Innovative
Policy Modelling and Governance Tools
for Sustainable Post-Crisis Urban Development

D4.2 Housing Location Model

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Executive Summary

Activity-based models of travel demand require a socio-demographic profile of individuals as input. The location of the house is a key variable as it is one of the pegs influencing the action space of individuals. These variables are constructed by creating a synthetic population. Current modelling approaches repeat this process on an annual basis, jeopardising the integrity of the data. This report describes an approach to creating a dynamic synthetic population that takes both demographic processes and residential choice behaviour into account.

Residential choice behaviour is based on a housing model which first predicts the intention to move house as a function of socio-demographics, housing attributes, key characteristics of activity-travel patterns, and the elapsed time since the previous move, adjusted according to empirical information about the relationship between the stated intention to move and actual moves. Monte Carlo simulation is then used to simulate actual housing choice of those intending to move, calibrated on empirical distributions taking their housing history into account. The approach is illustrated for the City of Rotterdam, The Netherlands

The model specification is limited due to publicly available information but can be extended if more data would be available.

1. Introduction

One important link in integrated land use models concerns the relationship between housing location and activity-travel patterns. Models of activity-travel patterns are based on the critical assumption that the locations of the house and the job serve as pegs around which individuals and households organise their daily lives as reflected in daily activity-travel patterns, constrained by spatial-temporal constraints. Vice versa, models of housing choice typically assume that accessibility to various facilities is one of the factors influencing residential satisfaction and housing choice.

Yet, this link between housing and activity-travel patterns has been rather weakly developed in the literature. Dynamics in housing choice has been rarely considered in applications of the current generation of activity-based models of travel demand forecasting. The inclusion of travel in models of housing choice is typically confined to several accessibility measures as opposed to the utility or satisfaction of daily activity-travel patterns. In this context, it should be emphasised that attributes of the house and the residential environment are the dominant set of attributes influencing housing satisfaction and housing choice.

This report documents the development of a dynamic population synthesizer in which a model of residential choice behaviour is embedded. The residential locations of the population are the pegs around which activity-travel behaviour is scheduled. The Albatross model system (Arentze and Timmermans, 2004) is used as the model of travel demand.

The city of Rotterdam is used as the case study to illustrate the principles of the approach. The level of detail was strongly influenced by the lack of free, micro-level data. It will become evident, however, that the presented approach can be elaborated in a straightforward manner once such data will become available. It implies that the focus in this report concerns the principles of the newly developed approach. The workings of the Albatross model system will be illustrated later in the project under the policy scenario studies.

The report is organised as follows. First the research problem is stated, followed by a literature review. Then the dynamic population synthesizer with the embedded residential choice model is explained in detail. The data and model environment are discussed next. The results of an empirical model of the intention to move is then presented, followed by the illustration of the developed dynamic population synthesiser that was linked to a model of housing choice dynamics. This report is finalized with discussions.

2. The problem

The purpose of this package was to develop a housing model that serves as an external link with the Albatross model: a household-level activity-based model of activity-travel behaviour. The goal is to improve the current state of the art. This can be characterized as a situation in which the location of the house is either given in the data or extracted from a population synthesis. The latter means that the socio-demographic profile of each situated individual and household is derived such that the summation of each element of the profile is consistent with the marginal distributions known for the selected spatial units and their correlations are consistent with the correlations in a sample.

A limitation of current practice is that in a forecasting context, the synthetic population has to be created every year on the basis of an external demographic forecast, which may or may not be linked to a housing model. This means that the link between demographic transitions and dynamics in the housing market are lost. In turn, this means that one cannot differentiate policy effects from the possible inconsistencies that may emerge due to the implicit dynamics in the creation of synthetic populations over time. It goes without saying that linking this possibly biased predictions in housing locations to the activity patterns will also impose bias in the decision making process.

The aim underlying the formulation of the housing model was to develop a solution for this problem. Constrained by the publicly available data, we developed a dynamic population synthesiser that was linked to a model of housing choice dynamics. In this context, it is important to realise that the house provides one of the pegs around which people organise their daily activities, which are reflected in daily travel patterns and action spaces.

Demographic processes underlie the dynamics of a (synthetic) population. In turn, socio-demographics are among the major factors influencing housing needs and explain housing moves. Long-term demographic developments such as changes in fertility, household formation patterns, income distribution, etc. have an impact on the changing demand for housing. The dynamics in the existing housing market determines the extent to which this demand can be accommodated.

In the housing market, households try to satisfy their housing needs and improve their satisfaction with every move. The housing market consists of two actors, which are tenants/households determining housing demand, and the landlords determining housing supply. In this model, we consider housing demand as a dynamic process. Although we excluded the dynamics of housing supply due to a lack of data from the empirical study, it is included in the model. The modelling of housing demand is described as follows:

- The housing demand of a household depends mainly on its position and changes in its lifecycle.
- The intention to move of a household is a function of socio-demographic characteristics, housing profile and work accessibility variables.
- The intention to move of a household is related to its dissatisfaction with the current housing situation.
- If a household’s intention to move is high then it searches for a dwelling that will satisfy its needs.
- According to the available data not all households with the intention to move will actually move. A subset of potentially interested households to move will actually move.
- The households are distributed to new houses according to the type of houses, ownership and zones.

In the following set of sections, the development of the model is documented. First, a summary of the main results of a literature study serves as a background and shows how the model is based on or akin to earlier research. Second, we introduce notation and general principles. Next, we discuss an illustration of the approach using data from the Rotterdam region.

