that non-commuting trip chains by public transport can be just as complex (Primerano et al., 2008; Currie and Delbosc, 2011). In our opinion, the national strategy for reducing car use in cities requires knowledge of how individual trips are included in travel chains related to people's daily activities.

A dense urban structure has been associated with lower odds of choosing the car, when analysing separate trips (Ewing and Cervero, 2001; Cervero, 2002; Zhang, 2004; Etminani-Gahsrodashti and Ardeshiri, 2016). Næss (2012) has given an overview and a theoretical discussion of a selection of research on urban density and transport in the Nordic countries, where the single trip has been the prevalent unit of research. Higher levels of trip chaining have also been found in more dense areas (Maat and Timmermans, 2006; Cheng et al., 2016), while Frank et al. (2008) found a negative association between land-use mix and trip chain complexity. Primerano et al. (2008) related

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[1] To support the strategy, the agreements require concentrated urban development and high density around public transport hubs outside the central urban areas.

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the facilitation of trip chaining by public transport to clustering of activities and services at destinations, but did not test for this conjecture. Vande Walle and Steenberghen (2006) pointed out that the lack of public transport on legs in a trip chain would render it an irrelevant option. Availability of parking lots at work, on the other hand, facilitates the use of car for commuting (Christiansen et al., 2017). Lower accessibility to activities and locations, measured as an increasing distance from the residence to centre zones, have been found to increase the likelihood of auto ownership (Gao et al., 2008; Cao et al., 2019) and auto mode choice (Chen et al., 2008; Van Acker and Witlox, 2010; Engebretsen et al., 2018). If density (of residents plus jobs) and other built environment features impacts on transport behaviour, then one question is whether we will find similar patterns in trip-chain samples from areas that differ considerably in relative density and other features.

To our knowledge, relatively few studies have investigated the association between trip-chaining behaviour and the built environment (Ma et al., 2014; Bautista-Hernández, 2020). Analysing trip chains, or tours, instead of single trips, is more consistent with a household activity-based approach to travel demand (Axhausen and Gärling, 1992; Bhat and Koppelman, 1999; Vande Walle and Steenberghen, 2006). Analysing home-to-home trip chains, or “tours”, take into account that, e.g., transport mode choice in one leg is conditioned by transport mode in a former leg of the chain. Another important distinction is commuting versus non-commuting tours that may show different patterns (Strathman et al., 1994). Trip chaining and transport mode choice in commuting might be considered more urgent in policy-making (Santos et al., 2010; Engebretsen et al., 2018). However, non-commuting tours are also numerous; and what frames individuals' transport choices in commuting may possibly have an impact on non-commuting transport behaviour.

Transport behaviour will also vary with respect to individual and household characteristics. Several studies have found that females chain trips more than males (McGuckin and Murakami, 1999; Vågane, 2012; Ma et al., 2014), while larger household size has been associated with less chaining (Maat and Timmermans, 2006; Ye et al., 2007). Children in the household have been associated with more trip chaining as well as higher probability of choosing the auto mode (Strathman et al., 1994; Hensher and Reyes, 2000). Number of vehicles in the household has been positively associated with both trip chaining and auto mode choice (Ma and Goulias, 1999; Golob, 2000).

In our study, we explore the relationships between the built environment, trip complexity, and auto mode choice, distinguishing between commuting and non-commuting trip chains. We control for various individual/household characteristics. The modelling is based on Norwegian travel survey data, geocoded, with attached built environment data at the 250 m statistical grid unit. The data set was split into two parts and analysed separately, one more urban subset and the other more rural. The attached geographical variables comprise a density variable, measured as the number of inhabitants plus employments, a derived job-population balance, and registered public car parking lots and transit stops. We also include the minimum straight-line distances to the nearest centre zone. We estimate binary logit models for trip chaining and for auto mode choice, in home-to-home trip chains. To our knowledge, this is the first study attaching public register data on public parking and transit stops/stations to travel survey data in such analyses of commuting and non-commuting tours.

2. Material and method

2.1. Trip chains based on trips from national travel survey data

The Norwegian National Travel Survey (NTS) 2013/14 constitutes a sample of >60,000 residents in Norway, aged from 13 and above, interviewed by telephone (Hjorthol et al., 2014). Each respondent filled in a one-day trip diary, where each trip was initiated for fulfilling a purpose on an address different from the current. In this study we include the adult population, yielding a sample of 57,405 persons aged 18 or more, of whom 51,770 (90%) reported at least one trip carried out on the assigned registration date.

NTS 2013/14 comprises nearly 200,000 trip registrations over a 12 month period, of which 151,300 trips were part of home-to-home trip chains of two or more legs completed within the 24 hour time frame. Excluding the trips that were part of trip chains with duration beyond the one-day limit, will concentrate the study sample to the most typical everyday travel activities. The daily trips in the NTS can be coded as adjoining parts (legs) of trip chains. Following the principal definition of home based tours, such that home is the starting point of the first trip and the ending point of the last trip in the chain, yields 57,079 home-to-home trip chains with auto, transit, cycle, or walking as the main transport modes. Single-stop tours (two legs only) are classified as simple, while multi-stop tours (three legs or more) are classified as complex (Strathman et al., 1994; Shiftan, 1998).

A main mode of transport is defined for each trip in the NTS. If more than one transport mode is used, the main mode is defined as the one covering the largest part of the trip distance (Hjorthol et al., 2014). If main modes on trips cover equal distances, priority ordering is applied (Ye et al., 2007); auto mode first, then transit before bicycling and walking. The transport mode “car on ferry” was defined as auto mode. Some very minor categories were dropped from analysis, comprising air transport, MC/moped, and the category “other mode of transport”, together with a small number of trip chains involving abroad legs. These exclusions amount to about 1% of the total home-based tours.

Trip purpose is registered for each trip in the NTS. In the literature it is generally distinguished between tours that involve mandatory activities, work or school, and tours that do not include work or school trips (Strathman et al., 1994; Stopher et al., 1996; Currie and Delbosc, 2011). Thus, the trip chains based on the NTS are also differentiated with respect to commuting tours (comprising both work and school) and non-commuting tours (flexible and/or optional activities). Most commuting tours as well as non-commuting tours were simple, respectively about 62% and about 77%.

Several individual/household characteristics are included in the travel survey data. Age categories of household members are split into four categories: preschool (0–6 yrs), primary school (7–12 yrs), teenage (13–17 yrs), and adults. Number of vehicles in the household is also included in the NTS. The home addresses of the NTS respondents as well as the registered trip destinations are geocoded.

2.2. The built environment

A basic built environment variable is the density of inhabitants plus employments, which is made available at the 250 m statistical grid unit by Statistics Norway (Strand and Bloch, 2009). We use “inhabitants” interchangeably with “residents” and “population”, meaning the number of people with principal home address in a specified area (the 250 m statistical grid unit). We also apply “employments” and “jobs” interchangeably, meaning the number of people working in firms/institutions (private or public) with street address in the specified area.

