Creating a two-way Land-Use and Transport Interaction model for Budapest

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Abstract: This paper intends to show that despite limited data availability it is still possible to elaborate semi-sophisticated LUTI models which can be a stepping stone for countries that are less developed in terms of transport modelling practice but eager to improve. It provides an outline of the model and of the calibrating process which was based on data from the city of Budapest. Based on the results it is undeniable that excluding land-use effects of transport in modelling could cause a serious distortion even in a shorter time period. It seems that such land-use effects and feedbacks can no longer be disregarded as it is not in accordance with the desire of improving transport modelling practice. From this aspect, the proposed approach is practical and can overcome general obstacles of time, cost and data availability issues. The next step should be to carry out tests for the estimation of real transport investments and compare the results with other models.

Keywords: land-use and transport interaction, modelling, urban transport, calibration

1. Introduction

Urban transport planning was mainly dominated by supply generative interventions in the second part of the last century and for most of the time car users were the beneficiaries. Approaching the turn of the millennium transport planning principles were about to change and the so-called principle of 'predict and provide' has been continuously replaced by 'aim and manage'. Nowadays urban transport planning is about to find the balance and the optimal solution in providing space and possibilities for different transport modes. Naturally and due to the "heritage" of the previous era, it involves the conflicting action to break the dominance of private cars besides the provision and promotion of different alternatives. In doing so it is going to be more and more crucial for policy- and decision makers to be able to recognize and assess all possible effects, consequences and scenarios. That is not only to increase transparency, public acceptance and to ensure accountability, but it comes with the responsibility to impose different "game-changing" acts upon travellers or to spend significant amounts of investment on infrastructure which could shape city structure and influence several aspects of life. [1-5]

Technical advances make it possible to create more and more accurate models of social and economic systems. With the emergence of these models, transport interactions, policies and strategies can be tested before implementation. That can aid the decision-making process in order to choose the best possible option, fine-tune solutions and also to prevent or minimalize undesirable side-effects. Such analyses can crucial as some interventions (e.g. the calming of road traffic) implemented in an inappropriate way may hinder economic competitiveness or lead to mass residential migration away. For instance, in the case of the city of Budapest three major traffic calming schemes have been abandoned in the last couple of years due to the significant amount of uncertainty and risk which were not possible to be adequately analysed in the absence of data and proper modelling tools [6]. [7-9]

The main set of issues with the prevailing practice in transport appraisal is that benefits arising from long-term impacts on land-use and economic activities are often ignored or remain hidden [10]. A role model that addressed those issues is the ULTrA (Unified Land-use/Transport Appraisal) approach from the UK which was developed based on the case of London and combined LUTI (Land-Use and Transport Interaction) modelling and transport appraisal methods. Based on this role model and its preliminaries (e.g. the DELTA LUTI modelling package), previous parts of this research also set up an assessment framework with a LUTI model in the centre of it (for details see: [6]).

The objective of this paper is to show that despite limited data availability it is still possible to elaborate semi-sophisticated LUTI models which can be a stepping stone for countries that are less developed in terms of transport modelling practice but eager to improve. The paper provides an outline of the model and of the calibrating process which was based on data from Budapest. It also intends to discuss the results obtained and the limitations of the model. It also summarizes the lessons learnt and draft further work.

2.   Overview of the model

The prototype of the LUTI model for Budapest was developed in 2015. The key intention and challenge in creating it was the simultaneous requirement to provide a certain level of quality compared to state-of-the-practice models and to lean on a reasonably limited set of data. The underlying concept was that leading models need a serious amount of data which is not available for cities in most countries and this fact restrains the practical application of them. Therefore it was intended to bypass this issue by model design. Another important aspect was that the model should be used within the previously mentioned assessment framework which means that its inputs and outputs should be compatible with those in the framework. [6]

The model was elaborated by the combination, modification and amendment of three previous models, namely the DELTA model from the UK [11], MARS model from Austria [12] and the TIGRIS XL model from the Netherlands [13]. It consists of three dynamically interconnected parts: a transport decision model, a land-use decision model and a population model. The first one estimates travel-related choices (number of trips per modes and routes) and their consequences (travel times and costs); the second model forecasts real-estate developments (number of houses to be built) and location choices of residents and businesses; while the third deals with ageing. The essential links between the transport and the land-use model are that travel times (and costs) estimated by the

transport model (as a result of the interaction between transport demand and supply) are used in the land-use model embedded in the endogenous variables of accessibility to influence land-use changes, while these changes are used in the transport model to generate transport demand [14]. In order to represent time lags and the evolution of the changes the model uses time steps of one year. So impacts of changes are emerging gradually over a number of years. Further details on the elaboration process, the origination and the concept of design can be found in [6].

