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Accessibility modeling and evaluation: The TIGRIS XL land-use and transport interaction model for the Netherlands

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ABSTRACT

In current practice, transportation planning often ignores the effects of major transportation improvements on land use and the distribution of land use activities, which might affect the accessibility impacts and economic efficiency of the transportation investment strategies. In this paper, we describe the model specification and application of the land use transport interaction model TIGRIS XL for the Netherlands. The TIGRIS XL land-use and transport interaction model can internationally be positioned among the recursive or quasi-dynamic land-use and transport interaction models. The National Model System, the main transport model used in Dutch national transport policy making and evaluation, is fully integrated in the modeling framework. Accessibility modeling and evaluation are disaggregated and fully consistent, which is not common in accessibility modeling research. Logsum accessibility measures estimated by the transport model are used as explanatory variables for the residential and firm location modules and as indicators in policy evaluations, expressing accessibility benefits expressed in monetary terms. Modeling results indicate that accessibility changes from transport investments in the Netherlands have a significant but modest positive influence on the location choice of residents and firms. This is probably mainly due to the spatial structure and already dense and well developed transport networks, and the large influence of national, regional and local governments on the Dutch land use markets.

1. Introduction

Common sense and a good deal of research suggest that major changes in the transport system influence patterns of urban development and location choices of households and firms, and that major changes in land use patterns influence the number of trips, and their destinations and modes. In short, land use and transportation systems are closely intertwined, and models used to support transportation planning need to be integrated with land use models to capture these effects (Waddell, 2011; Chang, 2006). The TIGRIS XL model is an example of such a land-use and transport interaction model.

The TIGRIS XL land-use and transport interaction model can internationally be positioned among the recursive or quasi-dynamic models, in which the end state of one time period serves as the initial state of the subsequent time period (Simmonds, Waddell, & Wegener, 2013). The TIGRIS XL model has further its composite structure, combining differently constructed submodels for different processes, in common with other LUTI models such as the DELTA modeling package in the UK (Simmonds, 1999), the Urbansim model (Waddell, 2001, 2002, 2014) and the IRPUD model for the Dortmund region (Wegener, 2011).

The paper contributes to the literature by presenting a comprehensive overview of how accessibility is included in the TIGRIS XL model, in the model estimations, its applications and evaluations in planning practice. The paper also highlights several features of particular interest, which are related to the availability of data and planning tradition in the Netherlands. Specific contributions are:

- Firstly, accessibility modeling and evaluation are disaggregated and fully consistent, which is not common in accessibility modeling research. The inclusion of the National transport Model System (NMS), a disaggregate discrete choice based transport model in the modeling framework enables using person type and purpose specific utility-based accessibility indicators (so-called logsums) in the TIGRIS XL model and in policy evaluations.

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- Secondly, improved insight in influence of transport on land-use as both the coefficients of the labor and housing market module are based upon formal statistical estimations using detailed large scale spatial data sources. While in international practice, often due to data limitations, informal calibration procedures or estimations based upon small scale surveys are more commonly applied to fit most LUTI models.
- Thirdly, the model is tailored to be applied in actual planning practice. Regardless of the large research efforts and growing number of available models is their use in practice still not common (e.g., see Waddell, 2011; Waddell, Ulfarsson, Franklin, & Lobb, 2007). The TIGRIS XL model, is developed for and owned by the Ministry of Infrastructure and Environment, which provide an operational focus. This means that the model need to be adjusted to and/or integrated with other planning instruments and procedures. This gives other constraints and opportunities than the models developed in a more academic environment. The model has furthermore been designed to operate in interaction with sector specific models, like the demographic model and National Model System for transport, as applied by the Dutch government.

Section 2 of this paper describes the structure of the modeling framework and Section 3 describes the applied accessibility measures in more detail. Section 4 describes the residential location choice model and its estimation results. A similar description is made in Section 5 for the employment location module. In both sections specific attention is given to how accessibility drives the location of households and employment. Section 6 presents a model application examining the accessibility effects of land use and public transport investment programs. Finally, in Section 7 presents the conclusions and discusses the results.

2. Structure of the TIGRIS XL model

2.1. Functional design

The TIGRIS XL model is an integrated system of sub-models addressing specific sectors. The model uses time steps of one year for most of its modules, and the model is a recursive or quasi-dynamic type of model, in which the end state of one time period serves as the initial state of the subsequent time period. The underlying assumption is that the system is not in equilibrium at a certain moment in time; therefore no general equilibrium is simulated within one time step, but that depending on time lags the system moves towards an equilibrium. For example, a high demand for houses at a certain location can result in additional housing construction at that location in the following years. The land-use model is fully integrated with the National transport Model System (NMS) of the Netherlands and the land-use modules and transport model interact, for reasons of computation time, every five years.

The TIGRIS XL model consists of five modules addressing specific markets. Core modules in TIGRIS XL are the housing market and labor market module; these modules include the mutual interaction between the population and jobs and the effect of changes in transport on residential or firm location behavior. The model has a multi-level set-up and different spatial scale levels are distinguished, namely the regional level (COROP, 40 regions in the Netherlands) to simulate interregional flows, the municipality level and finally the level of local transport zones of the National Model System (1379 zones covering the Netherlands). Fig. 1 presents an overview of the TIGRIS XL (TXL) model and the main relationships between the modules, for a more detailed description reference is made to Zondag (2007). In this section, we briefly describe the demography module and land and real estate module. The transport market, housing market and labor market modules are described in more detail in Sections 3–5.

The features of the transport market, housing market and labor market module are described in Section 3–5.

2.2. Demography module

The TIGRIS XL model uses the regional demographic model PEARL (de Jong, 2013) of the National Bureau of Statistics and Netherlands Environmental Assessment Agency as basis for its demographic module. The module works bottom-up and the transition processes of the population and households at the zonal level. The population is administrated by year of age, gender and household position and the transitions, such as birth, mortality and changes in household position, are applied at this level of detail as well. Besides the demographic characteristics the population and household data is enriched with socio-economic information regarding status of employment and household income.

2.3. Land and real estate market

The land and real estate market module processes the changes in land-use and buildings, office space and houses, and addresses both brown field and green field developments. The land and real estate market module interacts with the housing market and labor market module. The module distinguishes the land market, including land regulation policies, and the real estate market addressing the development or restructuring of buildings. The modeling of the changes in land-use depends on the user settings for the level of market regulation by the government. This can vary from a regulated residential land-use planning system to a unregulated residential land market. In a regulated market, all supply changes are planned by the government and handled as exogenous input for the model. In a less regulated market, supply changes are triggered by the preferences of the actors.