The balance of the number of jobs and the number of residents can be derived from the two inputs to the density variable, applying the following formulae (Ewing et al., 2011):

$$\text{Job} - \text{population index} = 1 \text{-} \frac{(|employment - a \times population|)}{(employment + a \times population)}$$

The constant, a, in the numerator and denominator, will determine how the index behaves. If a is equal to one, the index will be equal to one if the number of jobs in the area is equal to the number of inhabitants. The index would equal zero if the area is purely residential or purely industrial/business. Ewing et al. (2011) set a to the overall relationship between number of inhabitants and number of employments in the geographical area under investigation, which yielded $a = 0.2$ in their study, while Akar et al. (2016) applied $a = 0.5$ and Chen and Akar (2017) $a = 0.7$. When applying national data, with large variation, we opt for the unambiguous $a = 1$.[2]

We include a public parking lot measure from a recently-established national registry, as well as coordinates for transit stops/stations from another

[2] In the NTS-based area of Norway, the number of jobs is about half the number of inhabitants, that would imply $a = 0.5$; thus we test for $a = 0.5$ in addition to $a = 1$.

recently-established national registry.[3] The registry of public parking is currently only implemented in the more urban municipalities of Norway.

In a trip chain, built environment characteristics can be highly correlated across destinations, possibly also including the home area. As these characteristics may affect travel behaviour differently on the origin/home and on the destinations (Ewing and Cervero, 2001; Shiftan and Barlach, 2002; Chatman, 2003; Zhang, 2004), we need to select the point(s) of the trip chain where the built environment characteristics are to be attached. Although correlated, the variation across destinations in density, job-population balance, transit availability, and public parking availability, can impact on travel decisions on the whole tour (Vande Walle and Steenberghen, 2006; Chen et al., 2008). The number of transit stops/stations can be attached to both the home address and the destinations, while the public parking lot availability is considered more relevant for other trip destinations than the home; and also the density measure seems more relevant at the trip destinations beyond the home (Ewing and Cervero, 2001; Zhang, 2004). Moreover, the NTS includes questions about parking availability at work, as well as distance to nearest transit stop, formerly found to impact on the choice of the auto mode (Kitamura, 1984), and the transit frequency. Chen et al. (2008) applied the maximum density at destinations as density measure in the analysis. A maximum or minimum density of residents and employments as well as public parking lot number at destinations, measured at the 250 m statistical grid unit, can be attached to the NTS data via their geographical positions. In the same manner, a job-population index can be attached to the home address (Frank et al., 2008).

For the measurement of distance to urban centres, we apply a simplistic approach. We add straight-line distances between the geographical positions of residences and destinations in the NTS data set and the geographically-mapped centre zones from Statistics Norway.[4]

2.3. Binary logit models of complex tours and auto mode choice

We specify a binary logit model of complex tours, where the reference is simple tours (two legs only); and we specify a binary logit model of using car as main transport mode on the trip chain, with transit, bicycling, and walking together comprising the reference. For both analyses we differentiate between commuting tours (including school, as did Currie and Delbosc, 2011) and non-commuting tours. The specified single-trip purposes (activity categories) are retained; thus a non-commuting tour can be a shopping tour or a combined shopping and leisure tour. Thus, we do not define a main activity for non-work/school tours, differently from, e.g., Vande Walle and Steenberghen (2006).

The binary logit model for a complex tour (chained trips) or for auto mode choice can be specified as follows:

$$\ln\left(\frac{\pi(y=1)}{1-\pi(y=1)}\right) = \alpha + \sum_{p}\beta_p x_{ip} + \sum_{q}\gamma_q z_{iq} + \sum_{r}\eta_r v_{ir} \quad (1)$$

The probability, $\pi(y = 1)$, of an individual i having reported a complex tour/going by auto ($y = 1$), is represented by a logit-linear function of p individual/household variables, x_{ip}, and q built-environmentity-level variables related to the trip chain, z_{iq}, and r other variables of the individual travel context (e.g., day and season), v_{ir}. This is a simple logistic equation that is estimated as a standard binary logistic regression model, estimating the p coefficients, $ß_p$, of individual/household variables, the q coefficients, γ_q, of built-environment variables, and the r coefficients, η_r, of other travel context variables; and α is a constant term.

Based on initial testing, we chose to measure density and public parking lots at their minimum level across destinations (250 m statistical grid), not including the home. This prevents collinearity problems due to the correlation across destinations, including the home; and the minimum level is considered more conditioning for trip chaining and transport mode choices than the maximum. The job-population index is measured for $a = 1$, i.e., the index will increase monotonically in the balance of employments and inhabitants within the 250 m statistical grid, reaching 1 when the number of residents is equal to the number of jobs; and this variable is only attached to the home address. The number of transit stops is attached to the home address, as well as being set at the minimum level across (other) destinations in the trip chain. Likewise is distance to nearest centre included both for the home address and for the remaining destinations; and in this case we apply the maximum level across destinations.

2.4. Alternative models

In supplementary material to this article we add results of alternative model approaches. In some of the cited literature, tour complexity and auto mode choice are assessed with only public transport constituting the alternative mode (Primerano et al., 2008; Currie and Delbosc, 2011); and we test a model that omits cycle and walk. We also test multinomial logit models of transport mode choice where one of the included four transport mode is reference, focussing on the analysis of the auto mode choice when transit is reference. Moreover, we test a ordered logit model of complexity with four complexity levels, from the simple one stop tour (two legs) via two and three stops up to "four or more stops" (five legs or more); the maximum level is merged because the number of observations dropped abruptly beyond four stops. The supplementary data also includes presentations of the full NTS sample, with binary logit models of complex tours and auto mode choice.

2.5. Data overview

The following map of Norway with its 428 municipalities, in 2014, visualizes the geographical coverage of tours in our NTS sample, when we restrict the data to home-to-home trip chains with either auto or transit/cycle/walk as main transport mode. 340 of the municipalities were represented by individuals reporting both commuting and non-commuting tours (purple-coloured), while 15 municipalities are represented by only commuting tours (blue-coloured), and 49 by only non-commuting tours (pink-coloured). The 250 × 250 m squares including public parking registry information are shown by white bullets (Fig. 1).

As indicated by Fig. 1, the public parking registry covers a somewhat limited number of municipalities, primarily those in the more urban coastal areas of Norway. Thus, if parking availability at destinations is to be included in analysis, the number of represented municipalities drops from 404 to 151, and the total number of trip chains from 57,079 to 19,668.[5] As we find the parking registry variable particularly relevant for our analysis, we will retain it and proceed further with the 19,668 tour observations in what we term the more urban subset of the NTS data. The remaining more rural subset, consisting of 37,411 tour observations, will be analysed in parallel, but without any public parking register variable.

The share of complex trip chains, having more than two legs, is considerably higher in the more urban than in the more rural subset, i.e., 41% vs. 21%. Furthermore, there is a higher share of complex commuting tours than complex non-commuting tours, i.e., 50% vs. 35% in the more urban subset and 29% vs. 18% in the more rural subset. Tours with auto as main mode have the highest overall share of complex tours (47% in the

[3] Data from both registers were summarised on 250 × 250 m grids. For a description of the public transport registry, established in 2016 by the Norwegian Ministry of Transport and Communications, see https://developer.entur.org/pages-intro-files. For a short presentation (in Norwegian) of the parking registry, established in 2017 by the Norwegian Public Roads Administration: https://www.vegvesen.no/trafikkinformasjon/reiseinformasjon/parkeringsregisteret/om-parkeringsregisteret.