This paper focuses on the description of model elements (modules) to provide background for the calibration process. The structure and main relationships of the modules in one time period are illustrated by Fig. 1. Note that the study area is represented by zones as it is common in transport modelling. The model always simulates a base year and forecasts changes on that platform. One can also note that there are some changes in the scope and workings of the model compared to the prototype. These were all inevitable due to data availability during the calibration and will be described and discussed later on it the paper.
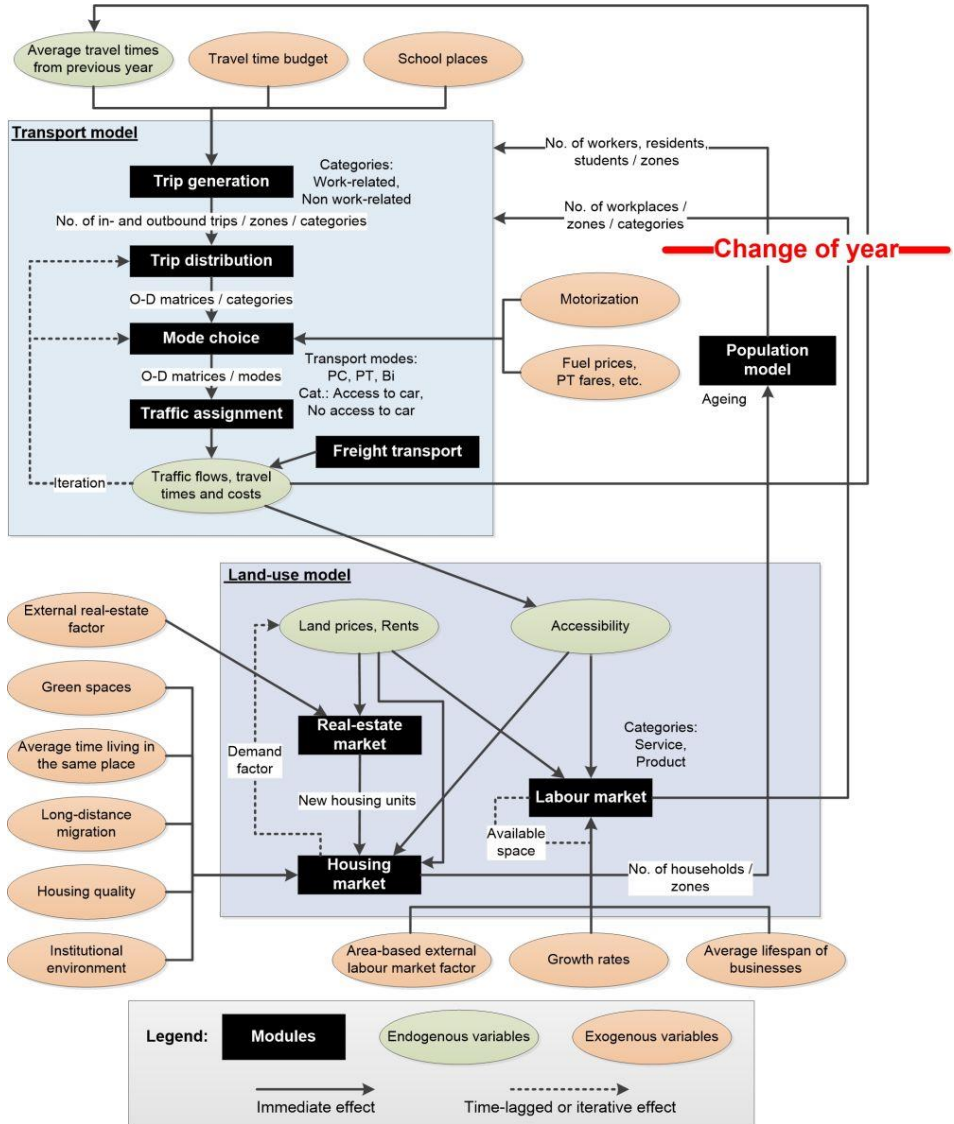
Figure 1: The overview of the LUTI model

Trip-generation

Each year starts with the trip generation module which calculates the number of trips induced within the modelling area. Two types of trips are considered in the model: work-related (WR) and non-work-related (NWR) trips. Daily outbound (production) and inbound (attraction) trips for each zone are calculated based on the following equations (1)-(7):

$$Prod_i = aR_i + bW_i + cS_i + ceSP_i + (7a + bd)WPS_i + bdWPP_i \qquad (1)$$

$$Attr_i = aR_i + bdW_i + ceS_i + cSP_i + (7a + b)WPS_i + bWPP_i \qquad (2)$$

$$Prod_{WR,i} = bW_i + cS_i + ceSP_i + bd(WPS_i + WPP_i) \qquad (3)$$

$$Attr_{WR,i} = bdW_i + ceS_i + cSP_i + b(WPS_i + WPP_i) \qquad (4)$$

$$Prod_{NWR,i} = Prod_i - Prod_{WR,i} \qquad (5)$$

$$Attr_{NWR,i} = Attr_i - Attr_{WR,i} \qquad (6)$$

$$a = \frac{TTB\ R^t - T_{WR}^{t-1} ATT_{WR}^{t-1}}{ATT_{NWR}^{t-1}(R^t + 7WPS^t)} \qquad (7)$$

where:

- Prod$_{WR,i}$ and Attr$_{NWR,i}$ are the work-related production and non-work-related attraction respectively for zone i
- R, W, S, SP, WPS and WPP are the number of residents, workers, students, school places, workplaces for services and workplaces for production respectively
- TTB is the travel time budget for an average resident (in mins)
- T$_{WR}$$^{t-1}$ is the number of total work-related trips in the previous year (time period t-1)
- ATT is the average travel time (in mins)
- b, c, d and e are constant parameters to be calibrated (a is also a parameter, but can be calculated)

Please note that the attraction values need a correction in order to ensure that its sum equals to the sum of production.

Trip-distribution

Then the trip distribution module distributes the generated trips to origin-destination pairs using a doubly-constrained gravity method (for details see chapter 5.3 in [15]). The deterrence function of the model is disaggregated into travel time bins (ranges). The number of bins can be adjusted during calibration. Trip distribution equations are the following (8)-(10):

$$T_{ij} = A_i Prod_i B_j Attr_j f(WTT_{ij}) \qquad (8)$$

$$f(WTT_{ij}) = \sum_k exp(\beta_k WTT_{ij})\,\delta_{ij}^k \qquad (9)$$

$$WTT_{ij} = \sum_m w_{ij,m} tt_{ij,m} \qquad (10)$$

where:

- T_{ij} is the total number of trips between the origin-destination pair of zone i and j
- A_i and B_j are balancing factors in the iterative part of the doubly-constrained gravity model (for details see chapter 5.3 in [15])
- $f(WTT_{ij})$ is the deterrence function
- WTT_{ij} is the weighted travel time between the origin-destination pair of zone i and j (in mins)
- $w_{ij,m}$ is the ratio of trips made by mode m between the origin-destination pair of zone i and j
- $tt_{ij,m}$ is the travel time of mode m between the origin-destination pair of zone i and j (in mins)
- β_k is a constant parameter for travel time bin k to be calibrated
- δ_k equals to 1 if the travel time between zone i and j falls in the travel time bin k and equals to 0 otherwise