These land developments are restricted by the availability of land and depend on the behavior of land owners and project developers. The development ratio, part of the available land that will be taken into development, depends here on how profitable a location is. And profit is here calculated as the difference between the market price of a building minus the construction and land costs. The development ratio further depends on the overall market conditions. The land and real estate market in the Netherlands is considered as an oligopolistic market with a few large players regulating housing production. In its specification the TIGRIS XL model benefits of the experiences with the Houdini housing market model of the Netherlands (Eskinasi, Rouwette, & Vennix, 2011).

3. Transport market and accessibility measures

TIGRIS XL uses the National Model System (NMS) of the Netherlands as transport model (Hofman, 2002; Joksimovic & van Grol, 2012). This model is rooted in discrete choice theory and a first version of the model has been operational in the Netherlands since the mid 1980s. The version of the NMS transport model in TIGRIS XL distinguishes 8 travel purposes, 5 modes, 1379 zones and over 354 person types, (depending on the travel purpose). The transport modes are car driver, car passenger, train, BTU (Bus, Tram, and Underground), and slow mode (split into cycling and walking). Five home-based travel purposes are included (home-work, home-business, home education, home shopping and home-other) and three non-home travel purposes (work-business, work-education and work-other).

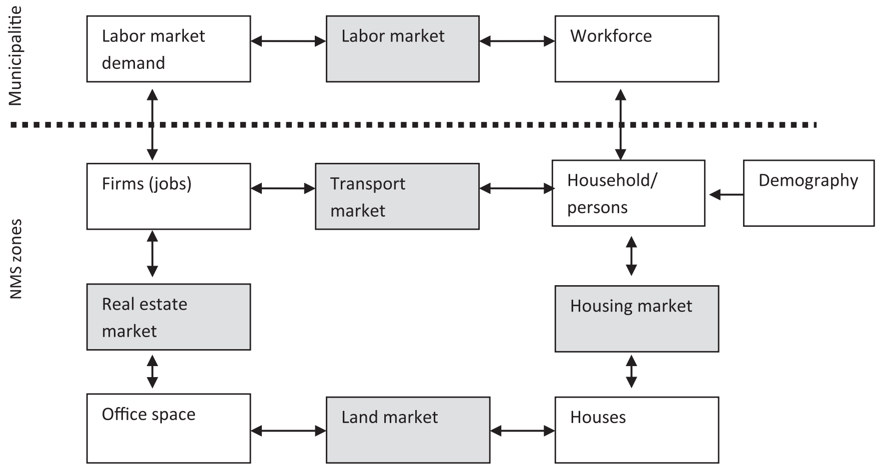

Fig. 1. Functional design of the TIGRIS XL model.

Accessibility is the main 'effect' of a transport system influencing spatial developments and settlement as calculated in the real estate-, residential location - and firm location modules. Therefore the selection of appropriate accessibility indicators for households and firms is an important aspect of LUTI models. Accessibility indicators can be categorized into four groups: location-based, activity-based and utility based accessibility measures (Geurs & van Wee, 2004).

For TIGRIS XL the utility-based accessibility measures, also referred to as logsums, are used as the preferred accessibility measure. These measures are rooted in economic theory, following the principle of utility maximization, and therefore the behavior of these accessibility measures is consistent with rational economic behavior. Further the utility-based accessibility measures can also cover a nested structure as shown by Zachary's theorem (Daly & Zachary, 1976). In such a nested logit the integral of the probability function is the logsum and this can represent for example the utility of combined mode- and destination choices. This option facilitates a consistent integration of multiple choices in one value, hereby reflecting the relative importance of each option.

The logsum measures are first used to measure the accessibility of a location. The logsum measures, derived from the NMS, include personal characteristics and preferences, and characteristics of the transport and land use system. Including the individual component of accessibility means that more realistic accessibility indicators, that represent more close the specific activity pattern and preferences of the households or firms, can be included as explanatory variable in residential or firm location choices. These logsums capture the utility of different available modes and destinations and are purpose specific. In TIGRIS XL the residential location choice is made at a household level and therefore depends on the composition, number and type of persons, of a household. In a first step the tour-based logsum values are transformed into person type specific logsum values depending on the tour generation characteristics of the person types. Next, the person type specific logsum values, are transformed into household type specific logsum indicators.

The travel resistance between the current residential location and a possible new locations is also measured with an utility based travel time indicator. The travel time and costs of the available transport modes, are aggregated into one generalized cost. In this case, the utility of both car and public transport modes are calculated (from the transport times and costs between zones) and summed into a logsum. This travel time indicator expresses the resistance for a residential move between old and new location. Changes in the travel times affect this resistance and therefore change the probability a new location is chosen. For example, if the travel times between regions change, this may affects the size of the urban housing market.

The influence these accessibility indicators on the location choices of residence and firms has been estimated tested and is reported in Section 4 and 5.

4. Residential location choice and influence of accessibility

This section describes the structure and calibration of the housing market module. The housing market module simulates housing availability (supply), and residential mobility (demand). The first version of the housing market module has been published in Zondag and Pieters (2005). The housing stock is simulated in the real estate market module and includes demolished houses and newly constructed houses. The number of vacant houses in a zone depends on changes in housing stock and factors influencing their occupancy such as household dissolution and migration.

4.1. Structure of the model

Fig. 2 presents the various steps at the demand side of the housing market. First a household makes a decision to move or to stay. Once a household decides to move this household enters the residential location choice module. The residential location choice module consists of a nested structure, first a household chooses a region and second a specific zone within a region.

The estimations of the move/stay decision and the residential location choice are based on a tri-annual national housing market survey for 2006 and 2009. For these years, the national housing market survey contains over 100 thousand records. The housing market surveys are coded at a very detailed spatial level of four digit postal zones. This allows an estimation of the housing market module at the level of transport zones.

The housing market module is segmented to household type, which allows household type specific residential mobility and location preference. The households in the housing surveys are aggregated to thirteen household types based on household size, children in the household, number of workers and age. The following table shows the number of observed household relocations in the 2006 and 2009 dataset.

A wide set of explanatory variables were tested during the move/stay and residential location choice model estimation phase. In addition to the previously discussed accessibility indicators, other variables address neighborhood characteristics and prices.