[4] Statistics Norway defines a centre zone in the following way: "A centre zone consists of one or more centre kernels and a 100-metre zone around them. A centre kernel is an area with at least 4 different main types of economic activity with centre functions. In addition to detail trade, governmental administration or health and social services or social and personal services must be present. The distance among enterprises must not be >50 m. At least 50 employees, (in businesses with centre functions) in the centre zone." (https://www.ssb.no/en/natur-og-miljo/statistikker/arealsentrum/aar/2015-12-08?fane=om)

[5] The main part, i.e. 80%, of this loss in observations is directly due to the coverage of the parking registry. The remaining part is due to missing coordinates on trip chain destinations reported in the NTS, and then applies to all destination variables measured on the 250 m grid, i.e., density, parking lots and transit stops.

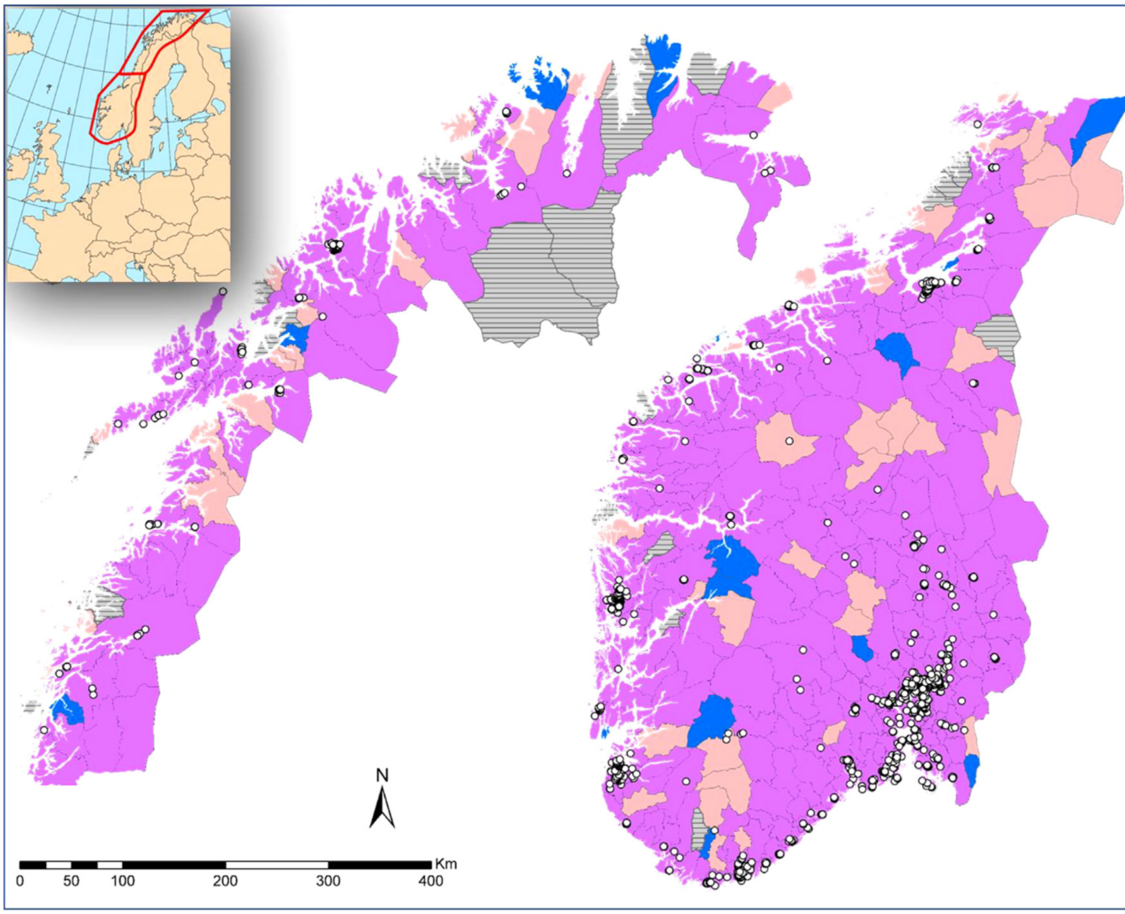

Fig. 1. Geographical cover of national travel survey (NTS) data 2013/14 (home-to-home trip chains with either auto, transit, cycle or walk as main transport mode): 340 purple-coloured municipalities with commuting and non-commuting tours; 15 blue-coloured municipalities with only commuting tours; 49 pink-coloured municipalities with only non-commuting tours; and 24 grey-striped municipalities with no trip chain observations. The white bullets represent 250 × 250 m squares that include public parking registry information. The trip chains with at least one destination in 250 × 250 m squares with public parking registration will represent "the more urban" subset of the NTS, while the remaining trip chains will represent "the more rural" subset of the NTS.

more urban and 24% in the more rural subset). There is an increasing share of the auto for an increasing number of legs in the trip chain, which applies both to the more urban and the more rural subset, and to commuting as well as non-commuting tours.[6] The following tables summarise the variables applied in the binary-logit model analyses.

The relatively high maximum values of public parking lots and density (residents + employments), particularly in the more urban subset (Table 1a), can be explained by business locations that extend the 250 m grid cell identified by main office street addresses. In such cases, employment numbers will be underrated in adjacent grid cells. Therefore, we also tested our models using clusters of neighbouring grid cells. However, probably due to the large data material, the widening of the geographical units did not alter the model results. Another salient feature is that commuting tours and non-commuting tours are carried out by somewhat different population samples. That is, the respondents behind the non-commuting tours have higher average age, lower average incomes, and lower shares of children in the household, compared to the commuting tour respondents. This pattern is similar for the more urban and the more rural subset.[7] The tour length in non-commuting is shorter; and the destinations have somewhat lower density and, for the more urban subset, slightly higher minimum number of public parking lots. The season of the year and the days of the week influence on travel behaviour, thus providing a reason for including these dummy variables in the modelling (Tables 1a and 1b).[8]

3. Results

3.1. Complex tours

The following two tables show binary logit model estimates of complex tours; trip chains with three or more legs are set to 1, while simple trip chains (two legs only) are set to zero. Table 2a shows the model results for the more urban subset of the NTS data.

Two of the built environment variables show a particularly strong negative association with complex tours, the minimum density of the destinations in the trip chain and the minimum number of transit stops at the destinations. That is, the higher the level of density and the higher the minimum number of transit stops, at the destinations of the trip chain (beyond

[6] For further overviews of the trip chains and the transport modes, see the Appendix/Supplementary material.

[7] Furthermore, a much larger share of the non-commuting tours involves persons travelling together, >40% vs. just above 15% in commuting tours. The differences between the commuting tour sample and the non-commuting sample are indicated in spite of both samples not being fully representative of the population carrying out trip chains within the given geographical area in 2013/14. E.g., the education level might be higher in these samples than in the «real» trip chain population. For analyses of NTS 2013/14 using statistical weights, see Hjorthol et al. (2014) or Engebretsen et al. (2018).