Mode-choice

Then in the mode-choice module the distributed trips are divided between modes. Three transport modes (private car, public transport and bicycle) are considered in the module. The probability that a trip is about to occur by a certain mode is based on a multinomial logit model taking into account the car availability of travellers according to the following method (equation (11)-(17)):

$$T_{c,ij,pc} = \sum_c T_{c,ij} CA_i \frac{Imp_{c,ij,pc}}{\sum_m Imp_{c,ij,m}} \quad for \ m = \begin{cases} pc \\ pt \\ bi \end{cases} \tag{11}$$

$$CA_i = COw_i COcc \tag{12}$$

$$T_{c,ij,pt} = \sum_c T_{c,ij} \frac{Imp_{c,ij,pt}}{\sum_m Imp_{c,ij,m}} \quad for \ m = \begin{cases} pt \\ bi \end{cases} \tag{13}$$

$$T_{ij,bi} = \sum_c T_{c,ij} \frac{Imp_{c,ij,bi}}{\sum_m Imp_{c,ij,m}} \quad for \ m = \begin{cases} pt \\ bi \end{cases} \tag{14}$$

$$Imp_{c,ij,pc} = \exp(a_{pc,c} + b_{pc,c} tt_{ij,pc} + c_{pc,c} pt_{ij} + d_{pc,c} \frac{rc_{ij}}{VOT_c} + e_{pc,c} \frac{VOC_{ij}}{VOT_c}) \tag{15}$$

$$Imp_{c,ij,pt} = \exp(a_{pt,c} + b_{pt,c} ivt_{ij} + c_{pt,c} cht_{ij} + d_{pt,c} wt_{ij,car} + e_{pt,c} \frac{PTF_{ij}}{VOT_c}) \tag{16}$$

$$Imp_{c,ij,bi} = \exp(a_{bi,c} + b_{bi,c} tt_{ij,bi}) geo_{ij} \tag{17}$$

where:

- $T_{c,ij,m}$ is the number of trips between zone i and j by mode m (modes: pc – privace car, pt – public transport, bi – bicycle) for WR and NWR trips (the latter is indicated by subscript 'c')
- $Imp_{c,ij,m}$ is the impedance of a trip between zone i and j by mode m for WR and NWR trips
- CA, COw, COcc is the car availability, car ownership (number of cars / 1000 residents) and car occupancy respectively

- $tt_{ij,pc}$ and $tt_{ij,bi}$ is the (congested) travel time between zone i and j by cars and bicycles respectively (in mins)
- pt, rc, VOC is the parking time, road charge (including parking fees) and vehicle operating cost respectively for private car trips (in mins and EUR)
- ivt, cht, wt and PTF is the in-vehicle time, transfer time, origin waiting time and fare respectively for public transport trips (in mins and EUR)
- geo is a geographical factor for bicycle trips (adopted from the official transport model for Budapest, see chapter 6 in [16])
- a, b, c, d, e for different modes are constant parameters to be calibrated

Note that both trip distribution and mode choice models use the prevailing travel time values of the actual time period. It means that these modules have an iterative process to ensure that actual travel times are taken into account.

For freight transport there is a separated and simplified trip generation and distribution step. The former is generating traffic based on the number of workplaces for each category (services and production); while the latter is simply distribute the production based on the relative attractivity of the zone compared to the sum of attractions.

Traffic assignment

As a result of the aforementioned modules daily origin-destination matrices for each transport mode can be produced. Then these matrices are assigned to the transport network. In this case it is also done based on the official transport model for Budapest, which uses standard equilibrium assignment for private modes and headway-based assignment for public transport. Details about the assignment method and the parameters of the impedance function can be found in [16] (chapter 7.1).

Intermediate calculations

Based on the results of the transport model (mainly "congested" travel times) the endogenous variable of accessibility can be calculated. Other endogenous variables can also be calculated based on the results of the land-use model from the previous time period. These calculations are the following (equation (18)-(21)):

$$Acc_i = \frac{\sum_j [(R_j + WPS_j + WPP_j)\, a\, WTT_{ij}]}{\sum_j (R_j + WPS_j + WPP_j)} \tag{18}$$

$$RT_i^t = RT_i^{t-1}\left(1 + bDF_i^{t-1^c}\right) \tag{19}$$

$$LP_i^t = LP_i^{t-1}\left(1 + dDF_i^{t-1^e}\right) \tag{20}$$

$$CB_i = LP_i + 100ABC \tag{21}$$

where:
- Acc_i is the accessibility of zone i
- RT is a virtual rent rate which represents the value of a housing unit in EUR/m²/month

- DF is the demand factor for each zone from the housing market module (which is described later on)
- LP and CB is the land price and the cost of building respectively in EUR/100m^2
- ABC is the average building cost of a m^2 in EUR
- a, b, c, d, e are constant scaling and elasticity parameters to be calibrated

Real-estate market

Following the previous steps, based on some exogenous variables and the accessibility, changes in the land-use system are calculated. At first, the real-estate market module forecasts the number of new housing units to be built by zones. Initially, the unconstrained demand for building is calculated based on the expected weighted profitability. Profitability of a zone is the difference between the market value and the building cost of a residential m^2. Weighting is done based on the value of existing residential floorspace. Then this demand is constrained as developers seek to retain a "development stock" [9]. The extent of actual development depends on the size of the demand relative to the total available space for building. Then the constrained demand is allocated to zones on the basis of relative expected profitability. The developed floorspace is then converted into number of housing units. If there is more demand for building than the available space in a certain zone, then that overflowing demand is not taken into consideration (it is a latent demand). The equations of the module are the following (22)-(24):

$$UncDB^t = a \sum_i FR_i^{t-1} \left(\frac{\sum_i (RT_i^t - CB_i^t) FR_i^{t-1}}{\sum_i FR_i^{t-1}} \right)^b \tag{22}$$

$$ConstDB^t = c \left(\frac{UncDB^t}{\sum_i AFR_i^{t-1}} \right)^d \tag{23}$$

$$NHU_i^t = \frac{ConstDB^t \frac{(RT_i^t - CB_i^t) FR_i^{t-1}}{\sum_i (RT_i^t - CB_i^t) FR_i^{t-1}}}{AHHS} \tag{24}$$

where:
- UncDB and ConstDB are the unconstrained and constrained demand for building in m^2
- FR is the existing floorspace of residential buildings in m^2
- AFR is the available floorspace for residential buildings in m^2
- NHU is the number of new housing units to be built
- AHHS is the average household size in m^2
- a, b, c, d are constant scaling and elasticity parameters to be calibrated