3. Literature review

Individuals and households experience several residential moves in their lives. These moves are the result of individuals/households' evaluations of their current house and their impact on daily activity-travel behavior. Many studies show that people intend to move due to a mismatch between their current house and their preferred housing situation (Landale & Guest, 1985; Moore, 1986; Lu, 1998), which leads to dissatisfaction with the current house and in turn may trigger the intention to move (Devisch et al., 2013). The intention to move is generally triggered by different factors such as changing attributes of the house, life cycle events and location of the house vis-a-vis work place and activity locations. Over time, the needs of households, the attributes of the house and its environment may change (Goetgeluk, 2011). Their needs may be more space, better environment, being closer to work or school, etc. Furthermore, changes in the housing market such as booms or decreasing mortgage rates may also trigger the intention to move house (Clark & Onaka, 1983; Henley, 1998).

One of the triggers of the moving intention is a change in the life course such as marriage, divorce or having children (Mulder & Hooimeijer, 1999). Having a child or cohabiting/marriage may result in the need for a bigger house, while breaking up/divorce may result in the need of a smaller house. Therefore, single people who want to cohabit or people who want to become single are more likely to move than couples expecting no changes. In summary, due to the changes in the number of persons living in the household, there may be the need for a larger or smaller house. In general, little space is an important reason for moving (Rossi, 1955; Brown & Moore, 1970; Speare et al., 1975; Clark & Onaka, 1983).

The intention to move house can also be triggered by the characteristics of the dwelling, in which people live. Those who are dissatisfied with the situation of their dwelling (old house, the need of renovation, etc.) are more likely to consider a move (Lansdale & Guest, 1985; Clark & Dieleman, 1996). Furthermore, type and size of house are significant aspects of the current house.

Another trigger for people's intentions to move is a change in education or work. If the location of the new job or education is further away or takes more time to reach, there may be a need to live closer to work to reduce the travel distance and/or travel time. However, some people may accept the longer travel distance/time instead of moving house for a variety of reasons. For example, the partner may work closer to the house or is not willing to leave the neighbourhood, one may wish being close to relatives etc.

The changing needs that are induced by changes in life course, work/education or the situation of the dwelling also interact with the resources and constraints of households. Residential moves involve direct and indirect monetary and non-monetary costs and these are generally associated with households' socio-economic characteristics such as their income, education, household composition, tenure situation, etc. These may not only affect people's intention to move but also impact the realization of the intention to move.

The main goal of this empirical analysis is to better understand the determinants of the intention to move house. From a transportation planning perspective, we are interested to learn the relative importance of transport related attributes influencing residential mobility intentions. As residential mobility is important to understand changing land use and transport networks, land use models should include residential mobility for forecasting socio-demographics and land use patterns, which are also critical inputs to activity-based models. Individuals choose where to live and work, where to conduct their activities and how to reach these activities.

All these decisions are interdependent. For instance, if a person starts to work at a location further away from home, it may be that this person is going to move closer to the work location. The resulting change in residential location may cause a change in the location of other activities as well, such as shopping, sporting, etc. As the long-term decisions generate the activity-travel patterns, they have a direct impact on the travel decisions for instance which transport mode to use or which route to take. Therefore, long-term decisions such as housing choice and short-term decisions such as transport mode influence each other, and in turn both are influenced by land-use and transport policies, showing the relevance of studying residential choice behavior in a travel behavior context. In the literature, for example Eliasson & Mattsson (2000) and Waddell et al. (2007) to name a few, have investigated the relation between long-term and short-term decisions. The relationship between residential choice behavior and travel behavior has a long history in the development and application of comprehensive integrated land-use transportation micro simulation systems, such as ILUTE (Salvini & Miller, 2005), ILUMASS (Strauch et al., 2005) and UrbanSim (Waddell et al., 2010).

4. Dynamic population synthesizer with embedded residential choice model

Consider an area, consisting of *I* zones. Let $i \in I$ be an index for the zones. At the start of the considered time $t = 0$ period, each zone has a certain number of residential units or dwellings $R_{icr}^{t=0}$ of type *c* and ownership status *r*. The dynamics in the housing stock in each zone are given by

$$R_{icr}^{t+1} = R_{icr}^{t} + N_{icr}^{t} - D_{icr}^{t}$$

where,

N_{icr}^{t} is the number of newly constructed or converted residential units of type *c* (house, apartment, other) and ownership status *r* (rent vs. own) in zone *i*.

D_{icr}^{t} is the number of demolished or converted (into other use) residential units of type *c* and ownership status *r* (in zone *i*.

Let *h* be an index for households, who live in one of the set of zones *i* of the study area $h \in \mathcal{H}_i$. At the start of the considered time period $t = 0$ each zone has a certain number of households $\mathcal{H}_{icr}^{t=0}$ living in residential units of type *c* and ownership status *r*. The dynamics in the number of households in each zone are given by

$$\mathcal{H}_{icr}^{t+1} = \mathcal{H}_{icr}^{t} \pm \mathcal{M}_{icr}^{t} \pm \mathcal{S}_{icr}^{t} - \mathcal{D}_{icr}^{t}$$

where,

$\mathcal{H}_{icr}^{t}$ is the number of households leaving in residential units of type *c* and ownership status *r* in zone *I in time t*

$\mathcal{M}_{icr}^{t}$ is the number of households moving in/ out residential units of type *c* and ownership status *r* in zone *i* due to marriage.