[8] All variables in Tables 1a and 1b were run in pairwise correlation analysis, which showed very few pairs reaching a Pearson correlation above 0.35, except for age and age squared. The vehicle number against the natural log of household income obtained a Pearson correlation of just below 0.4. We have also tested the models specified as ordinary least square models, which is inappropriate as such but enables a simple check of the variance inflation factor (VIF), which yields a measure of potential multicollinearity. We find no covariate with VIF value above 2, except age and age squared. The reason for retaining age squared is that dependence with age is assumed at the outset and that it enables assessing curvilinear relationships.

Table 1a
Descriptive statistics of variables applied in analyses – commuting tours and non-commuting tours – the more urban subset (n = 19,668).

Variable	Commuting tours (n = 8059)					Non-commuting tours (n = 11,609)				
	Mean	St.dev.	Min	Max	Median	Mean	St.dev.	Min	Max	Median
Share of complex trip chains	0.50	0.50	0	1	1	0.35	0.48	0	1	0
Length of trip chain (km)	30.7	42.5	0.2	948	16.0	19.1	37.1	0.2	895	8.0
No. of legs in trip chain	2.97	1.32	2	14	3	2.61	1.07	2	15	2
Auto main mode in trip chain	0.55	0.50	0	1	1	0.67	0.47	0	1	1
Male gender	0.48	0.50	0	1	0	0.47	0.50	0	1	0
University or equivalent education	0.68	0.47	0	1	1	0.58	0.49	0	1	1
Age (yrs)	44.7	13.4	18	87	46	53.1	17.0	18	94	55
Personal income (in 1000 NOK)	506	295	0	4000	480	421	267	0	5000	400
Household income (in 1000 NOK)	900	468	0	5000	900	752	441	0	5400	700
No. of household members 0–6 yrs	0.21	0.53	0	4	0	0.16	0.48	0	6	0
No. of household members 7–12 yrs	0.23	0.57	0	15	0	0.17	0.48	0	4	0
No. of household members 13–17 yrs	0.23	0.52	0	4	0	0.17	0.45	0	3	0
No. of household members ≥18 yrs	2.02	0.77	1	9	2	1.93	0.71	1	8	2
No. of vehicles (four classes)	1.33	0.79	0	≥3	1	1.25	0.74	0	≥3	1
Access to bicycle	0.81	0.39	0	1	1	0.77	0.42	0	1	1
Holder of periodic/multi ticket	0.43	0.49	0	1	0	0.32	0.47	0	1	0
Distance (km) to nearest stop/station from home	0.51	0.77	0	9.0	0.30	0.46	0.68	0	9.0	0.25
Frequency per hour of nearby transit	5.08	3.96	0	12	4	4.88	3.92	0	12	4.0
Parking lot available at work	0.63	0.48	0	1	1	0.40	0.49	0	1	0
Min. no. of public parking lots at destinations (250 m grid)	234	332	1	3459	120	262	390	1	21,016	139
Min. no. of transit stops at destinations (250 m grid)	1.00	1.54	0	12	0	1.14	1.61	0	12	1
No. of transit stops/stations at home address (250 m grid)	0.63	1.04	0	11	0	0.67	1.05	0	11	0
Job-population balance on home address (250 m grid), $a = 1$	0.23	0.25	0	1	0.13	0.25	0.26	0	1	0.14
Min. density of residents/employments at destinations (250 m grid)	1016	1418	0	11,135	464	730	908	0	11,135	423
Max. distance (km) from destination to nearest centre	0.87	2.28	0	58	0	0.72	1.90	0	39	0
Distance (km) from home to nearest centre	1.86	2.77	0	35	1	1.63	2.60	0	36	1
Nearest centre to home is main centre of the municipality	0.45	0.50	0	1	0	0.49	0.50	0	1	0
Share of winter trip chains (Nov–March)	0.44	0.50	0	1	0	0.41	0.49	0	1	0
Share of Saturday trip chains	0.03	0.16	0	1	0	0.15	0.36	0	1	0
Share of Sunday trip chains	0.02	0.13	0	1	0	0.08	0.28	0	1	0

Note: These descriptive statistics are based on the NTS sample of individuals reporting trip chains that covered the area where the public parking registry is in lieu; the more urban subset of the NTS. The share of other modes than auto were, respectively for transit, cycling and walking, 0.25, 0.09, 0.11 in commuting tours, and 0.10, 0.04, and 0.20 in non-commuting tours. Dummy variables equal to zero might comprise missing values in original variables, e.g. the higher education dummy was derived from a four-level variable that included 0.6% missing. Income was first asked open-ended, and for item non-response followed up by a question of assignment to income intervals; and for those not reporting income within interval (about 13%), it was imputed by regression modelling, applying age, gender, education, household type, region dummies, employment and occupational variables. The OLS income model ($R^2 = 0.65$) was also applied for the identification of extremely high income figures that were most likely due to punching errors; about 1% of the income figures were more than five times above the model estimates and were subsequently adjusted downwards. Some few observations are missing for gender: 5 for commuting tours and 11 for non-commuting tours. Distance (km) to nearest transit stop/station was reported for, respectively, 7776 and 11,104 trip chains.

the home), the lower are the odds of a complex trip chain. This applies to commuting tours as well as non-commuting tours. Also the minimum number of public parking lots at destinations, as well as the job-population balance ($a = 1$) in the home area, for commuting tours, show negative association with complex tours. (Calculating job-population balance using $a = 0.5$ would not alter this result.) For the number of transit stops near home, no significant relationship is found with the choice of a complex tour. Self-reported transit frequency near home shows a positive association with complex tours. The maximum distance between a destination in the trip chain and the nearest centre shows a particularly strong association with complex tours, while the distance between the residence and the nearest centre shows a negative association; and the latter is not influenced by the centre being a main centre of the municipality or not (Table 2a).

Regarding individual/household characteristics, male gender, as well as the number of cars and the number of adults in the household, shows negative association with complex tours. Regarding the non-commuting tours, the age and age squared variables show a positive but diminishing association between age and complex tours. Age squared is non-significant for the commuting tours, and omitting it would leave a significantly negative age coefficient, indicating a more constant reduction in complex tours by age. Higher education increases the odds of complex tours; which is also the case for holders of periodic/multitrip transit tickets on non-commuting tours. Regarding complex commuting tours, both the household income (log transformed) and pre-scholar children in the household show a positive association (Table 2a).

Table 2b shows the results of the same model applied to the more rural subset of the NTS data, the municipalities that had not implemented the registration of the public parking lots. In this subset, some of the associations between complex tours and the built environment found for the more urban NTS subset are no longer present. Job-population balance shows no significant association with complex commuting tours; the maximum straight-line distance from a destination in a trip chain to the nearest urban centre (centre zone) shows no significant association with complex non-commuting tours; and self-reported transit frequency shows no longer any significant association with tour complexity. The latter might be related to the stronger positive associations between complex tours and the no. of transit stops near home, in the more rural NTS subset. The pattern for the individual/household characteristics remains mostly the same as for the more urban subset; except that for age there is a positive and diminishing association with complex commuting tours instead of non-commuting tours (Table 2b).

3.2. Auto mode choice

The following two tables show the binary logit model estimates of the auto mode choice. Table 3a shows the model results for the more urban subset of the NTS data.