Housing market

Next, in the housing market module location choices of residents (grouped to households) are estimated. At first, a "moving-out" equation calculates the number of households that are leaving their actual location based on an average time-span for living in the same place. As a result of the moving-out process there will be empty housing units above those which are already empty. These empty ones plus the new housing units

calculated by the real-estate market module give the total housing unit supply in a time period. Consequently the demand for housing units is the sum of the households that moved out and those who are moving into the study area from a longer-distance. The latter is calculated by a so-called "long-distance migration" factor. Please note that in the model every household lives in one housing unit. A "moving-in" equation distributes the constrained demand between zones based on zonal utility. Five factors are influencing the choices: housing quality, ratio of public green spaces, institutional environment, accessibility and the virtual rent rate. Within the utility function there is a correction factor for zone size as the number of out-movers depends on the size so the utility for in-movers also needs correction for that. The demand is constrained by the total number of available housing units. If there is an overflowing demand in a zone then it is re-distributed to the second best alternatives with available space. One can note that a household can move out from a certain zone and then move in again which would not mean a change in the number of households in that zone. The module consists of the following equations (25)-(31):

$$HHmo_i^t = \frac{HH_i^{t-1}}{ATSL} \tag{25}$$

$$HS_i^t = NHU_i^t + HHmo_i^t + (HS_i^{t-1} - HHmi_i^{t-1}) \tag{26}$$

$$HD^t = \sum_i HHmo_i^t + R^{t-1}LDM^t \tag{27}$$

$$HHmi_i = HD\frac{RU_i}{\sum_i RU_i} \tag{28}$$

$$RU_i = \exp(aAcc_i + bHQ_i + cGS_i + dINS_i + eRT_i + fUCFH_i) \tag{29}$$

$$UCFH_i = \frac{HH_i}{HH_t} \tag{30}$$

$$DF_i = \frac{HHmi_i}{HS_i} \tag{31}$$

where:
- HH_{mo} and HH_{mi} is the number of households moving-out and moving-in, respectively
- HS and HD are the housing supply and demand respectively
- ATSL is the average time-span for living in the same place (in years)
- LDM is a long-distance migration factor in % (positive if the number of residents is increasing in the study area)
- RU is the utility for residents
- HQ, GS, INS are the variables representing the housing quality, the ratio of public green spaces and the institutional environment (values between 0-10)
- UCFH is the utility correction factor for zone size
- a, b, c, d, e and f are constant parameters to be calibrated

Labour market

The following is the labour market module which forecasts the location choices of businesses (represented by number of workplaces). The module considers two types of

business activities: services and production. It works similarly to the housing market module. First of all there is also a moving-out process based on the average life-span of businesses which means that a business is either moving to another location (outside the study area) or it is closing. As a result of the moving-out process some business floorspace will become unoccupied. The next step is to exogenously define the number of in-moving businesses which represents re-locating or newly developed ones. The zonal allocation of these workplaces is done based on a utility function which considers the cost of building (land prices), accessibility and an area-based external factor. The latter represents those utility aspects that are not included in the model. Similarly to the real-estate market module there is also a constrained development by available floorspace and just like in the housing market module, a correction factor for zone size is included. The equations of the module are the following (32)-(38):

$$WPmo_{i,c}^t = \frac{WP_{i,c}^{t-1}}{ALSB} \tag{32}$$

$$WPD_c^t = WP_c^{t-1} \cdot BGR^t \tag{33}$$

$$WPmi_{i,c} = WPD_c \cdot \frac{BU_{i,c}}{\sum_i BU_{i,c}} \tag{34}$$

$$BU_{i,c} = \exp\big(a_c \cdot Acc_i + b_c \cdot CB_i + c_c \cdot UCFB_{i,c} + ELMF_{i,c}\big) \tag{35}$$

$$UCFB_{i,c} = \frac{WP_{i,c}}{\overline{WP}_{i,c}} \tag{36}$$

$$WPS_i = WP_{i,c} \quad if \ c = 1 \ (services) \tag{37}$$

$$WPP_i = WP_{i,c} \quad if \ c = 2 \ (production) \tag{38}$$

where:

WP_{mo} and WP_{mi} is the number of businesses (workplaces) moving-out and moving-in respectively for service and production sector (the latter is indicated by subscript 'c')

WPD is the total number of workplaces "moving-in" (total demand)

ALSB is the average life-span of businesses (in years)

BGR is the business growth rate in %

BU is the utility for businesses

UCFB is the utility correction factor for zone size

ELMF is the external factor for utility components that are not involved

a, b, c are constant parameters to be calibrated for each category

Demographic changes and feedback loops

Finally, the population module deals with demographic changes. It is modelling the ageing of the society using the following Markovian transition model of probabilities (Table 1).

Table 1: Probabilities of the Markovian transition model for demographic changes

States	Potential mother	0-15 year group	16-65 year group	65+ group	Deceased
Potential mother	1-a	a	0	0	0
0-15 year group	0	1-(b+c)	b	0	c
16-65 year group	0	0	1-(d+e)	d	e
65+ group	0	0	0	1-f	f
Deceased	0	0	0	0	1

The conversion between the number of residents and households is done by an average household size. There is another conversion between spaces and housing units and workplaces based on average sizes.

As a result of the population model, the number of residents, workers and students can be calculated based on ratios from previous years or on external changes. These values along with the number of workplaces, school places and average travel times provide input for the transport model to run another year (cyclic phase).

3.   Calibration process

Previously, in the paper describing the structure of the model, there was a demonstration case to verify and check the operation of the model on a hypothetical scenario [6]. In this paper the objective is to calibrate model parameters on a real case. For that reason all relevant and available data were collected for the city of Budapest. An ideal calibration of the whole model would require actual (observed) data on transport and land-use decisions and disaggregate data on a large sample of travellers and households revealing the explanatory factors of their decisions. Data should be sufficiently precise to allocate them spatially (to zones) and to person or household groups. In spite of the fact that such stated- and revealed-preference data would be highly desirable, this researched faced many challenges to obtain the most needed parts of the dataset. It was previously highlighted that model design was also intended to handle some of these "lack of data" and "lack of disaggregation" problems to be able to provide a semi-sophisticated structure. However, these issues still affected the calibration process.