$\mathcal{S}_{icr}^{t}$ is the number of households moving in/ out residential units of type *c* and ownership status *r* in zone *i* due to divorce/separation

$\mathcal{D}_{icr}^{t}$ is the number of households moving out residential units of type *c* and ownership status *r* in zone *i* due to death.

Note that the question whether marriage (respectively divorce) leads to an increase or decrease of the number of households depends on whether or not the marriage (respectively divorce) coincides with a residential move of one or both partners. In case of a marriage without residential moves beyond the previous zone, two single member households are replaced by one. This means a decrease in the number of households. If one of the members has moved from another zone, the change in the number of households in zone *i* will be zero. If both members have moved from another zone, the number of households increased with one. In case of divorce, if both members continue to live in zone *i*, the number of households will increase by one. If one continues to live in *i* and the other member leaves, there will be no change in the number of households in *i*. In case both move outside of zone *i*, the number of households will be reduced by one. It is clear that the demographic process and the residential move process can be considered as two separate processes. In that case, the accounting system should add the number of household leaving, respectively entering a particular zone.

Albatross requires a synthetic population as input for the scheduling of daily activity-travel patterns. This means that for each member (*q)* of household of the population Q a set z_{qik} of $k = 1, 2, \dots K$ socio-demographic and possible other characteristics/attributes is constructed such that the summation of an attribute across individuals in the synthetic population is consistent with corresponding known statistics Z_{ik} for zones or larger spatial entities, while the correlation between attributes of the synthesized population is consistent with the observed correlation in the sample used for the synthesising. Thus,

$$\sum_{q=1}^{Q_i} z_{qik} = Z_{ik}; \quad \forall\, k$$

$$\rho(z_{Q_{ik}}, z_{Q_{ik'}}) = \rho(z_{Q'_{ik}}, z_{Q'_{ik'}}) \quad k, k' \in K \quad Q' \subset Q$$

However, the synthesized population lacks the residential characteristics. Therefore, data fusion is required, involving in the present case merging the synthetic population with the WoON data (H''), which for a sample of the population has the type of dwelling *c*, ownership *r* as well as some other social demographics. This fusion was based on some individuals and households variables. The code for this fusion process is as follows:

```
For h' = 1: H'
  For h=1:H
    If z_h= z_h'
      Then   c_h=c_h' & r_h=r_h'
        H=H-{h}
  end
end
```

H' is the total number of households in WoON and *h'* is an index of that, while *H* and *h* correspond to the synthesized population. If more than one housing type and ownership status can be matched with a specific social demographic profile, the assignment is based on proportionality. Matching was based on "household composition", "income" and "age of children". It should be noted that, disregarding vacancy, because the proportion of each housing type and ownership is known for each zone *i*, the matching procedure satisfies the following constraint.

$$\mathcal{H}_{icr}^{t=0} = R_{icr}^{t=0}$$

When the complete population, including the housing type and ownership of dwelling is synthesized, the dynamic demographic process is simulated as follows.

The set of socio-demographics includes attributes such as age, civil status and number of kids. As the accounting system is based on a single year, the age of each individual is increased with one unit every year. Civil status includes marriage and divorce. Changes in civil status are based on Monte Carlo draws from age (*A*) and gender (*G*)-specific marriage and divorce rates available from the Central Bureau of Statistics.

$p_q^{s,m}(t+1,t) = f(G_q, A_q)$

$p_q^{m,s}(t+1,t) = f(G_q, A_q)$

where,

$p_q^{s,m}(t+1,t)$ is the probability that individual *q* will change from married to single between *t* and *t*+1.

$p_q^{m,s}(t+1,t)$ is the probability that individual *q* will change from single to married between *t* and *t*+1.

As for demographic processes, births and deaths are modeled in a similar vein using gender and age-specific fertility and mortality rates. With the explained process, at the end of each time period *t*, the socio-demographics of the population will change.

Population change in the zones thus equals the number of births minus the number of deaths plus the balance of in- and out-migration. The latter process is linked to the process of residential choice. The residential choice model differentiates between the willingness to move and actual move. Willing to move is a function of the current housing satisfaction.

$$W_h^{t+1,t}(c,r) = \frac{1}{1+\exp(-(\beta_0 + \mathbf{Z}_h\boldsymbol{\theta}' + \mathbf{X}_{\boldsymbol{h}}\boldsymbol{\eta}' + \boldsymbol{A}_{\boldsymbol{q}\in\boldsymbol{h}}\boldsymbol{\delta}'))}\phi \tag{4}$$

where,

$W_h^{t+1,t}(c,r)$ is the intention of household *h* to move house from type *c* and ownership *r*

$\mathbf{Z}_h$ is a row vector of socio-demographic variables of household *h*.

$\mathbf{X}_{\boldsymbol{h}}$ is a row vector of housing attributes of the current house of household *h*

$\boldsymbol{\theta}'$ is a row vector of the effects of socio-demographic variables on the intention to move

$\boldsymbol{\eta}'$ is a row vector of the effects of housing attributes on the intention to move

$\boldsymbol{A}_{\boldsymbol{q}\in\boldsymbol{h}}$ is a row vector of accessibility measures of household member *q* belonging to household *h*.

$\boldsymbol{\delta}'$ is a row vector of the effects of accessibility on the intention to move

ϕ is a correction factor

The correction is suggested to accommodate findings in empirical research that on average only 50% of the households expressing the willingness to move will actually move.