Looking first at the built environment variables, the minimum density of the destinations in the trip chain has a negative association with the auto mode choice (Table 3a). That is, the higher the minimum density, the lower are the odds of choosing the auto mode. The minimum public parking capacity at the destinations has a positive association with the auto mode choice. The number of transit stops, both near home, and at the destinations show negative association with the auto

Table 1b
Descriptive statistics of variables applied in analyses – commuting tours and non-commuting tours – the more rural subset (n = 37,411).

Variable	Commuting tours (n = 10,583)					Non-commuting tours (n = 26,828)				
	Mean	St.dev.	Min	Max	Median	Mean	St.dev.	Min	Max	Median
Share of complex trip chains	0.29	0.45	0	1	0	0.18	0.38	0	1	0
Length of trip chain (km)	30.4	45.5	0.2	998	16.0	19.0	39.0	0.2	1097	8.0
No. of legs in trip chain	2.49	0.97	2	12	2	2.26	0.67	2	10	2
Auto main mode in trip chain	0.75	0.43	0	1	1	0.78	0.42	0	1	1
Male gender	0.54	0.50	0	1	1	0.51	0.50	0	1	1
University or equivalent education	0.54	0.50	0	1	1	0.54	0.50	0	1	1
Age (yrs)	45.7	13.3	18	85	47	53.6	16.1	18	95	55
Personal income (in 1000 NOK)	481	270	0	5000	450	428	256	0	4000	400
Household income (in 1000 NOK)	855	426	0	5000	800	767	417	0	5800	700
No. of household members 0–6 yrs	0.20	0.53	0	3	0	0.20	0.54	0	4	0
No. of household members 7–12 yrs	0.24	0.56	0	4	0	0.21	0.54	0	15	0
No. of household members 13–17 yrs	0.25	0.55	0	4	0	0.20	0.50	0	5	0
No. of household members ≥18 yrs	2.06	0.76	1	9	2	1.97	0.67	1	9	2
No. of vehicles (four classes)	1.55	0.76	0	≥3	2	1.45	0.72	0	≥3	1
Access to bicycle	0.81	0.39	0	1	1	0.79	0.41	0	1	1
Holder of periodic/multi ticket	0.21	0.41	0	1	0	0.22	0.42	0	1	0
Distance (km) to nearest stop/station from home	0.58	0.93	0	9.0	0.30	0.55	0.86	0	9.2	0.30
Frequency per hour of nearby transit	3.86	3.65	0	12	2	3.74	3.49	0	12	2.0
Parking lot available at work	0.81	0.39	0	1	1	0.43	0.50	0	1	0
Min. no. of transit stops at destinations (250 m grid)	0.49	0.85	0	9	0	0.55	0.87	0	9	0
No. of transit stops/stations at home address (250 m grid)	0.49	0.86	0	11	0	0.48	0.83	0	10	0
Job-population balance on home address (250 m grid), $\alpha = 1$	0.22	0.25	0	1	0.11	0.22	0.25	0	1	0.11
Min. density of residents/employments at destinations (250 m grid)	365	766	0	6401	155	193	368	0	6401	117
Max. distance (km) from destination to nearest centre	2.62	4.62	0	63	1	3.25	5.34	0	69	1
Distance (km) from home to nearest centre	3.02	4.46	0	67	1	3.01	4.68	0	67	1
Nearest centre to home is main centre of the municipality	0.50	0.50	0	1	1	0.52	0.50	0	1	1
Share of winter trip chains (Nov–March)	0.44	0.50	0	1	0	0.38	0.49	0	1	0
Share of Saturday trip chains	0.03	0.16	0	1	0	0.14	0.35	0	1	0
Share of Sunday trip chains	0.02	0.15	0	1	0	0.12	0.32	0	1	0

Note: These descriptive statistics are based on the NTS sample of individuals reporting trip chains that did not cover the area where the public parking registry is in lieu; the more rural subset of the NTS. The share of other modes than auto were, respectively for transit, cycling and walking, 0.08, 0.07, 0.09 in commuting tours, and 0.02, 0.03, and 0.17 in non-commuting tours. For the education and income variables, see note under Table 1a. Some few observations are missing for gender: 15 for commuting tours and 41 for non-commuting tours. Distance (km) to nearest transit stop/station was reported for, respectively, 10,067 and 25,769 trip chains.

Table 2a
Binary logit model of complex tours – commuting tours and non-commuting tours – the more urban subset of the NTS.

Covariates	Commuting tours (n = 7771)					Non-commuting tours (n = 11,093)				
	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)
Constant	−0.139	0.368	0.143	0.705	0.870	−0.351	0.285	1.510	0.219	0.704
Age	0.009	0.015	0.373	0.542	1.009	0.015	0.010	2.535	0.111	1.015
Age squared	−0.0001	0.0002	0.7315	0.392	1.000	−0.0002	0.0001	3.8691	0.049	1.000
LN income	0.117	0.049	5.566	0.018	1.124	0.057	0.042	1.809	0.179	1.058
Male	−0.157	0.056	7.948	0.005	0.855	−0.367	0.047	60.823	0.000	0.692
Univ. degree	0.344	0.063	29.518	0.000	1.411	0.136	0.050	7.280	0.007	1.146
No. of children 0–6	0.251	0.059	18.284	0.000	1.285	0.027	0.051	0.287	0.592	1.027
No. of children 7–12	−0.076	0.051	2.252	0.133	0.926	−0.086	0.051	2.834	0.092	0.917
No. of teenagers 13–17	−0.013	0.056	0.052	0.820	0.987	−0.109	0.054	4.057	0.044	0.896
No. of adults	−0.101	0.041	6.019	0.014	0.904	−0.078	0.040	3.872	0.049	0.925
No. of cars	−0.147	0.044	10.928	0.001	0.863	−0.138	0.039	12.433	0.000	0.871
Access to bicycle	−0.119	0.073	2.611	0.106	0.888	0.034	0.058	0.337	0.562	1.034
Holder of periodic/multi-use transit ticket	0.095	0.061	2.444	0.118	1.100	0.135	0.053	6.380	0.012	1.144
Tour length	0.007	0.001	67.179	0.000	1.007	0.014	0.001	226.268	0.000	1.014
Distance to stop/station	0.031	0.039	0.615	0.433	1.031	−0.024	0.035	0.453	0.501	0.977
Transit frequency	0.048	0.008	32.895	0.000	1.049	0.036	0.007	25.833	0.000	1.036
Parking available at work	−0.106	0.060	3.108	0.078	0.899	−0.108	0.054	3.975	0.046	0.898
Min no. of parking lots at dest.	−0.466	0.089	27.494	0.000	0.628	−0.152	0.070	4.645	0.031	0.859
Min no. of transit stops at dest.	−0.419	0.024	300.153	0.000	0.658	−0.481	0.022	458.907	0.000	0.618
No. of transit stops near home	0.032	0.028	1.356	0.244	1.033	0.022	0.024	0.862	0.353	1.022
Job-pop. balance at home address ($\alpha = 1$)	−0.304	0.113	7.245	0.007	0.738	−0.096	0.093	1.068	0.301	0.908
Min density at dest.	−0.683	0.032	442.708	0.000	0.505	−0.974	0.048	411.575	0.000	0.377
Max. distance from dest. to nearest centre	0.606	0.037	272.426	0.000	1.833	0.364	0.022	272.885	0.000	1.439
Distance from home to nearest centre	−0.056	0.012	21.272	0.000	0.945	−0.034	0.011	10.419	0.001	0.966
Nearest centre to home is main centre	−0.055	0.056	0.958	0.328	0.947	−0.025	0.047	0.287	0.592	0.975
Winter	0.143	0.055	6.734	0.009	1.154	0.030	0.047	0.407	0.524	1.030
Saturday	−0.148	0.167	0.787	0.375	0.862	0.219	0.064	11.666	0.001	1.244
Sunday	−0.439	0.206	4.539	0.033	0.644	−0.324	0.090	13.107	0.000	0.723
Log-likelihood	−3979.8					−5608.7				
Cox & Snell	30.4%					25.0%				
Nagelkerke	40.5%					34.4%				