Due to the limitations of available data and constrains of this research on assembling new data, much of the calibration of the model has been based on existing, observable changes of dependent and explanatory variables. Unfortunately it led to some further simplification of the model, which also suggests handling the results with care. From that point the main objective was to calibrate each sub-system (module) separately for a time period for which all relevant data is available or there is a way to reliably replace or estimated them. Some data manipulation was also needed as for some variables either the aggregation level was not adequate or annual changes of values was not available.

First of all, as a starting point and a reference case, the official transport model of Budapest has been selected. That model was available for the year 2015 with a transport

demand part which was well-supplemented by household surveys. Relevant statistical data for Budapest (e.g. number of residents) was available between 2007 and 2014 from the Hungarian Central Statistical Office. Then, the time period from 2007 to 2013 has been chosen for the calibration of the land-use model in which changes usually require a longer time-span to evolve. It was also an influencing factor that the metro line M4 was opened in 2014 and it was intended to avoid its short-run disturbing effects. Therefore 2014 was used to calibrate the transport model based on the official one.

Secondly, the spatial system for the model had to be decided. It was evident that annual land-use data is only available for the district level (for 23 districts in Budapest). However, a proper transport model needed a higher resolution than that, so the sub-district level has been chosen as the zonal basis of the transport model (with 162 zones for the sub-districts). In order to model suburban areas in the region of Budapest, another 30 zones were set up as cordon zones. In the land-use model these were aggregated into 5 agglomeration zones. For an illustration see Fig. 2.
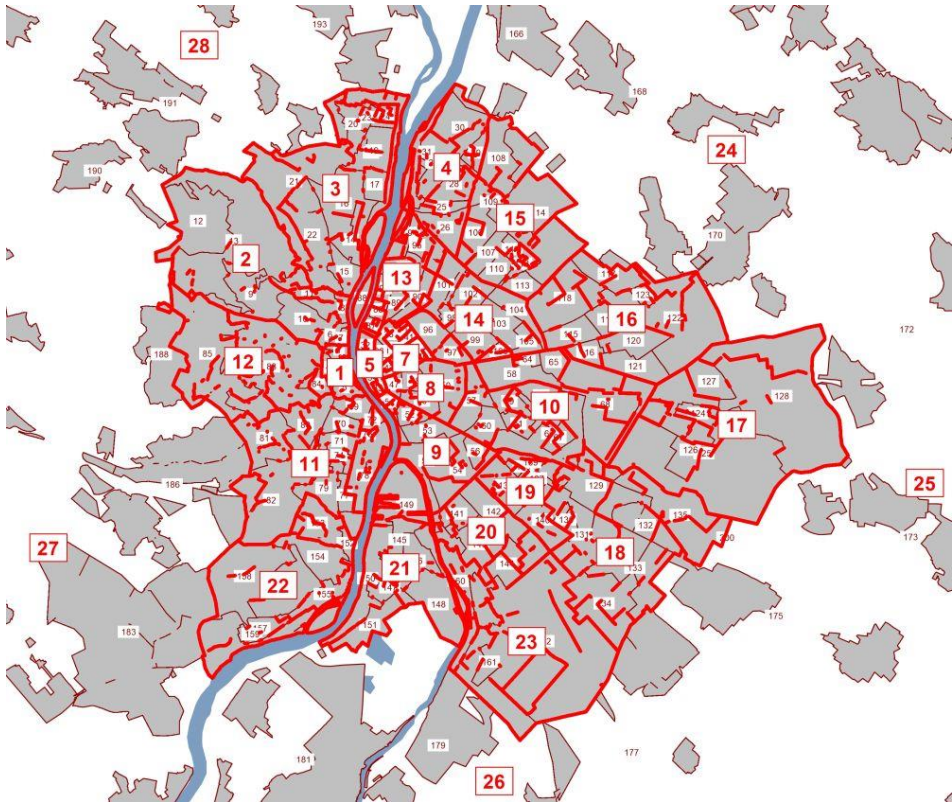

Figure 2: Zone system of the model (grey: transport zones – sub-districts, red: land-use zones - districts)

During the calibration of the transport model, the official network model of 2015 (with around 1200 zones) was used as a basis. This model was modified to represent the year of 2014 (there were some minor changes in the network and in public transport services).

Then transport zones were aggregated and their connectors were adjusted to create the modified model with 192 zones. Then it was needed to replicate the demand model in a synthetic way. It is important to note that the official model uses direct demand modelling and its matrices for the base year are originated that way. However, in its matrix forecasting method, the official model also uses a synthetic demand model combined with pivoting. In this research this synthetic demand model was replaced to be compatible with the land-use model. The calibration has been done for 2014 in each module. Trip generation module was calibrated in a way that its results (i.e. the sums of outbound and inbound trips for zones) approximate the sums of the direct matrices of the official model. Trip distribution module approximates the values of each cell, while mode-choice module tries the same for the direct matrices of each transport mode.

Since land-use model calculations require transport-related data (e.g. travel times) for each year between 2007 and 2013, transport models were needed to be produced for these years. Network models for these earlier years were created by stepping backwards from 2014. Considering the demand side, it was done by the calibrated transport-related modules based on the network states of each year. Matrices were calculated by using the pivoting method as quite naturally direct demand matrices cannot be properly approximated by synthetic models [15]. As a result transport-related values were calculated for the mentioned seven years.

Based on travel time values the explanatory variable of accessibility was calculated for the land-use model from 2007 to 2013. Values of other explanatory variables such as rents or housing quality indicators were available or calculated. The modules of the land-use model were calibrated in order to approximate the changes in the number of households, workplaces and new housing units. For the real-estate, housing and the labour market module the calibration was done for the entire time period taking into consideration the total change of the dependent variable. This issue comes from the nature of the real-estate and the housing market where there are hectic changes, while for the number of workplaces there was not data for exact annual changes. Endogenous variables of land prices and rents were calibrated normally for changes per annum (i.e. 6 years as the land-use changes of 2007 are not included). For real-estate market the agglomeration area has not been taken into account.