Ideally, the probability of moves is an elaborated model of house and zonal attributes. However such data were not publicly available. Because the implications for the Albatross model are relatively small, we therefore implemented a more robust model that was calibrated on the available data. Particularly, the latent number of residential moves from zone *i* in any given year, from housing type *c* and ownership status *r* equals:

$$\widetilde{M}^{t+1,t}(c,r,i) = \sum_{h\in\mathcal{H}_i} W^{t+1,t}\,(c,r) \quad (5)$$

It should be noted here that in the actual simulation, equation (5) may not be perfectly met as the willingness to move house depends on Monte Carlo draws.

Let $p(c',r'|c,r)$ denote the transition probability of moving from housing type *c* and ownership status *r* to from housing type *c'* and ownership status *r'*, then the latent number of residential moves from zone *i* in any given year, from housing type *c* and ownership status *r* to from housing type *c'* and ownership status *r'* equals:

$$\widetilde{M}^{t+1,t}(c',r'|c,r,i) = p(c',r'|c,r)\sum_{h\in\mathcal{H}_i} W^{t+1,t}\,(c,r) \quad \forall c,r,i \quad (6)$$

The number of residential moves from housing type *c* and ownership status *r* in zone *i* to housing type *c'* and ownership status *r'* originating from zone *i'* then equals:

$$M(c',r',i'|c,r,i) = \lambda_{ii'}\theta_{c',r',i'}\widetilde{M}^{t+1,t}(c',r'|c,r,i) \qquad \forall c,r,i \quad (7)$$

where

$\theta_{c',r',i'}$ is the share of available houses of type *c'* and ownership status *r'* in zone *i'*

$$\lambda_{ii'} = M(i',i)/\sum_{c',r'}\theta_{c',r',i'}\widetilde{M}^{t+1,t}(c',r'|c,r,i)$$

5. Data

The data used derives from the Netherlands Housing Survey (Woning Onderzoek - WoON), conducted by Statistics Netherlands in 2012. Housing surveys are based on a large cross-sectional survey in which information is gathered about the housing situation of people living in the Netherlands. The sample, which consists of 69,339 respondents, is representative of the Netherlands population. However, only respondents pertaining to the highly urbanized areas in the Netherlands were analysed (13.043 respondents), as selecting respondents only from the Rotterdam area would not yield a sufficient sample size.

The WoON dataset includes detailed information on individual and household characteristics. Furthermore, the dataset includes information on the intention to move house in the next two years after the interview, and information on the location and characteristics of the current residence. Households' willingness to move house within the next two years is measured by giving the respondents several options to choose. The options 'Possibly yes, maybe', 'I would like to but I cannot find anything', 'I have decided' and 'I have already found another house' were treated as indications that they intend to move house. In contrast, 'I haven't decided' or 'I don't know' were taken to suggest not having the intention to move. As independent variables, we added socio-demographics (gender, household composition, income, age of respondent, age of children, number of cars, working hours respondent and partner), house characteristics (type, ownership status, size, duration of living and value of dwelling) and variables related to the work commute (distance to work of the respondent and partner). As the dependent variable is categorized as the intention to move and no intention to move, we applied a binary logit analysis. The independent variables are all categorical variables and were effect-coded.

6. Study area

Rotterdam is a city in South Holland, the Netherlands, located geographically within the Rhine–Meuse–Scheldt river delta at the North Sea. It slowly grew into a major logistic and economic center. Its main road network links the harbour in the West to the East of the Country, while another major highway runs North-South. Nowadays, it is home to Europe's largest port and has a population of 624,799 (2014, city proper), ranking second in the Netherlands. The Greater Rijnmond area is home to approximately 1.4 million people and the Rotterdam The Hague urban area makes for the 168th most populous urban area in the world. Rotterdam is part of the yet larger Randstad conurbation with a total population of 7,100,000. It has 15 zones however as this study is related to housing, we considered only 10 zones, which includes the mostly dense areas.