Table 2b
Binary logit model of complex tours – commuting tours and non-commuting tours – the more rural subset of the NTS.

Covariates	Commuting tours (n = 8464)					Non-commuting tours (n = 20,221)				
	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)
Constant	−1.553	0.395	15.455	0.000	0.212	−1.002	0.258	15.030	0.000	0.367
Age	0.026	0.014	3.349	0.067	1.026	−0.001	0.008	0.009	0.924	0.999
Age squared	−0.0003	0.0002	3.9950	0.046	1.000	0.0000	0.0001	0.1214	0.727	1.000
LN income	0.114	0.056	4.108	0.043	1.121	0.049	0.038	1.613	0.204	1.050
Male	−0.341	0.052	43.681	0.000	0.711	−0.284	0.037	58.331	0.000	0.752
Univ. degree	0.230	0.054	17.966	0.000	1.258	0.095	0.040	5.744	0.017	1.100
No. of children 0–6	0.492	0.049	100.486	0.000	1.636	0.071	0.036	3.752	0.053	1.073
No. of children 7–12	−0.048	0.046	1.071	0.301	0.953	−0.049	0.036	1.914	0.166	0.952
No. of teenagers 13–17	−0.033	0.048	0.484	0.487	0.967	−0.041	0.039	1.084	0.298	0.960
No. of adults	−0.150	0.041	13.604	0.000	0.861	−0.132	0.034	15.083	0.000	0.876
No. of cars	0.087	0.041	4.495	0.034	1.091	0.051	0.031	2.770	0.096	1.052
Access to bicycle	0.124	0.069	3.273	0.070	1.132	0.045	0.048	0.865	0.352	1.046
Holder of periodic/multi-use transit ticket	−0.182	0.069	6.911	0.009	0.834	0.027	0.046	0.351	0.554	1.028
Tour length	0.007	0.001	106.799	0.000	1.007	0.011	0.001	390.546	0.000	1.011
Distance to stop/station	0.031	0.029	1.144	0.285	1.032	−0.036	0.023	2.429	0.119	0.965
Transit frequency	0.003	0.009	0.115	0.735	1.003	−0.006	0.007	0.877	0.349	0.994
Parking available at work	−0.154	0.072	4.575	0.032	0.858	−0.110	0.043	6.608	0.010	0.896
Min no. of transit stops at destinations	−0.479	0.039	149.556	0.000	0.620	−0.502	0.030	284.284	0.000	0.605
No. of transit stops near home	−0.005	0.032	0.027	0.869	0.995	0.048	0.023	4.373	0.037	1.050
Job-pop. balance at home address (a = 1)	0.042	0.105	0.163	0.686	1.043	−0.047	0.075	0.398	0.528	0.954
Min density at destinations	−1.103	0.095	134.323	0.000	0.332	−1.308	0.120	118.262	0.000	0.270
Max. distance from dest. to nearest centre	0.032	0.007	22.199	0.000	1.032	0.001	0.005	0.023	0.881	1.001
Distance from home to nearest centre	−0.020	0.007	7.546	0.006	0.980	−0.015	0.005	7.614	0.006	0.985
Nearest centre to home is main centre	−0.119	0.051	5.321	0.021	0.888	−0.012	0.037	0.112	0.738	0.988
Winter	0.141	0.050	7.869	0.005	1.152	0.032	0.038	0.698	0.403	1.032
Saturday	−0.504	0.181	7.758	0.005	0.604	0.068	0.052	1.689	0.194	1.070
Sunday	−1.218	0.240	25.684	0.000	0.296	−0.293	0.060	24.133	0.000	0.746
Log-likelihood	−4722.4					−9465.1				
Cox & Snell	12.8%					6.6%				
Nagelkerke	17.9%					10.5%				

mode choice. The job-population balance (a = 1) in the home area also has a negative association with the auto mode choice (and it would remain negative if a instead was set equal to 0.5). The distance between the residence and the nearest centre as well as the maximum distance between a destination in the trip chain and the nearest centre show positive association with the auto mode. If the nearest centre to the residence is the main centre of the municipality the association with the auto mode choice is negative.

An increase in (self-assessed) transit frequency in the home area lowers the odds of auto mode choice; while an increased (self-assessed) distance to

Table 3a
Binary logit model of auto mode choice – commuting tours and non-commuting tours – the more urban subset of the NTS.

Covariates	Commuting tours (n = 7771)					Non-commuting tours (n = 11,093)				
	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)
Constant	−4.260	0.400	113.352	0.000	0.014	−4.420	0.305	209.946	0.000	0.012
Age	0.064	0.015	18.586	0.000	1.066	0.069	0.009	54.566	0.000	1.072
Age squared	−0.0006	0.0002	12.444	0.000	0.999	−0.0006	0.0001	36.193	0.000	0.999
LN income	0.430	0.057	56.897	0.000	1.537	0.418	0.044	88.232	0.000	1.518
Male	0.326	0.055	35.242	0.000	1.386	0.405	0.049	68.775	0.000	1.499
Univ. degree	−0.455	0.064	50.672	0.000	0.635	−0.080	0.052	2.358	0.125	0.923
No. of children 0–6	0.056	0.055	1.016	0.313	1.057	0.064	0.054	1.410	0.235	1.066
No. of children 7–12	0.067	0.049	1.857	0.173	1.069	0.262	0.059	19.490	0.000	1.300
No. of teenagers 13–17	0.094	0.055	2.895	0.089	1.099	0.215	0.062	11.883	0.001	1.239
No. of adults	−0.092	0.041	4.993	0.025	0.912	0.198	0.040	24.578	0.000	1.219
Trip chain length	−0.0004	0.001	0.226	0.634	1.000	0.006	0.001	30.784	0.000	1.006
No. of legs in trip chain	0.181	0.026	47.611	0.000	1.198	0.169	0.030	30.590	0.000	1.184
Distance to stop/station	0.045	0.040	1.274	0.259	1.046	0.054	0.045	1.393	0.238	1.055
Transit frequency	−0.110	0.008	188.867	0.000	0.896	−0.106	0.007	243.963	0.000	0.900
Parking available at work	0.827	0.057	208.128	0.000	2.286	0.241	0.057	18.138	0.000	1.272
Min no. of parking lots at dest.	0.115	0.082	1.953	0.162	1.122	0.482	0.077	38.822	0.000	1.619
Min no. of transit stops at dest.	−0.055	0.019	8.444	0.004	0.947	−0.063	0.015	17.992	0.000	0.939
No. of transit stops near home	−0.079	0.028	7.847	0.005	0.924	−0.046	0.023	4.115	0.043	0.955
Job-pop. balance at home address (a = 1)	−0.200	0.111	3.246	0.072	0.818	−0.484	0.093	27.236	0.000	0.616
Min density at dest.	−0.363	0.026	200.843	0.000	0.696	−0.418	0.031	185.248	0.000	0.658
Max. distance from dest. to nearest centre	0.181	0.026	46.624	0.000	1.198	0.257	0.033	62.047	0.000	1.293
Distance from home to nearest centre	0.144	0.014	100.742	0.000	1.155	0.248	0.020	153.793	0.000	1.281
Nearest centre to home is main centre	−0.276	0.055	24.954	0.000	0.759	−0.488	0.049	101.133	0.000	0.614
Winter	0.107	0.054	3.855	0.050	1.113	0.160	0.049	10.787	0.001	1.174
Saturday	0.407	0.169	5.812	0.016	1.502	0.053	0.067	0.618	0.432	1.054
Sunday	0.703	0.208	11.460	0.001	2.019	0.274	0.091	9.031	0.003	1.315
Log-likelihood	−4098.9					−5335.5				
Cox & Snell	27.4%					26.4%				
Nagelkerke	36.7%					36.7%				