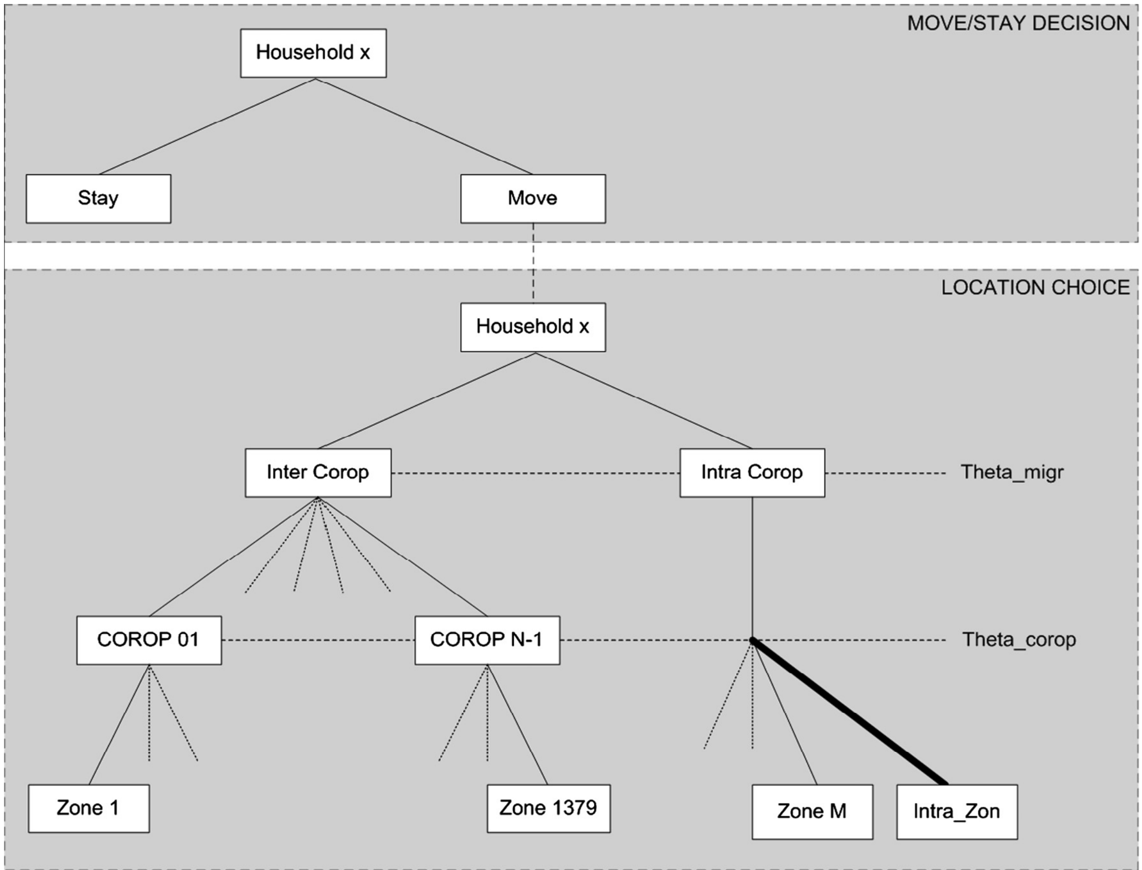

Fig. 2. Structure of the housing market module.

The selection of explanatory variables to be tested is based on a review of other operational models (Simonds & Feldman, 2005; Urbansim, 2014; Wegener, 2011), literature on residential location choices (Ben-Akiva & Bowman, 1998; Kendig, 1984; Oskamp, 1997; Zhou & Kockelman, 2008) and the data availability in the Netherlands. The ratio of price and income is a less dominant variable in the Netherlands (Oskamp, 1997), due to large scale rent control on the public housing market, in comparison with international findings (Kendig, 1984). Further the research does not classify different dwelling types due to data restrictions and scale level of the model.

4.2. Estimation results for move/stay

The move/stay decision is mainly influenced by dynamic changes such as change of job/study or changes in the household composition (e.g. marriage, birth of child). In the survey data it is not possible to link the move/stay decision to this type of dynamic changes and therefore in the model estimation static variables such as age or household size were used. Table 1 describes the explanatory variables in the move-stay model.

Table 2 presents the estimation results for the move/stay models. The large differences in the stay constant show that households have very different residential mobility: older households (type 12 and 13) have a high stay constant, and thus a lower probability of relocating. Younger households, with the head of the household below 35 (type 2, 5 and 7) are the most mobile households. Application of the move stay module yields large differences in residential mobility, from only 4% yearly moves for households above 65, to around 25% for households under 35.

Table 2 presents both significant and insignificant coefficients to ensure the best model fit. For policy evaluation purposes one needs to be careful with insignificant coefficients for relevant policy variables. The results show that the percentage of vacant houses in a region has a significant impact on the dynamics of the housing market (for 10 out of the 13 households). This finding confirms an ongoing discussion in the Netherlands that supply side restrictions in the housing market seriously affect the dynamics of housing and labor market. The result further indicate that accessibility affects the willingness of people to move from a location: less people are willing to move away from easily accessible locations than from less accessible locations. Note, however, that this effect is for most household types not statistically significant.

Table 1
Explanatory variables in move-stay models.

Variable	Description	Unit
stayconst	ASC for stay alternative	0/1 dummy
staywmtBC	% Of zone peripheral urban area (reference)	Percentage
staywmtCD	% Of zone village area	Percentage
staywmtCS	% Of zone city center area	Percentage
staywmtGS	% Of zone peripheral low urban density	Percentage
staywmtLW	% Of zone in rural area	Percentage
staypvac	% Of vacant dwellings	Percentage
stayls_com	Accessibility of location for commuting tours	Logsum
stayls_edu	Accessibility of location for education tours	Logsum
stayls_shp	Accessibility of location for shopping tours	Logsum
stayls_oth	Accessibility of location for other tours	Logsum

4.3. Estimation results for residential location choice

The location choice preferences of the thirteen household types have been estimated following a nested structure (see Fig. 2) and

Table 2
Estimation results move/stay models.

Household type	1	2	3	4	5	6
#Pers	1	1	1	>1	>1	>1
#Child	0	0	0	0	0	0
#Workers	0	>0	>0	0	1	1
Lft 65+	No	No	No	No	No	No
Lft <35		Yes	No		Yes	No
Observations	6457	5149	9789	4337	1679	6490
Final log (L)	−2765.2	−3489.9	−3604.2	−1523.6	−1159.1	−1792.2
D.O.F.	7	7	6	7	7	7
Rho^2(0)	0.382	0.022	0.469	0.493	0.004	0.602
stayconst	1.535 (2.1)	−0.3188 (−0.7)	3.280 (16.9)	2.302 (3.1)	−0.9573 (−1.0)	4.249 (5.8)
staywmtCS	−0.00305 (−2.4)	−0.00287 (−2.7)	−0.00152 (−1.3)	−7.39e−4 (−0.3)	−0.00268 (−1.5)	−0.00404 (−2.1)
staywmtBC (ref)						
staywmtGS	8.67e−4 (0.6)	−0.00112 (−0.9)	−0.00425 (−3.4)	5.35e−4 (0.3)	−0.00112 (−0.5)	−0.00267 (−1.5)
staywmtCD	0.00166 (1.2)	−0.00657 (−6.0)	−0.00104 (−1.0)	0.00306 (2.0)	−0.00255 (−1.4)	0.00346 (2.3)
staywmtLW	−0.00120 (−0.7)	−0.00184 (−1.3)	−0.00265 (−2.0)	0.00410 (2.1)	−0.00178 (−0.8)	5.10e−4 (0.3)
staypvac	−0.00272 (−0.1)	0.02015 (1.4)	−0.07886 (−6.6)	−0.1074 (−6.4)	−0.02457 (−1.4)	−0.1455 (−9.3)
stayls_com					0.1809 (1.5)	
stayls_edu	0.02699 (0.3)					
stayls_shp		0.1099 (1.2)				
stayls_oth				0.3275 (1.7)		0.08483 (0.4)