During the calibration of the location choice (housing and labour market) modules there was a technical challenge as only the changes in the number of households and workplaces were known from the available data. There was not a sample of "from-to" moves. Therefore the observed changes were artificially recreated in a moving-out and moving-in structure which is in line with the model design. Then the main focus was to explain the moving-in process with a multinomial logit model and calibrate its parameters. Technically the calibration was done on an amended dataset in which each household/workplace represented in the demand function chooses a location based on the artificial choice-set. It means that if a household/workplace select the first district as its new location (regardless of the previous one), it also means that all other alternative locations are rejected. Based on these choices coefficients can be estimated for the independent variables and for the utility correction factor.

Finally, the population model was also calibrated for the annual changes of the size of the given age groups, the number of births and deaths.

Due to the aforementioned calibration issues, compared to the original LUTI model there were a few changes:

- walking as a transport mode is neglected;

- trip distribution and mode choice is modelled separately;

- greenfield and brownfield developments within the real-estate market module are not differentiated due to a lack of data;

- there is an external variable for the labour market module as conventional changes of the explanatory variables have not described the phenomena well enough (meanwhile the variable of available floorspace is not included in the model as it happened to be insignificant);

- households are not differentiated based on income as there was not reliable data on actual income of residents;

- there is an extra variable for institutional environment within the housing market module which adds to the explanatory power of the model;

- motorization became an external variable as available data (GDP, fuel prices, travel times, accessibility, etc.), as it was not enough to give an adequate prediction.

4.   Results

Table 2 shows the calibration dimension and the goodness of fit for each module. It is important to note that in this chapter modelled values are compared to observed values which mean that the values of the saturated model would equal to the observed ones (y=x). Observed values are really observed in terms of land-use data (e.g. the changes of the number of households), while these are original values in case of the transport-related values (e.g. the cell values of the direct demand matrices of the official transport model for Budapest).

Land-use and demographic modules provided a quite good fit to actual data. Transport-related modules are worse in that sense, but one should take into consideration that these modules are mostly consecutive and small errors in the first module (trip generation) might be multiplied in latter stages. However, coefficient values of determination calculated for the cells of the matrices suggest that these matrices should not be applied directly in the transport model. Pivoting the changes of these synthetic matrices to the direct ones can bridge the gap and still provide reliable modelling results. It is also important to take into consideration that it was not intended in this research to replicate the more comprehensive and detailed official transport model of Budapest. The purpose was to provide a less detailed, but still reliable transport modelling background in order to be able to carry out the calibration of the land-use modules. Fig. 3 illustrates the differences between the travel time distributions of the model and the official one, while Figure 4, 5, 6 and 7 show the differences between the modelled and observed changes of the number of new housing units, households, workplaces in service and production sector respectively. All of these differences can be considered acceptable and hint that the model works reliably.

Table 2: Results of the model calibration

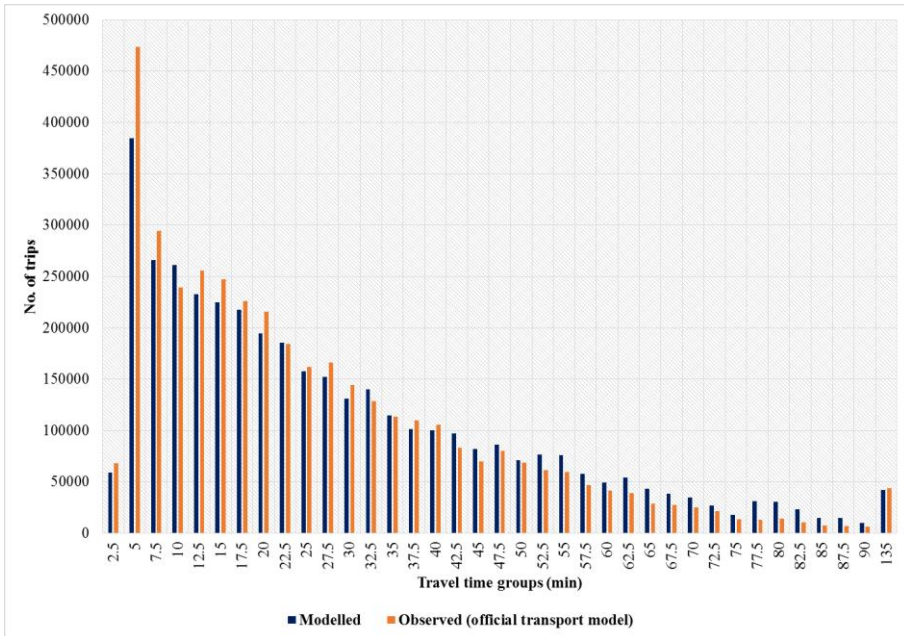| Module		Calibration		Calculated R^2: (SST-SSE) /SST	Comment
		spatial dimension	time dimension		
Trip generation		192 zones (sub-district level: 162+30 suburban)	2014	0.93	R^2 is calculated for the production
Trip distribution				0.80	R^2 is calculated for the cells of the matrices
Mode-choice	Private car			0.51	
	Public transport			0.63	
	Bicycle			0.22	
Freight modelling				0.18	
Rent and land price		28 zones (districts level: 23+5 suburban)	2007-2013 per annum	0.98	
Real-estate market			2007-2013 as a whole	0.71	The suburban areas are not included in the module
Housing market				0.87	
Labour market	Services			0.82	
	Production			0.77	
Population		-	2007-2013 per annum	0.99	