stop/station shows no significance for the auto mode choice. Both the total length of the tour and the tour complexity (no. of legs) have positive association with the auto mode choice. The self-assessed availability of parking at work increases the odds of the auto, even for non-commuting tours, which might be considered an oddity or a confounding effect, or possibly a habit formation effect from commuting transport to non-commuting transport (Table 3a).[9]

Male gender has a positive association with the auto mode choice. The positive association between the log of household income and the auto mode choice is strongest for the non-commuting tours, while the negative association with higher education is only significant for the commuting tours. The age coefficient is positive, while the coefficient of the squared age variable is negative, indicating that middle-aged have the highest probability of choosing the auto mode. A higher number of adults lower the odds of auto mode choice on commuting tours, while school children/teenagers in the household have a positive association with the auto mode on non-commuting tours (Table 3a).

Table 3b shows the results of the same model applied to the more rural subset of the NTS data. For the built environment variables there is actually one switch of sign: in the model of the more rural NTS subset, the maximum straight-line distance from a destination in the trip chain to the nearest urban centre (centre zone) obtains a negative coefficient for non-commuting tours. The status of the nearest urban centre, whether it is the main centre of the municipality or not does not show any significant association with the auto mode choice. The same applies to the minimum no. of transit stops at destinations in the trip chain. The pattern for the individual/household characteristics remains very similar to what was found for the more urban subset, except a more significant positive association between children in the household and auto mode choice on commuting tours in the more rural subset (Table 3b).

4. Discussion and conclusions

We have explored the relationships between individuals' trip chaining, auto mode choice and the built environment, distinguishing between commuting and non-commuting trip chains. We applied a large subset of the Norwegian travel survey (NTS) data from 2013/14, where we derived home-to-home trip chains from single trips (legs). Beyond a descriptive study of trip chains in NTS 2009 (Vågane, 2012), our study represents the first analyses of this kind of home-to-home trip chains in Norway. In a fairly generalised approach, we included variables that are applicable to a large range of land areas with human activity. Our analyses were carried out in separate for two parts of the NTS data: one subset representing the more urban areas of Norway (municipalities having implemented public parking registration) and the other representing the more rural areas.

The minimum number of public parking lots at destinations in the trip chain showed negative association with complex tours and positive association with auto mode choice, in non-commuting tours. The positive association with auto-mode choice on non-commuting tours is as expected, and extends the results reported by Christiansen et al. (2017). Another built-environment variable from recently established public registries was the minimum number of transit stops/stations at destinations in the trip chain. Higher minimum number of transit stops/stations was only found to lower the odds of auto mode choice in the more urban subset, providing only partial corroboration of the conjecture by Vande Walle and Steenberghen (2006) about the importance of a transit alternative on each leg in a trip chain. We do not know of former studies that have applied objective measures of public parking and transit availability attached to national travel survey data, in models of tour complexity and auto mode choice. The importance and need for a more relevant transit availability measure have been called for in former Norwegian studies (Engebretsen et al., 2018; Cao et al., 2019).

Minimum density (residents plus jobs) at the destinations and distance between home and nearest centre were the two built-environment variable that showed the most consistent association with complex tours and auto mode. Lower odds of a complex tour the higher the minimum density of tour destinations is consistent with studies based on US data (Krizek, 2003; Noland and Thomas, 2007). The same result for auto mode choice is consistent with former studies that higher (minimum) density at the destinations in a trip chain lowers the odds of going by car (Zhang, 2004; Ewing and Cervero, 2010).

Self-assessed transit frequency, from the NTS, is also consistent across data subsets; a positive association with complex tours and negative association with auto mode choice. The self-assessed parking availability at work has a positive association with the auto mode notwithstanding data subset, which falls into line with findings from Christiansen et al. (2017); and we also found an association between parking availability at work and auto mode choice on non-commuting tours. It is consistent with former studies that higher job-population balance at the home address, in the more urban subset, is negatively associated with the auto mode, as well as with complex tours (Frank et al., 2008; Lee et al., 2017). However, job-population balance is not significantly associated with complex commuting tours when we apply the more rural subset; that to some extent might follow from low density levels as such. Considering the Wald values from the logit models, density, centre distance, transit stops and parking lots are at least as important for non-commuting tours as for commuting tours. Moreover, some of these built-environment variables show even stronger association with tour behaviour than demographics.

In the more rural subset of the NTS, we find a positive association between the number of vehicles in the household and the odds of the tour being complex, similarly to Ma and Goulias (1999) and Golob (2000). However, in the more urban subset, we found a negative association between the number of vehicles in the household and the odds of the tour being complex. Possibly, the more rural area of Norway resembles more the areas studied in the US when comes to car dependency; and the household characteristics might show different relationship in a more urban European context. Consistently with Maat and Timmermans (2006) and Ye et al. (2007) we found a negative association between the number of adults in the household and complex tours. The assumed additional leg via the kindergarten in commuting tours was indicated by a positive coefficient for prescholar children in the household, in the tour complexity model (Strathman et al., 1994; Hensher and Reyes, 2000). The relationship between age and auto mode choice was that of an inverse U shape. The same shape was indicated, albeit statistically weakly, in relation to complex non-commuting tours, in the more urban subset; while in the more rural subset the inverse U shape was found in relation to complex commuting tours. The gender difference was consistent with former findings, female gender positively associated with complex tours and negatively associated with auto mode choice (Vågane, 2012; McGuckin and Murakami, 1999; Ma et al., 2014; Scheiner and Holz-Rau, 2017). Higher education showed positive association with complex tours (Islam and Habib, 2012) and negative association with the auto mode choice on commuting tours (Carse et al., 2013; Engebretsen et al., 2018), which may relate to an underlying relationship between education level and concentrations of employment located in city centres with high accessibility by public transport and limited availability of parking.