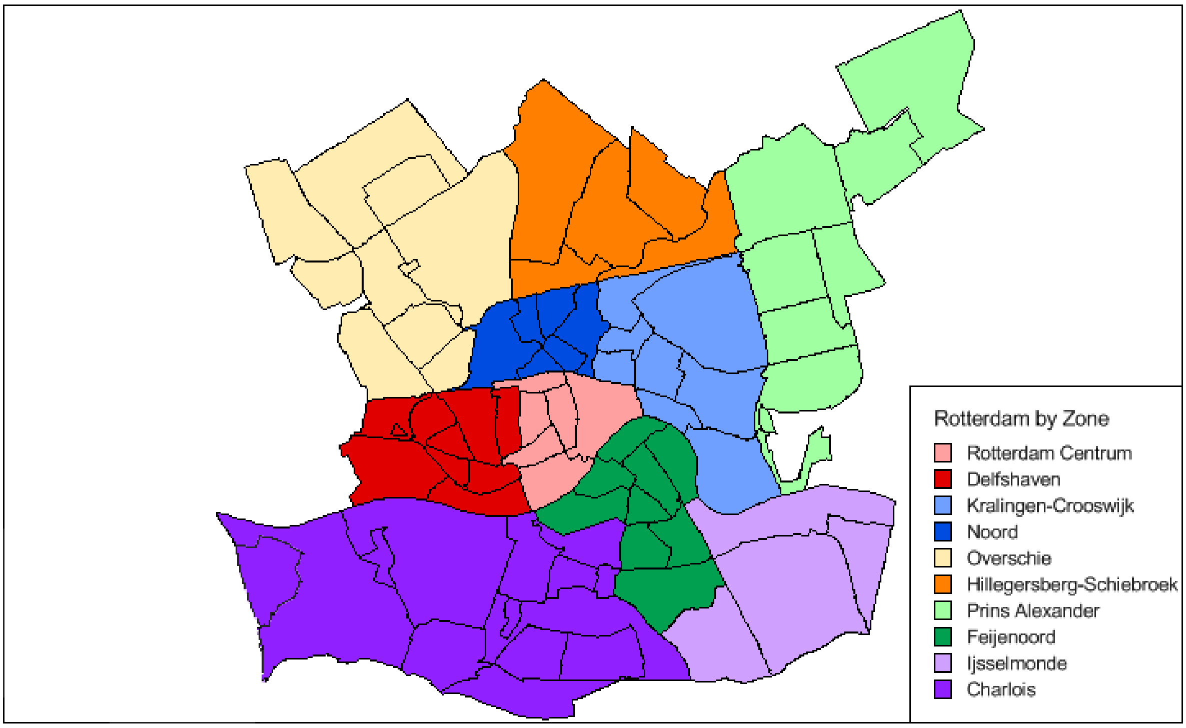

Figure 1. Rotterdam by zone

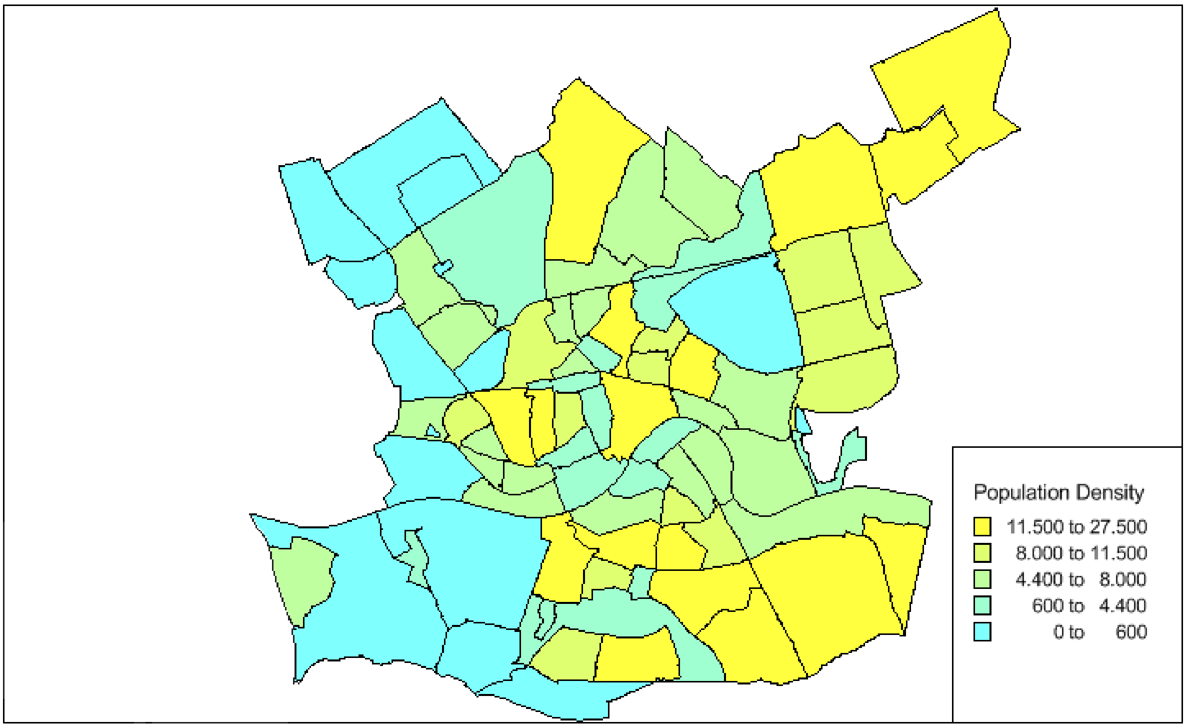

Figure 2. Population Density by postcode

7. Results

7.1 Intention to move

The analysis was conducted using NLogit version 5 (Greene, 2007). McFadden Pseudo R-squared was found to be 0.136. The results are shown in Table 1. The value for the constant suggests that on average the probability that respondents are intending to move is larger than the probability they do not intend to move.

Firstly, we will explain the effects of the socio-demographic variables on the intention to move. Looking at household composition, the results show that single worker and double non-workers have a negative effect on the intention to move. It suggests that in particular these categories, on average, have a lower intention to move house. Those results are in line with the literature. For singles, it is easier to move as they are not tied to other household members. However, single people in general have lower income than couples as there is only one source of income, which may make it difficult to afford new housing. Those living in single-family dwellings are known to be the least likely to intend to move (Clark & Dieleman, 1996; Helderman et al., 2004). As for the double non-workers, as they might be living on pension money, they willingness to move would also be constrained by income. The coefficients for double one-workers and double workers are positive and significant, meaning that those groups, on average, have a positive effect on the intention to move.

Regarding income, the two lowest income categories have a negative effect on the intention to move while the other categories were found to have a positive effect on the intention to move. This might be due to the direct effect of income on the affordability of a dwelling (de Groot, 2011).