Figure 3: Travel time distributions of the LUTI model and the official transport model for Budapest
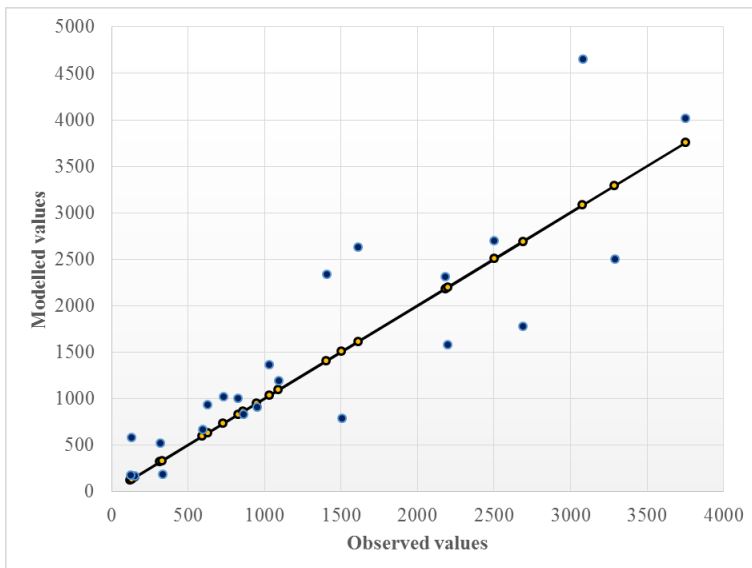

Figure 4: Differences between modelled and observed changes of the number of new housing units
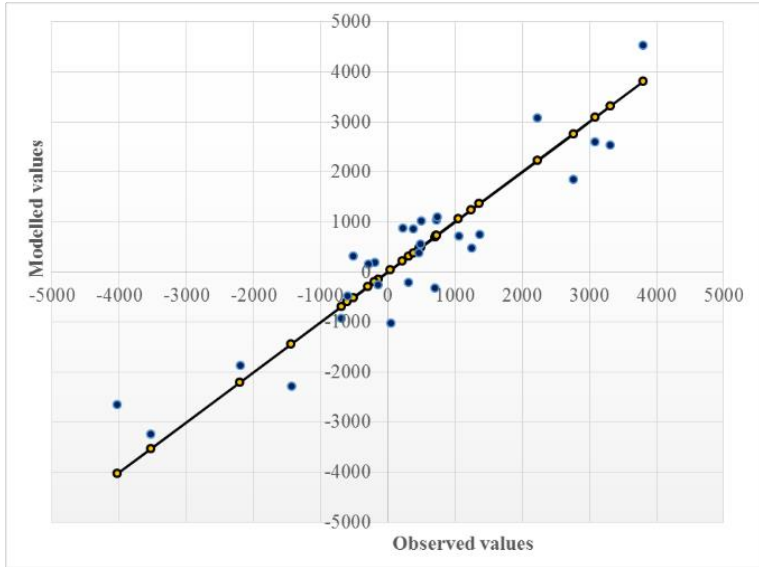
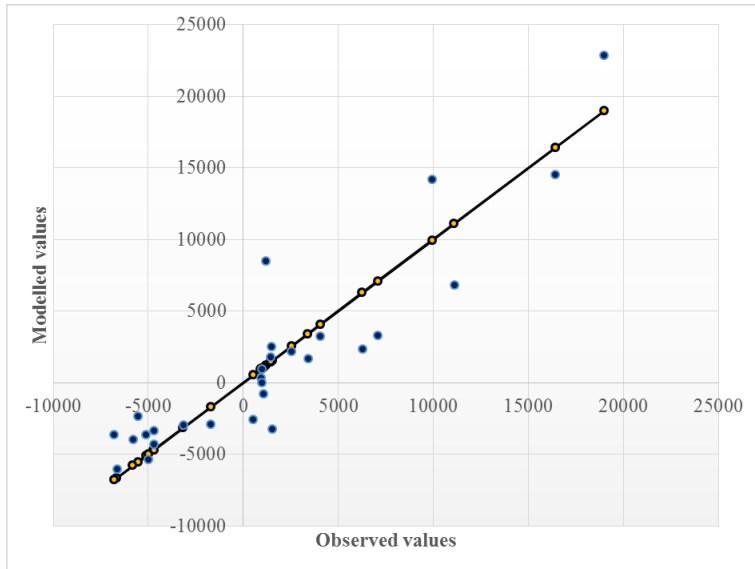Figure 5: Differences between modelled and observed changes of the number of households

Figure 6: Differences between modelled and observed changes of the number of workplaces in service sector
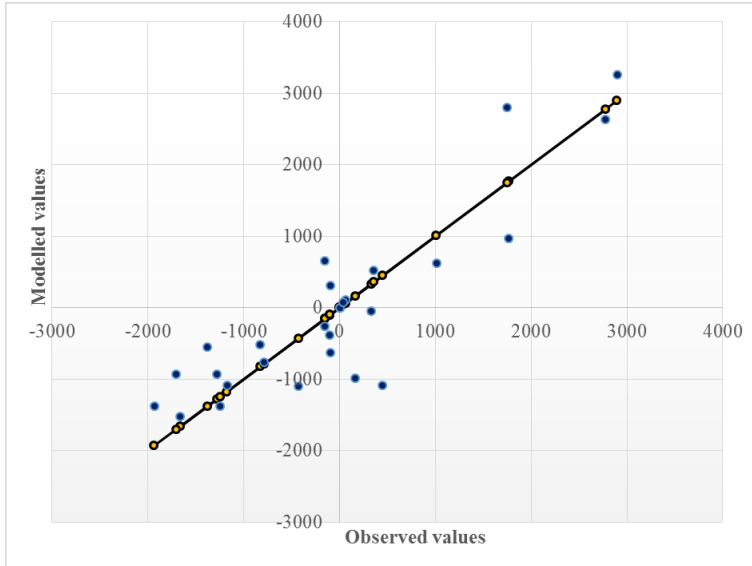
Figure 7: Differences between modelled and observed changes of the number of workplaces in production sector

Table 3, 4 and 5 show the calibrated values of model coefficient and parameters. It is encouraging that the coefficients of the land-use modules were of the correct (theoretically expected) sign and significant at the 85-95% level. This chapter is focusing on the interpretation of these results.