Research on trip chaining in Norway is still relatively limited (Vågane, 2012). Although most of our results might be similar to what has been found in analyses of single trips (legs), analysing trip chains provides a better representation of the transport decision-making context (Axhausen and Gärling, 1992; Bhat and Koppelman, 1999; Vande Walle and Steenberghen, 2006). Obviously, policy implications will differ with respect to the type of geographical area. Job-population balance, the possibilities to select/shift between transit lines, and availability of parking lots, are more relevant for policy and planning in more urban areas. Density (of residents plus jobs) at destinations in trip chains and the distance from home to nearest

[9] The choice of the auto mode will also be positively associated with the number of cars in the household and negatively associated with having access to bicycle and holding of a periodic transit card, but these represent preceding decisions that frame the auto mode choice (see, e.g., Van Acker and Witlox, 2010).

Table 3b
Binary logit model of auto mode choice – commuting tours and non-commuting tours – the more rural subset of the NTS.

Covariates	Commuting tours (n = 8464)					Non-commuting tours (n = 20,221)				
	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)	Coeff.	St.err.	Wald	Sig.	Exp(coeff.)
Constant	−3.363	0.397	71.598	0.000	0.035	−3.445	0.259	176.650	0.000	0.032
Age	0.059	0.014	16.857	0.000	1.061	0.046	0.008	35.955	0.000	1.047
Age squared	−0.0006	0.0002	13.697	0.000	0.999	−0.0004	0.0001	24.043	0.000	1.000
LN income	0.319	0.055	33.945	0.000	1.375	0.260	0.035	55.569	0.000	1.297
Male	0.372	0.057	42.696	0.000	1.451	0.353	0.038	86.561	0.000	1.424
Univ. degree	−0.343	0.061	31.816	0.000	0.710	−0.194	0.040	23.286	0.000	0.823
No. of children 0–6	0.114	0.062	3.381	0.066	1.121	0.043	0.037	1.330	0.249	1.044
No. of children 7–12	0.136	0.056	5.998	0.014	1.146	0.198	0.039	25.480	0.000	1.219
No. of teenagers 13–17	0.011	0.055	0.038	0.846	1.011	0.283	0.045	39.489	0.000	1.328
No. of adults	−0.124	0.041	9.217	0.002	0.884	0.143	0.033	19.299	0.000	1.154
Trip chain length	0.012	0.001	98.366	0.000	1.012	0.077	0.003	738.345	0.000	1.080
No. of legs in trip chain	0.439	0.044	101.111	0.000	1.551	0.432	0.046	86.471	0.000	1.540
Distance to stop/station	0.037	0.041	0.783	0.376	1.037	0.050	0.028	3.101	0.078	1.051
Transit frequency	−0.117	0.009	177.997	0.000	0.890	−0.072	0.006	135.429	0.000	0.930
Parking available at work	0.573	0.073	61.449	0.000	1.773	0.135	0.044	9.388	0.002	1.144
Min no. of transit stops at dest.	−0.011	0.032	0.116	0.733	0.989	−0.024	0.022	1.197	0.274	0.976
No. of transit stops near home	−0.059	0.031	3.621	0.057	0.943	−0.065	0.020	10.182	0.001	0.937
Job-pop. balance at home address (a = 1)	−0.429	0.113	14.419	0.000	0.651	−0.307	0.074	17.281	0.000	0.736
Min density at dest.	−0.351	0.035	98.200	0.000	0.704	−0.358	0.053	46.337	0.000	0.699
Max. distance from dest. to nearest centre	0.032	0.011	9.179	0.002	1.033	−0.037	0.009	18.492	0.000	0.964
Distance from home to nearest centre	0.042	0.012	13.260	0.000	1.043	0.034	0.009	13.388	0.000	1.034
Nearest centre to home is main centre	−0.139	0.057	5.878	0.015	0.870	0.020	0.038	0.286	0.593	1.021
Winter	0.112	0.056	3.957	0.047	1.119	0.196	0.039	25.402	0.000	1.216
Saturday	0.320	0.192	2.773	0.096	1.377	0.111	0.056	3.930	0.047	1.117
Sunday	0.396	0.195	4.122	0.042	1.486	−0.131	0.061	4.613	0.032	0.877
Log-likelihood	−3980.8					−8861.7				
Cox & Snell	16.3%					14.0%				
Nagelkerke	24.2%					21.8%				

centre work more in the same direction across more urban and more rural areas, as well as across travel purpose. Both the access to a car and built environment characteristics are associated with trip chaining, and built environment characteristics are associated with auto mode choice. Thus, assuming that it is not only a matter of residential self-selection (Mokhtarian and Cao, 2008), the decisions about urban development can be expected to impact on individuals' perceived necessity of chaining trips, their abilities of chaining trips, and their transport mode choices. The same applies to facilities for other transport modes than the car, including the access to public transport.

The results indicate that both land use planning and accessibility planning are important factors in meeting the objectives of the “urban growth agreements”. Planning for a high functional mix at the home is important because it usually means easy access to different types of service and thus less need for complex trip-chains and less need for car use. Similarly, high density at the destinations gives greater flexibility for combining travel purposes with the use of public transport. Good transit accessibility is nonetheless crucial, and gives better opportunity for complex trip-chains also with public transport. At the same time, of course, parking restrictions and other restrictions at travel destinations is important for reducing car use.

We acknowledge that there are omitted characteristics of the built environment that might impact on travel behaviour, thus possibly also the choice of complex tours and the auto as the main mode on tours. Examples comprise the more detailed land use mix (Bhat and Guo, 2007; Van Acker and Witlox, 2010), not just the overall balance between employments and residents, and more specifications of the centre structure of single or adjacent municipalities (Engebretsen et al., 2018; Cao et al., 2019). Our measure of distance to nearest centre zone was also simplistic, applying straight-line distances. Notwithstanding, we have contributed to the analysis of country-wide travel survey data of trip chains with added built environment data, that are still not numerous in the literature, in particular the analysis of non-commuting tours.

Future research can develop our modelling and conjectures in various ways. Our models were limited to the measurement of associations, between tour complexity or auto mode choice on the one hand, and the built environment and household characteristics on the other. We did not endeavour into causal relationships and the decision-making stages, like, e.g., the approach by Ye et al. (2007). For transport mode choice, that direction of modelling could also involve restrictions on what modes are available (see, e.g., Sicotte et al., 2017). Another development, somewhat similar to Frank et al. (2008) and Roorda et al. (2009), would comprise monetisation of various variables, e.g., mode costs, parking costs, and travel time, thus heading into economic transport modelling, where, e.g., for mode choice the non-chosen trip or trip chain alternatives would be specified. Many options for new investigations remain.

CRediT authorship contribution statement

Berit Grue: Conceptualization, Methodology, Software, Writing - original draft. **Knut Veisten:** Conceptualization, Methodology, Software, Writing - original draft. **Øystein Engebretsen:** Conceptualization, Methodology, Software, Writing - original draft.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2020.100134.

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