Model results suggest that age of children also play a role for intention to move. Households with no children or with a child (the youngest) between the age of 6 and 11 intend to move more compared to others.

There is a decrease in the intention to move for an increasing age. It may reflect that with increasing age, people are more settled, while young people are more likely to move. The young adult years in particular are years of change since young people move because of education or work and try to settle their life.

Respondents without a car are more likely intending to move than respondents with one or more cars. This suggests that for respondents without a car it is more important to live in a place with good accessibility to work, services etc.

Estimated parameters for gender were not significant at conventional statistic levels.

When we look at the work related variables, people who do not work, or work 32 hours or more are more likely intending to move compared to the people who work 32 hours or less. This might be related to the income based on the working hours of people. Coefficients are not significant for working hours of partner.

Regarding the distance to work of respondents and partners, coefficients are not significant. Overall, results show that the utility households tend to attach to the residential situation is higher than the disutility of commuter travel.

When we look at type of dwelling, house and apartment are found to have a negative effect on the intention to move compared to the "other type" of housing which includes village houses, houses with shops and shared houses or rooms.

Looking at the duration of living, people living in a dwelling for more than 10 years are more likely intending to move compared to people living in a dwelling for 5 years or less. This may be due to the decay of the house facilities.

Considering tenure type, house-owners are less likely intending to move. This is an expected result as many studies (Speare et al., 1975; Clark & Dieleman, 1996; Dieleman, 2001; Helderman et al., 2004) show that home-owners are less likely to move than renters. Buying a house often involves long-term financial and non-financial commitments (Helderman et al., 2007).

Regarding the size of the dwelling, living in a dwelling 50 m^2 or less has a positive effect on the intention to move while living in a dwelling with more than 100m^2 shows a negative effect on the intention to move. In general, little space is an important reason for moving (Clark & Onaka, 1983; Rossi, 1955; Speare et al., 1975).

Considering the value of land, it is found that people living in lower valued lands are more likely to intend to move out than people living in higher valued land. This might be due to the environment and services that are less good in low-value lands. Thus, people intend to move out of their dwellings in such areas.

Table 1. Estimation results of intention to move in two years

Variable	Level	Coefficients
Constant		0.609***
Household Composition	Single non-worker	0.00062
	Single worker	-0.61234***
	Double one-worker	0.15504***
	Double workers	0.56857***
	Double non-workers	-0.11189*
Income	Below average	-0.28544***
	Average	-0.07207*
	More than average less than 2 times average	0.11654***
	Two times average or more	0.24097***
Age of children	No children	0.2191***
	Younger 6	-0.31794***
	6 to 11	0.3422***

Variable	Level	Coefficients
	Older 12	-0.24336***
Age of respondent	34 or less	1.25007***
	35 to 54	0.15767***
	55 to 64	-0.19729***
	65 to 74	-0.36603***
	>75	-0.84442***
Number of cars	No car	0.15506***
	1 car	-0.09372
	2 or more cars	-0.06134
Gender	Male	0.00873
	Female	-0.00873
Working hours respondent	no work	0.29759***
	Less than 32 hours week	-0.62411***
	32 hours or more week	0.32652***
Working hours partner	no work	0.04611
	Less than 32 hours week	0.00026
	32 hours or more week	-0.04637
Distance to work respondent	0-5km	-0.02732
	5-10km	0.02709
	More than 10km	0.00023
Distance to work partner	0-5km	-0.0066
	5-10km	0.00682
	More than 10km	-0.00022
Type of dwelling	House	-0.99433***
	Apartment	-0.60782***
	Other	1.60215***

Variable	Level	Coefficients
Years living in the dwelling	5 years or less	-0.27234***
	6 to 10	0.00324
	More than 10	0.2691***
Ownership	Owner	-0.19952***
	Renter	0.19952***
Size of the dwelling	50 m² or less	0.31483***
	50 to 99 m²	0.00332
	100 to 129 m²	-0.09323**
	130 m² or more	-0.22492**
Value of the dwelling (Euros)	74,999 or less	1.58196***
	75,000 to 149,999	-0.35713***
	150,000 to 249,999	-0.61283***
	250,000 or more	-0.612

Note: ***, **, *: Significance at 1%, 5%, 10% level

The empirical analysis examines the intention to move house as a function of socio-demographic characteristics, house attributes and work commute variables. Intention to move is an indicator of dissatisfaction with the housing situation, which can be conceptualized as a discrepancy between housing preference and the experienced housing situation. This discrepancy may ultimately lead to the changing dwelling situation and/or changing needs that may be triggered by life cycle events.

The results show that socio-demographic variables, house attributes and variables related to the work commute have plausible and expected effects on the intention to move. Overall, the results give insight into residential mobility, which in turn is important to understand changing land use and transport networks. Land use models should include residential mobility for forecasting future socio-demographics and land use patterns, which are also critical inputs to activity-based models.

7.2 Demographic Dynamics

In order to process knowledge and to conduct decision analysis in agent-based systems, population data is necessary. In the case of Albatross, it simulates activity-travel patterns of individuals and households as a function of their socio-economic profile. It is unrealistic to assume that all required data for such analysis can be provided by a single data source as it doesn't exist or even if it does, due to privacy problems it is not possible to obtain such data. Therefore, there is a need for the synthetic population. Albatross produces a synthetic population, which is based on the notion to derive individual and household profiles such that (i) aggregations of the derived data are consistent with available distributions for the city and (ii) the correlations in the derived profiles are consistent with those observed in sample data (Rasouli & Timmermans, 2013).