Household type	7	8	9	10	11	12	13
#Pers	>1	>1	>1	>1	>1	1	>1
#Child	0	0	>0	>0	>0	0	0
#Workers	>=2	>=2	0	1	>=2		
Lft 65+	Nee	Nee				Ja	Ja
Lft <35	Ja	Nee					
Observations	5276	8949	4960	14,145	24,313	14,511	14,824
Final log (L)	−3608.8	−3486.1	−1837.9	−5485.8	−9069.9	−3370.5	−3368.9
D.O.F.	7	7	6	7	7	7	6
Rho^2(0)	0.013	0.438	0.465	0.440	0.462	0.665	0.672
stayconst	−0.3253 (−0.6)	2.979 (4.5)	3.789 (16.0)	3.038 (6.6)	3.626 (8.9)	4.691 (10.1)	4.492 (20.4)
staywmtCS	−0.00511 (−4.3)	−0.00456 (−3.8)	−0.00392 (−2.2)	−0.00187 (−1.8)	−0.00302 (−3.4)	−0.00219 (−1.4)	−2.56e−4 (−0.1)
staywmtBC (ref)							
staywmtGS	−0.00167 (−1.4)	0.00111 (0.8)	−0.00389 (−2.4)	−1.07e−4 (−0.1)	−1.15e−4 (−0.1)	−0.00306 (−2.3)	−0.00245 (−1.7)
staywmtCD	−7.79e−5 (−0.1)	0.00313 (3.0)	0.00276 (1.7)	0.00290 (3.5)	0.00396 (6.7)	−0.00192 (−1.6)	−2.34e−4 (−0.2)
staywmtLW	−0.00381 (−3.2)	0.00222 (1.6)	−0.00540 (−3.0)	0.00186 (1.7)	0.00420 (5.2)	−0.00509 (−3.3)	−0.00335 (−2.6)
staypvac	−0.04484 (−4.9)	−0.08486 (−7.8)	−0.1152 (−8.2)	−0.1179 (−13.7)	−0.1284 (−19.2)	−0.1597 (−13.7)	−0.1128 (−8.4)
stayls_com	0.1185 (1.9)	0.00653 (0.1)		0.06273 (1.1)			
stayls_edu							
stayls_shp						0.1410 (1.4)	
stayls_oth					0.00659 (0.1)		

therefore the model includes regional as well as zonal variables. The explanatory variables in the residential location choice model are summarized in Table 3 and include type of neighborhood, local amenities, social-economic indicators, average price of houses in a zone, vacant houses, accessibility of the location and the logsum travel time indicator between the current and new location.

All variable are briefly described in the table, but the transport related variables are explained hereunder in more detail.

- *Accessibility between zones* (i_1_dist, loslogsum, i_loslogsum), the travel time indicators express the impedance between location of origin and new location. For inter- and intraregional relocations, different parameters are estimated to allow a different sensitivity. And to better represent the propensity of households to relocate over short distances, the logsum travel time indicator was combined with the inverse of travel distance.
- *Accessibility of locations*, household type specific logsum variables (acc_oth10 k and acc_oth) have been tested for all household types. For each household type purpose specific logsums, such as work, education, other and all purposes, have been tested to select the variable with best fit.

A variety of model specifications has been tested to find the preferred model structure as presented in Tables 4 and 5. The nested structure has been confirmed for most household types and the parameters for the nesting coefficients are between 0 and 1. For all household types the travel time between current location and new location was a dominant variable. However the distances decay function for interregional migrations is less steep than for intraregional moves. The interregional moves are more likely to be initiated by a change of workplace, or education, and much less by housing and accessibility preferences. The match between the modeled migration distance distribution and observed distribution in the surveys was an important evaluation criteria in selecting the optimal model structure, and accessibility attributes.

The following figure illustrates the gradual effect of alternative model specifications by comparing the observed migration distance, with the migration distance resulting from the estimated model. The first model was not nested and all location alternatives, within region and interregional, had similar substitution patterns. This leads to a model that underestimates the migrations between 4 and 8 km, and an overestimation of migrations in the 16–32 km category. Applying a regional nesting structure, brings the modeled distribution more close to the observed. Adding the travel distance and accessibility indicators to the models improves the fit of the distribution, in particular for migrations over short distances, 4–8 km (see Fig. 3).

The accessibility of the location itself is mainly important for the short distance relationships and the logsum accessibility is included for locations within 10 km. The estimation results of this

Table 3
Explanatory variables residential location choice model.

Variable	Description	Unit
thetamigr	Nesting coefficient for inter or intraregional choice	–
thetacorop	Nesting coefficient for regions	–
intracorop	Dummy for alternative in origin region	0/1 dummy
intrazon	Dummy for alternative in origin zone	0/1 dummy
wozwaarde	Average dwelling price in zone	Euros
wmtCS	% Of zone city center area	%
wmtBC (ref)	% Of zone peripheral urban area (referentie)	%
wmtGS	% Of zone peripheral low urban density	%
wmtCD	% Of zone village area	%
wmtLW	% Of zone in rural area	%
area_facil	Area of facilitating functions	m^2
area_work	Area of work related landuse	m^2
area_water	Area of watersurface	m^2
Popdens	Population density	pop/m^2
income	Average yearly income of a household in a zone	Euros/year
i_1_dist	1/Distance for intraregional relocations	1/m
loslogsum	Accessibility to alternative	Logsum
i_loslogsm	Accessibility to alternative for intraregional alternative	Logsum
acc_oth10k	Accessibility for trip purpose other for location within 10 km	Logsum
acc_oth	Accessibility for trip purpose other	Logsum

variable are significant and plausible for most household types. The interpretation of this result is that households moving within a region value their local accessibility in their location choice. A second reason might be that they have a better perception of the actual accessibility within their region.

The residential location choice behavior differs by household type. Dwelling price is significant for most household types, and has a negative sign: a higher dwelling prices reduces the probability of a household choosing the location. Urban areas with a high urban density are the least preferred by elderly in a two (or more) person household, and multi person household without workers. The income parameter captures a social economic clustering effect: in some neighborhoods homogenous income groups cluster. The households that have the strongest preference for higher income neighborhood (positive and significant parameters for income) are households with one or more workers (type 11, 6, 8, 10) Households above 65 have their own typical very local pattern. First of all these households do not move often and if they make a move it is in the neighborhood of the current location.