For this study a synthetic population of Rotterdam was generated by Albatross, which consists of 279.578 households and Rotterdam area postcode level specific. It contains information about the following socio-demographic variables:

- Gender: male, female
- Household composition: single non-worker, single worker, double one worker, double two workers, double non-workers
- Income: Below average, Average, More than average less than 2 times average, Two times average or more
- Age: Less than 34, 35 to 54, 55 to 64, 65 to 74, 75 or more
- Age of children: No children, Younger than 6, 6 to 11, Older 12
- Working hours (respondent): no work, less than 32 hours week, 32 hours or more week
- Working hours (partner): no work, less than 32 hours week, 32 hours or more week
- Number of cars: no car, 1 car, 2 or more cars
- Distance to work (respondent): 0 to5km, 5 to 10km, More than 10km
- Distance to work (partner): 0 to 5km, 5 to 10km, More than 10km
- Postcode of home location

For that purpose, the Dutch National Travel Survey (MON) and a division of the Netherlands into 1308 zones are used. Iterative proportional fitting (IPF) was used to synthesize individual data. The concept of a relation matrix was used to convert individual count data to household count data for age groups and work status. More specifically, an age-group relation matrix specifies the relation between our age groups and three household status positions for females and males. Again, the IPF technique is used to derive estimated cell frequencies, based on the MON sample data and marginal constraints, derived from demographic data. The frequencies of a similar work-status relation matrix were obtained in a similar vein. This matrix distinguishes no work, part-time work and full-time work, which are linked to the household status categories. It results in a distribution of 15 household types comprising 3×3 double work status groups, 3 single female work status groups and 3 single male work status groups (Arentze et al., 2007).

One of the aims of activity-based models is to predict future activity-travel patterns. Thus, there is a need for a representation of the spatially distributed population, while addressing future population transitions. Therefore, we generated a dynamic synthetic population by using an age-structured two-sex model for household dynamics.

The created synthetic population is used as input for the base year of the dynamic population. As this synthetic population is based on households, each individual in the household is added as a new record to the individual database for the purpose of dynamic population. By using that, two files are created. One is for keeping individual records, while the other is for keeping household records.

Individual records include household id, personal id, age, gender, civil status (single or married), position in the family (adult or child), work status (worker or non-worker) and life situation (dead or alive). Household records include household id, number of people in the household, number of children in the household and the household composition.

Changes in households are treated as time-dependent. For households such changes include demographic changes in the lifecycle such as aging, death, birth, marriage and divorce and all new or dissolved households resulting from these changes. If there is a change at the individual level, this change is updated also in the household file. In the model, time-dependent changes to be simulated are interpreted as events occurring to an individual with a certain probability in time interval t, t+1. The population is iterated each year and all the changes are located at the end of year t. Each year, the age of each individual is increased by 1 and logically their genders stayed the same. Each year the possible changes in the population are calculated.

These basic event probabilities are determined exogenously. For that purpose, a demographic sub-model is used to form an index file consisting of 1 and 0, indicating the change that will occur next year for each individual in the population. Basic event probabilities are based on age and gender of the individuals. The application of basic event probabilities uses Monte Carlo sampling based on the conditional probabilities that are derived from census surveys of Statistics Netherlands (CBS). The information that is used for that purpose is:

- The probability of death for males and females at different ages.
- The probability of giving birth to first, second, third or fourth child for a female at different ages.
- The probability of getting divorced of married couples for males and females at different age (the age information is categorised).
- The probability of getting married of singles for males and females at different age (the age information is categorised).

In addition, in order to match the single individuals for marriage, the sex-dependent age difference distributions, derived from the travel survey data were used. This information consisted of the probabilities of a man in an age group marrying a woman in all age groups. For that reason, first the individuals who can potentially get married are selected and then males and females are matched taking the age difference probabilities gathered from the baseline population into account.

The following assumptions are made for updating the population:

- Entry to the population from outside is allowed.
- When two single individuals get married, they form a new household. In the individual record, their civil status is changed to married from single. Moreover, their old household id is erased and they are assigned to a new household id together. Therefore, the information of number of people and number of children in the household is also updated in the household file. If there is a child(ren) attached to the single individual, child(ren) is also assigned to the new household.
- If there is a divorce event, the married couple is separated and thus their civil status is changed from married to single. One of the individuals keeps the same household id while the other is assigned a new id. If there is a child(ren) in the household, s/he stayed with the mother or father according the respectively the ratios of 90% and 10%, using Monte Carlo simulation.
- If a woman gives birth, this new person is given an id and added to the population in the individual file. The child's age is set to 0 and the gender is given randomly, civil status is set to single, position in the family is set to child and life situation is set to alive. In addition to that, child is added to the household that s/he belongs

to. In the household file, the number of children and number of households is increased by 1 for the household that the child belongs to.

- If an individual dies, this person's life situation is set to dead for the next year. Moreover, in the household file, the number of households is decreased for that person's household. If the death person is a child, the number of children in the households is also decreased by 1. If the dead person is a spouse, then the living spouse is assigned to be single.

7.3 Residential moves in Rotterdam

This section describes the procedures applied for simulating residential moves in Rotterdam. According to this procedure, the updated synthetic population is used. Although the synthetic population contains the information about the postcode of home locations, the characteristics of the dwelling are not present. As described in section 4, in order to assign dwellings to every household of the synthetic population, the WoON dataset was used. It contains the same socio-demographic variables as present in the synthetic population. However, the postcode of home locations is not known in the WoON dataset. Therefore, the two datasets were merged by concatenating "household composition", "income" and "age of children". In order to control for dwelling type per zone, the assignment of dwellings to households was constrained given the information showed in Table 2.

Table 2. Dwelling type per Zone – Source: Basisregistraties Adressen en Gebouwen –BAG 2012

Zone	House	Apartment	Other
(1) Rotterdam Centrum	7.3%	65.2%	27.4%
(2) Delfshaven	7.1%	79.5%	13.4%
(3) Overschie	25.4%	44.8%	29.8%
(4) Noord	4.5%	83.5%	12.0%
(5) Hillegersberg-Schiebroek	36.0%	49.1%	14.9%
(6) Kralingen-Crooswijk	9.9%	76.4%	13.7%
(7) Prins Alexander	39.1%	50.4%	10.4%
(8) Feijenoord	23.5%	66.4%	10.2%
(9) IJsselmonde	32.5%	54.5%	13.0%
(10) Charlois	15.3%	71.6%	13.0%

As a result, the following information was added from WoON dataset to the synthetic population: Type of dwelling: House, Apartment, Other; Ownership status: Owner, Renter; Value of land (Euros): €74,999 or less, €75,000 to €149,999, €150,000 to €249,999, €250,000 or more; Years of living: 5 years or less, 6 to 10 years, More than 10 years

Table 3. Movements between zones in Rotterdam – Source: Rotterdamcijfers.nl

Zone	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Rotterdam Centrum	**37%**	14%	2%	10%	6%	11%	6%	7%	2%	4%
(2) Delfshaven	7%	**48%**	3%	9%	3%	7%	6%	7%	4%	8%
(3) Overschie	3%	14%	**43%**	7%	6%	5%	6%	6%	5%	4%
(4) Noord	7%	13%	4%	**36%**	9%	12%	7%	5%	2%	4%
(5) Hillegersberg-Schiebroek	5%	6%	4%	9%	**51%**	7%	10%	4%	2%	3%
(6) Kralingen-Crooswijk	12%	10%	2%	11%	4%	**44%**	8%	4%	2%	3%
(7) Prins Alexander	4%	6%	2%	5%	5%	7%	**61%**	4%	3%	4%
(8) Feijenoord	4%	8%	1%	4%	2%	4%	4%	**46%**	12%	16%
(9) IJsselmonde	2%	5%	1%	2%	2%	3%	6%	15%	**50%**	13%
(10) Charlois	2%	8%	2%	3%	2%	3%	4%	17%	11%	**50%**

Table 4. Transitions probabilities: Ownership status and Dwelling type – Source: WoON 2012

		Owner future dwelling			Renter future dwelling			Sum
		House	Apartment	House	Apartment	House	Apartment	
Owner current dwelling	House	8.9%	39.4%	3.4%	27.1%	20.7%	0.5%	100%
	Apartment	6.0%	18.5%	1.1%	39.7%	33.2%	1.6%	100%
	Other	10.5%	21.1%	5.3%	21.1%	36.8%	5.3%	100%
Renter current dwelling	House	16.7%	56.8%	7.3%	8.5%	10.6%	0.1%	100%
	Apartment	8.4%	63.4%	2.3%	8.6%	17.1%	0.2%	100%
	Other	9.8%	61.2%	17.3%	1.9%	9.3%	0.5%	100%

Consequently, the occupancy matrix that will be used in the simulation is obtained by combining the household matrix and dwelling matrix. The occupancy matrix contains all households occupying a dwelling and also all dwellings occupied by households.

The simulation of households to move in the synthetic population were also controlled by other probabilities found in statistics of the Netherlands: dwelling types per zones (showed before on Table 2), movements within and between zones (Table 3) and constrained by transition probabilities regarding ownership status and dwelling type (Table 4).

8. Conclusions

In this extension of the Albatross model, the “dynamic synthesized population” and “residential moves” components are merged. As described, some events can be applied separately to the population or to dwellings. However, events such as marriage, birth of a child or divorce, require changes that must be applied to both the population and dwellings. For simulations, the households are assigned to dwellings in the Rotterdam area. Consequently, all households occupy a dwelling. In this study, we do not consider migration from other cities.

At the end of the simulation for each year, firstly the households are progressed in their lifecycles. For instance, every member of the population is aged by one year, some people died, children were born, people got married or divorced, etc. However, the dwelling that they are living is still the same. This means that the households who were satisfied with their dwellings may be dissatisfied with their dwelling at the end of simulation period. Since, with the changes in the lifecycle, the needs of households with respect to the dwelling might have changed and they might be intending to move.

This is handled in the housing relocation model by including the updated population (t+1). The behaviour of the households is determined by the intention to move model. The intention to move of a household is a function of socio-demographic characteristics, housing profile and work accessibility variables. The value for intention to move is used to sample the households looking for a new dwelling. Then the households look for a suitable dwelling considering the type of house, ownership status and the zone of dwelling. This is simulated in the search step of the simulation. As the last step, households decide whether to accept the dwelling. In the end of the simulation, migration flow of households by dwelling type, ownership and zones and population changes are calculated. This output will be used as input in Albatross in order to improve it by considering the long-term decisions and their effects on short-term decisions such as daily activity-travel behavior.

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