The market clearance mechanism, to match housing supply and demand, follows an iterative procedure to match supply and demand within a time step. In case of excess demand the utility of these locations are adjusted for each of the household types. This adjustment represents a change in prices as well as longer waiting times on the more regulated part of the rental market. In the long run, depending on the selected market conditions by the model user, housing demand can influence the housing prices and housing construction.

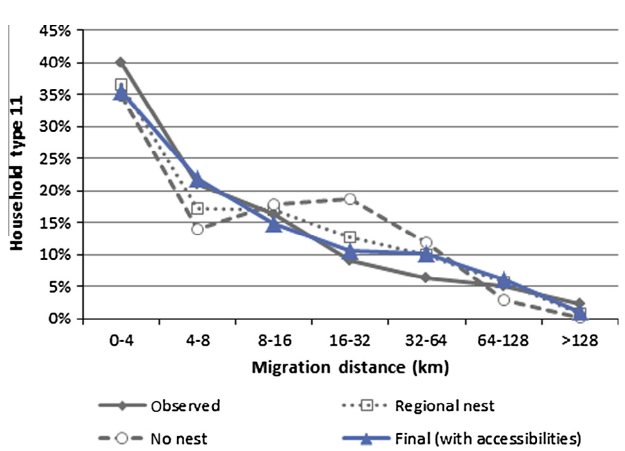

Fig. 3. Example of impact of model specification on migration distances distribution.

5. Employment location choice and influence of accessibility

This paragraph briefly describes the integration of a population–employment interaction model in the TIGRIS XL framework. For a more detailed description we refer to de Graaff and Zondag (2013). The labor market module in TIGRIS XL is simulates the changes in number of jobs by sector at the level of municipalities and transport zones. The developments in employment by sector calculated at the municipality level are subdivided to the zonal level by sector specific allocation rules, based on population, industrial sites or office space.

The population–employment interaction module does not only include the interaction between population and employment but also between economic sectors. The approach can be labeled both as 'jobs follow people' and 'jobs follow jobs'. The objective is to avoid postulating a priori an endogenous relation between population and employment. The main principle is a simultaneous dynamic process between population and employment; both might influence each other at the same time. To analyze this phenomenon a multisectoral simultaneous model has been developed and estimated along the lines of Boarnet (1994), with as crucial difference that various economic sectors are differentiated. The model estimation procedure allows controlling for spatial spillovers in the endogenous variables and incorporates spatially correlated errors. The module is estimated using the GS3SLS estimator of Kelejian and Prucha (2004), and incorporates endogenous spatial spillovers as well as intra-sector and inter-sector linkages.

The location preferences of firms, in the regional labor market module, depend on the value of location variables and the parameter values. The model simulates the behavior of firms at the level of jobs. This simplification is similar to other LUTI-models like IRPUD (Wegener, 2011), MEPLAN (Williams, 1994) and DELTA (Simmonds, 1999), although more recent research work is available focusing on modeling firm demography and mobility (de Bok, 2009; Kumar & Kockelman, 2008; Maoh & Kanaroglou, 2009; Moeckel, 2009).

The change in the number of jobs in a municipality depends on the change in the number of jobs by sector at the national level, the so-called changes in economic structure and part of the scenario input of the model, and on local characteristics, here addressed as location factors. The model measures spatial externalities from accessibility, through an impedance matrix with logsums between municipalities, W, multiplied with a vector of a specific spatial variable (e.g. the population or employment in a sector). The final employment location model predicts the changes in the number of jobs, $\Delta E^s_{r,t}$, for sector s in a municipality r, in year t, as:

$$\Delta E^s_{r,t} = Y_{r,t}\beta_{E^s} + \delta_p(W \times P_{r,t-1}) + \sum_{j\neq s}\delta^j_E\left(W \times E^j_{r,t-1}\right) - \lambda_{E^s}E^s_{r,t-1}$$

with $Y_{r,t}$ as a set of exogenous variables (e.g. land use), $(W \times P_{r,t-1})$ as the accessibility of the population in year $t-1$, $(W \times E^j_{r,t-1})$ as the accessibility of the employment in sector j in year $t-1$, and $E^s_{r,t}$ as the employment in sector j in year $t-1$. For a full derivation of the employment location model see de Graaff and Zondag (2013).

At the municipality level specific models have been estimated for seven economic sectors to account for the differences in location behavior between economic sectors. The parameters have

Table 4
Estimation results for location choice models for household types 1–6.

Household type	1	2	3	4	5	6
#Pers	1	1	1	>1	>1	>1
#Child	0	0	0	0	0	0
#Workers	0	>0	>0	0	1	1
Lft 65+	No	No	No	No	No	No
Lft <35		Yes	No		Yes	No
Observations	992	2245	1192	502	840	536
Final log (L)	−3458.3	−7966.4	−4268.5	−2024.9	−3583.3	−2064.4
D.O.F.	18	18	18	17	17	18
$Rho^2(0)$	0.518	0.509	0.504	0.442	0.410	0.467
intrazon	0.5312 (1.2)	0.2681 (1.0)	2.137 (5.7)	1.264 (2.1)	−0.5894 (−1.4)	3.041 (5.4)
intracorop	3.992 (6.1)	4.453 (6.5)	4.229 (4.6)	3.417 (4.4)	2.454 (5.7)	3.740 (4.2)
wozwaarde	−3.43e−6 (−2.6)	−1.36e−6 (−1.6)	−1.55e−6 (−1.4)	−2.95e−7 (−0.2)	−3.43e−6 (−2.4)	−5.31e−6 (−3.2)
wmtCS	−0.00519 (−3.2)	−0.00242 (−2.6)	−0.00145 (−1.1)	−0.00512 (−2.2)	−0.00378 (−2.4)	−0.00461 (−1.9)
wmtBC (ref)						
wmtGS	1.56e−4 (0.1)	−2.26e−4 (−0.2)	0.00306 (2.0)	−0.00221 (−1.0)	−6.07e−4 (−0.4)	7.96e−4 (0.4)
wmtCD	−0.00515 (−2.5)	−0.00550 (−4.1)	−0.00249 (−1.5)	−0.00444 (−1.8)	−0.00490 (−2.3)	2.44e−4 (0.1)
wmtLW	0.00145 (0.7)	−0.00150 (−1.0)	0.00409 (2.2)	9.47e−4 (0.4)	7.96e−4 (0.4)	0.00546 (2.2)
i_1_dist	1.346 (4.7)	1.552 (8.7)	1.568 (6.2)	1.856 (4.6)	0.8744 (2.8)	2.244 (5.9)
loslogsum	0.3698 (6.7)	0.6586 (13.2)	0.8089 (8.5)	0.4342 (5.7)	0.4682 (13.5)	0.6918 (6.8)
i_loslogsm	1.483 (6.9)	1.409 (11.1)	1.476 (8.1)	0.9616 (3.6)	1.247 (6.2)	1.462 (5.8)
area_facil	3.51e−7 (2.1)	9.97e−8 (0.8)	1.73e−8 (0.1)	3.22e−7 (1.5)	1.42e−7 (0.8)	3.27e−7 (1.6)
area_work	−1.72e−7 (−2.4)	−5.29e−8 (−1.2)	−4.45e−8 (−0.7)	−3.34e−7 (−3.2)	−5.04e−8 (−0.7)	−1.08e−7 (−1.3)
area_water	−4.68e−8 (−1.1)	5.21e−9 (0.2)	1.57e−8 (0.6)	−2.65e−8 (−0.6)	−2.85e−8 (−0.8)	2.08e−8 (0.7)
Popdens	−76.84 (−6.2)	−17.70 (−2.8)	−24.66 (−2.9)	−71.77 (−3.7)	−17.53 (−1.8)	−53.98 (−3.1)
income	−5.23e−5 (−3.8)	−6.24e−5 (−6.9)	−9.39e−6 (−0.8)	−5.52e−5 (−3.0)	−7.84e−5 (−5.4)	5.30e−5 (2.8)
acc_oth10 k	0.2544 (4.5)	0.1911 (5.7)	0.1685 (3.6)	0.3179 (3.9)	0.2944 (5.2)	0.1235 (1.7)
acc_oth						
thetacorop	0.8342 (8.7)	0.9379 (15.4)	0.7431 (9.0)	0.6736 (7.7)	1.000 (*)	0.6849 (7.0)
thetamigr	0.7964 (4.8)	0.4035 (6.0)	0.5736 (4.3)	1.000 (*)	0.5257 (6.3)	0.8057 (3.3)

Table 5
Estimation results for location choice models for household types 7 to 13.

Householdtype	7	8	9	10	11	12	13
#Pers	>1	>1	>1	>1	>1	1	>1
#Child	0	0	>0	>0	>0	0	0
#Workers	>=2	>=2	0	1	>=2		
Lft 65+	Nee	Nee				Ja	Ja
Lft <35	Ja	Nee					
Observations	2870	1210	626	1916	3148	934	903
Final log (L)	−10803.5	−5036.9	−2150.1	−6374	−10610.5	−2686.9	−2759
D.O.F.	18	17	18	18	18	17	18
$Rho^2(0)$	0.479	0.424	0.525	0.540	0.534	0.602	0.577
intrazon	2.344 (9.9)	3.735 (10.3)	2.061 (1.8)	3.263 (4.5)	6.353 (26.4)	2.921 (6.0)	3.311 (6.6)
intracorop	11.19 (2.4)	3.237 (5.9)	7.270 (4.4)	6.928 (6.4)	5.527 (3.8)	4.244 (5.3)	7.406 (3.5)
wozwaarde	−4.93e−6 (−6.4)	−3.52e−6 (−3.4)	−4.67e−6 (−2.6)	−3.96e−6 (−4.1)	−4.18e−6 (−6.3)	7.06e−7 (0.6)	−1.71e−6 (−1.3)
wmtCS	−0.00203 (−2.1)	−0.00287 (−1.8)	−0.01258 (−4.6)	−0.00849 (−5.9)	−0.00661 (−5.6)	−0.00489 (−2.6)	−0.00239 (−1.2)
wmtBC (ref)							
wmtGS	−0.00262 (−2.6)	6.98e−4 (0.5)	−8.12e−4 (−0.4)	3.50e−4 (0.3)	−0.00124 (−1.2)	0.00125 (0.7)	0.00108 (0.6)
wmtCD	−0.00167 (−1.8)	0.00139 (1.1)	−4.93e−4 (−0.2)	−0.00286 (−2.3)	−0.00251 (−2.8)	−0.00212 (−1.1)	−0.00141 (−0.8)
wmtLW	5.10e−4 (0.4)	0.00360 (2.2)	9.92e−5 (0.0)	0.00138 (0.9)	0.00250 (2.2)	0.00113 (0.5)	8.07e−4 (0.4)
i_1_dist	1.641 (10.0)	1.865 (7.3)	1.647 (5.2)	2.185 (11.5)	3.280 (21.7)	2.451 (8.0)	2.458 (7.5)
Loslogsum	0.7213 (14.8)	0.3278 (11.4)	0.5421 (5.1)	0.8863 (10.2)	0.9586 (13.4)	0.6150 (6.8)	0.5981 (6.1)
i_loslogsm	1.321 (13.0)	1.031 (6.7)	1.678 (9.1)	1.731 (16.0)	0.3798 (4.4)	1.867 (7.4)	1.796 (7.5)
area_facil	−3.53e−8 (−0.4)	8.91e−9 (0.1)	−1.86e−7 (−0.8)	−6.47e−8 (−0.5)	−2.67e−8 (−0.3)	2.86e−7 (1.5)	3.66e−7 (2.1)
area_work	6.94e−8 (2.1)	−6.42e−8 (−1.1)	−1.37e−8 (−0.2)	−1.03e−7 (−2.0)	5.42e−9 (0.1)	−1.30e−7 (−1.5)	−1.70e−7 (−2.2)
area_water	−1.82e−8 (−1.0)	−3.45e−9 (−0.2)	−2.41e−8 (−0.6)	6.54e−9 (0.3)	3.01e−9 (0.2)	−2.71e−8 (−0.7)	2.37e−9 (0.1)
Popdens	−17.45 (−2.5)	−50.95 (−4.3)	−58.21 (−3.7)	−58.72 (−6.1)	−55.53 (−6.5)	−61.23 (−4.1)	−104.0 (−5.4)
Income	2.74e−5 (3.4)	4.93e−5 (4.2)	−2.21e−5 (−1.2)	3.25e−5 (3.2)	8.74e−5 (11.1)	−8.36e−6 (−0.6)	3.28e−5 (2.1)
acc_oth10k	0.2335 (7.9)	0.3026 (6.4)			0.4083 (14.3)	0.1433 (2.3)	0.1347 (2.1)
acc_oth			0.4845 (1.8)	0.2765 (1.5)			
Thetacorop	0.8401 (16.2)	1.000 (*)	0.5941 (5.8)	0.5250 (10.0)	0.5908 (13.8)	0.6865 (7.9)	0.5919 (6.6)
Thetamigr	0.1460 (2.2)	0.5250 (4.8)	0.7553 (2.8)	0.7304 (4.6)	0.4243 (4.0)	1.000 (*)	0.5814 (2.4)

been estimated on a historical data set (1996–2010) on employment figures by sector, accessibility indicators (logsums) and additional explanatory variables at a municipality level.

The economic sectors are: agriculture, industry, logistics, retail, consumer services, business services and government and other non-commercial services. The detail in economic sectors is important to address the large variety in preferences between economic sectors. The economic sectors differ in their land-use, interaction with the population and in their response to changes in accessibility. The results are presented in Table 6.

The estimations show that changes in the housing stock, and associated changes in the population, are a main driver of population–employment dynamics and that there is substantial interaction between the economic sectors. The economic sectors can be both directly and indirectly influenced by changes in the housing stock. For example, a change in the housing stock has an influence on the employment in the financial service sector and the employment change in this sector influences the employment in other sectors.

Transport is included in the modeling via multi-modal logsum accessibility measures denoting the distance relation for all municipalities in the spatial weight matrix. Using this spatial weight matrix it can be indicated whether two municipalities belong to the same local labor market. In the model the employment growth in a municipality depends on the employment growth in the surrounding local labor market and of values of employment growth and population growth in the previous year.

6. A case study on transport investments, accessibility changes and land use effects

6.1. Land use and rail transport investment in the Airport Schiphol–Amsterdam–Almere corridor

This section describes an application of the TIGRIS XL model as part of an economic appraisal of public transport investments for the corridor between Amsterdam Airport Schiphol, Amsterdam and Almere (Zwaneveld, Romijn, Renes, & Geurs, 2009). Almere is a new town, located 30 km east of Amsterdam, built on reclaimed land (a polder). It is linked with two bridges linking two motorways (A6 and A27) and a railway (parallel to the A6) linking to the mainland. Local governments developed spatial policy alternatives for the development of Almere with tailored public transport investment programs, involving adding 60,000 dwellings and 100,000 jobs between 2010 and 2030.

Three alternative land use scenarios were developed by the municipality of Almere, each containing a dedicated supportive public transport investment program: the westward and Amsterdam oriented Almere Water Town scenario, the eastward and more rural oriented Almere Polder Town and the more mixed Almere Town of Water and Green. These scenarios are briefly explained here. To disentangle the effects of land use changes and public transport investments on accessibility, the three 'reference' land use variants have also been examined with the same spatial developments, but without the supportive public transport investments.

In the Almere Water Town scenario, a large part of the land development program (35,000 dwellings, 17,000 jobs) in concentrated to the west of the existing town Almere (Almere Pampus) and new reclaimed land (Almere IJland). The public transport program includes the construction of a new IJmeer railway link, connecting Almere to Amsterdam and Amsterdam Airport Schiphol with a regional rail link through the IJmeer lake which reduces train travel times from Almere Pampus to Amsterdam with 17 min.

In the Almere Polder Town Scenario, urban growth is concentrated towards greenfield development to the east of Almere in Almere Hout (35,000 dwellings and 16,000 jobs). The public transport investments include an upgrade of the existing rail link across the Hollandse Brug (and doubling the train frequency from 8 to 16 trains/h) and the construction of a new rail link, the 'Stichtselijn', connecting Almere to Hilversum and Utrecht by regional rail, to the south.

In the Almere Town of Water and Green Scenario, urban growth takes place more evenly across the town. The public transport investments include an upgrade of the existing rail link (across the Hollandsebrug).

Fig. 4 Main alternatives for improving the rail link between Amsterdam and Almere (Geurs, de Bok, & Zondag, 2012)

6.2. Population and employment effects of public transport projects

All of the alternative public transport projects have a marginal effect on the population growth in Almere, in particular if these changes are compared to the total growth of 133 thousand inhabitants between 2010 and 2030. The public transport projects are each compared to a spatial reference scenario. The housing and real estate supply was assumed to be fixed, regardless the public transport investments, so the population effects that we measure only result from the location preferences of the relocating households, and not from a change in housing supply. Therefore positive as well as negative population effects occur reflecting the different size of households that are attracted by the transport project.

Employment effects of the improvement of accessibility are relatively larger than population effects. Most employment growth is accomplished in the Polder Town scenario and when the Hollandsebrug (HB) rail link is upgraded, and the new Stichtselijn (SL) rail link is built. The IJmeer rail link in the Water Town leads to an employment increase of around 1000 jobs in Almere. This rail scenario has a positive effect on the employment development of Amsterdam as well (+1200 jobs). The Town of Water and Green scenario has the most modest public transport investments program (upgrade of existing Hollandsebrug rail link) and there for the smallest increase in employment (+400 jobs) (see Table 7).

The public transport investments influence employment through an increase in accessibility. In addition to that employment in sectors like retail or government is affected by changes in the local population. The effects of the public transport investments on employment are relatively small compared to the scenario developments between 2010 and 2030. In regions with a well-developed infrastructure these effects can be expected to be small (Banister & Berechman, 2000; SACTRA, 1999).

The public transport investments have a wider spatial economic effect on region surrounding Almere. The regional rail link across the IJmeer proves to have a substantial positive effect on Amsterdam (+1260 jobs) and a few other municipalities along the track. The purpose of the TIGRIS XL model is to forecast the distributive effects of accessibility changes. At a more strategic level the effect of transport investments between Almere and Amsterdam is that the Northern part of the Randstad increases its competitive position which effects especially the employment development in the Southern part of the Randstad.

The Stichtselijn railway link construction and HB upgrade mainly have an effect on the axis from Almere to the South, and where Almere itself benefits the most of the employment growth. Both projects lead to a redistributive effect of employment from the Amsterdam region to Almere. The combined effect of the Stichtselijn construction and HB upgrade in the Polder Town scenario has a positive effect on Almere (+1615 jobs) and Utrecht (+360 jobs), but these effects are less compared to the IJmeer link. The employment effect of only upgrading the existing rail link is relatively small.

6.3. Accessibility benefits of public transport investments

Table 8 shows the travel time benefits for train passengers. The travel time benefits are calculated between a run with the public transport investment projects and the reference of each corresponding spatial growth scenario.

The travel time benefits of the combined Stichtselijn construction and upgrade of the HB rail link are comparable to those of the IJmeer regional rail: around 70 million euro yearly computed with the logsum methodology. A comparison of the logsum benefits and the traditional rule-of-half benefits has been made

Table 6
Estimation results for employment location models.

Coefficient	1 agriculture Δ AG	2 industry Δ IN	3 logistics Δ LO	4 retail Δ CS	5 cons. serv. Δ RT	6 buss. serv. Δ FS	7 gov. & oth serv Δ GO
γ_I							
δ_p population					0.0486		0.0523
δ_E^1 agriculture		0.0152	0.0190			−0.0243	
δ_E^2 industry							
δ_E^3 logistics						0.0366	
δ_E^4 retail	0.1293	0.0515					
δ_E^5 cons. Serv.	−0.0898	−0.0333					
δ_E^6 bus. Serv					0.0247		
δ_E^7 gov. & other		−0.0310					
λ_i	−0.0356	−0.0044	−0.0034	−0.0050	−0.0081	−0.0104	0.0080
β_i							
% < 25 jr.							
% > 65 jr.							
Δ Houses				1.29E−05		1.50E−05	
Surface r							
Landuse variables							
% Water					0.0006		
% Agriculture						0.0005	
% Nature					0.0004	0.0005	
% Semi-built			0.0027				
% built							
% infrastructure						0.0031	
Δ Industrial sites		0.0006					
Rel. representation							−0.0338

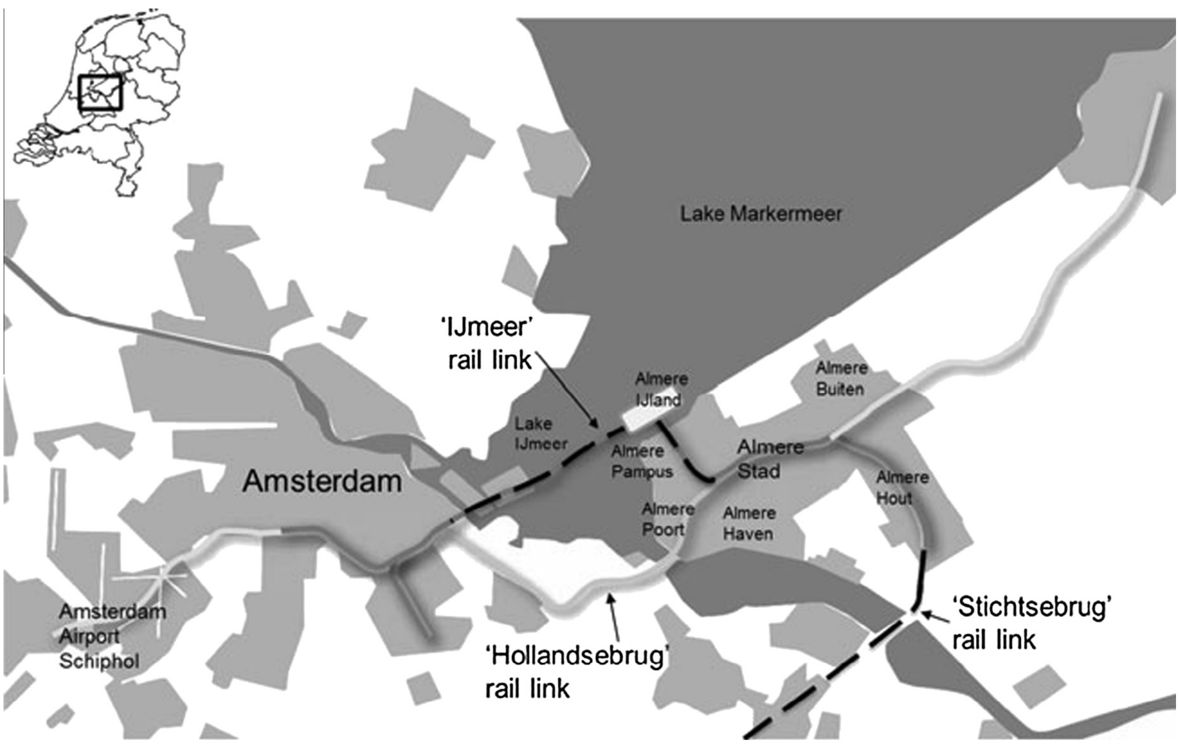

Fig. 4. Main alternatives for improving the rail link between Amsterdam and Almere.

in Geurs et al. (2012) and shows that the logsum benefits are substantially higher than the conventional rule of half (20% to 30%). The differences can be attributed to two factors. Firstly, the logsum provides a more exact measure of consumer surplus than the rule of half. The logsum is computed at the same level of disaggregation as the mode-destination model, uses non-linear demand functions and all changes in all mode and destination alternatives are weighed simultaneously. Secondly, it is well known in the literature that the rule of half will provide inaccurate or incorrect welfare estimations of transport strategies that lead to changes in the spatial distribution of activities (Bates, 2006; Geurs, van Wee, & Rietveld, 2006; Simmonds, 2004). This is because the rule of half only captures welfare effects of changes in generalized transport cost. The logsum, however, also captures accessibility benefits due to changes in location and the relative attractiveness of locations. The modest changes in location choices resulting from the railway link investments thus seem to have significant effects on the accessibility benefits for train users.

Table 7
Population and employment effects of public transport measures, 2030.

	Population in Almere 2030	Additional population in PT run	Employment in Almere 2030	Additional employment in PT run
Almere in 2010	190,000		61,000	
Almere 2030				
Reference	248,000		84,000	
Water Town	323,000		106,000	
+new IJmeer rail link		−245		+1000
Polder Town	323,000		107,000	
+new HB and SL rail links		+1115		+1615
Town of Water and Green	323,000		107,000	
+new HB rail link		−730		+410

Table 8
logsum accessibility benefits for train users, 2030 [in million euros a year].

Scenario	Reference scenario	Logsum Train
New IJmeer rail link in Water Town	Water Town reference	72.9
HB regiorail and Stichtse rail in Polder Town	Polder Town reference	67.6
HB regiorail in Town of Water and Green	Town of Water and Green reference	33.1

7. Conclusions and discussion

The general observation derived from the empirical work underlying the TIGRIS XL model is that accessibility has a modest positive influence on the location choice of residents and firms. Regarding residential location choices other explanatory variables, like demographic developments, neighborhood amenities and especially housing attributes seem to be more dominant. It should be noted that the context, such as spatial structure and density of the transport network, has a large impact on the findings. For example, accessibility differences in the Netherlands (a rather homogenous network and spatial structure) are rather small compared to larger countries and therefore their expected impact on spatial structure is relatively low. Another particularity for the Netherlands is a rather regulated land market for residential construction. Ultimately the local government appoints the type of land use by law and procedures to change the land use type requires substantial administrative effort and time. Much more competition exists between municipalities regarding land allocation for commercial and industrial development and here it assumed that demand preferences are dominant.

The housing and labor market module are an integral part of the total TIGRIS XL model package to explore the spatial outlook following different socio-economic scenarios and to analyze policy implications for various transport and land use measures. The applications so far have confirmed the finding that large transport measures do have a significant but modest effect on the spatial distribution of residents and jobs. The magnitude of these effects depend on the time horizon (it takes a long period to observe the full effects), and assumed level of regulation of the residential land market.

These changes in accessibility also result in accessibility benefits for these actors and the TIGRIS XL model calculates these benefits consistently with the transport model by using logsum accessibility measures. The advantage of logsum accessibility measures is that they can also be used to calculate monetary accessibility benefits of land-use changes, and are directly applicable in economic appraisals of transport investments. The logsum estimations illustrate that modest changes in location choices of residents and firms can have significant effects on the accessibility benefits of transport investments.

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