Table 3: Calibrated model parameters and coefficients

Module	a	b	c	d	e	f
Trip generation	NWR trip component (calculated)	workers going to work	students going to school	workers returning-home rate	students returning-home rate	
	0.243	0.8	0.4	0.71	0.8	
Mode-choice	constant	travel time	parking time	road charges	vehicle operating cost	
Private car	0	-0.18	-0.36	-0.25	-0.03	
	constant	in-vehicle time	transfer time	origin waiting time	fare	
Public transport	-3.25	-0.18	-0.36	-0.27	-0.18	
Bicycle	constant	travel time				
WR	-4.3	-1.08				
NWR	-3.4	-0.85				
Inter-mediate calcula-tions	Access-ibility scaling	RT-DF scaling	RT-DF elasticity	LP-DF scaling	LP-DF elasticity	
	-1	-0.038	-0.112	-0.003	-0.509	

Real-estate market	UncDB scaling	UncDB elasticity	ConstDB scaling	ConstDB elasticity		
	50	1.6	0.000025	1.6		
Housing market	Access-ibility (normalized min)	Housing quality	Green spaces	Institu-tional environ-ment	Rent rate (for a month)	Utility corr. factor
	0.015	0.169	0.382	0.101	-0.125	0,775
Labour market	Access-ibility (normalized min)	Cost of building	Utility corr. factor			
Services	0.032	-0.057	1.22			
Production	0.040	-0.024	1.25			
Population	Pot. → 0-15	0-15 → 16-65	0-15 → D	16-65 → 65+	16-65 → D	65+ → D
	0.072	0.0715	0.001	0.0166	0.005	0.054

Table 4: Calibrated parameters for the trip distribution model (for travel time bins)

k	1	2	3	4	5	6	7	8
Travel time range	10-	10-20	20-30	30-40	40-50	50-60	60-75	75+
β_k	0.04	0.07	0.065	0.06	0.055	0.05	0.045	0.035

Table 5: Other parameters of the model

Other parameters	Value
Travel time budget	58 mins
Average household size	67 m²
Average workplace size	12 m²
Average time-span for living in the same place	25 years
Average life-span for businesses	20 years
Value of time (work-related)	0.1 EUR/min
Value of time (non-work-related)	0.07 EUR/min
Average building cost	530 EUR/m²

At first, the real-estate market module was able to predict the overall demand for building new housing units and the average zonal profitability seemed to be a good indicator for the location choice of the development. The estimated parameters are much more different than those of the DELTA model from where the method is originated, but the Hungarian construction sector is also different (both in its scale and also in terms of the elasticity to profitability) from the British.

In the housing market module the explanatory variables combined with the correction factor for size described the changes in the number of households quite well. Fig. 8 shows the deviation of calculated utility for each district from the average utility (which is the basis of the applied multinomial logit model) compared to the actual changes in the households.
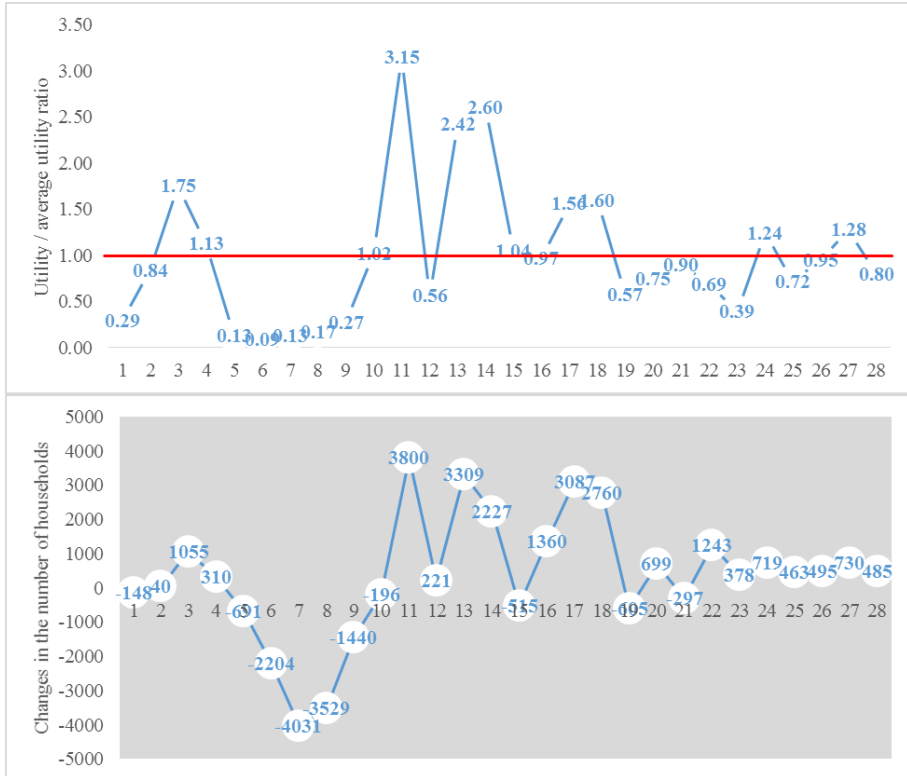
Figure 8: Deviation of the calculated utility from the average utility for each district (top) compared to the actual changes in the number of households (bottom)

According to Table 3, the coefficient of accessibility is around 0.015. The variable of accessibility describes a normalized weighted value (in minutes) for every potential trip purposes. The magnitude of the coefficient is in line with values from other researches in the UK (0.01-0.07 mins/trip, [17]). It is also reassuring that if value of time (VOT) is derived from the coefficients (i.e. the ratio of the accessibility coefficient to that on rent) it is also somewhere of the expected magnitude. As rent rate is calculated for a month, accessibility coefficient needs an adjustment with the average monthly trips rate (division by the estimated value of 45). The mentioned ratio of utility per minute to utility per money implies a VOT of about 0.16 EUR/hour. This is quite low compared with the value used in the transport model (4.2 and 6 EUR/hour for non-work-related and work-related trips respectively). A potential explanation for the difference could be the way in which accessibility and rent rates are measured. In addition to that there are also differences in the way of how accessibility is built into the housing market module to how travel time is perceived in travel choices in which standard values of time are estimated. Very similar results were found by [17] on the same issue. It also seems to be logical that VOT in a location choice aspect could be lower than in a transport sense.

In the labour market module only the variables of accessibility and cost of building have been found to be significant. Other variables previously suggested by other models

(e.g. the available floorspace from the MARS model) were not included for this reason. An external variable was also calibrated with the intention to control areas with different characteristics which seemed to be relevant for business location choice. The values of these external factors are shown in Fig. 9.
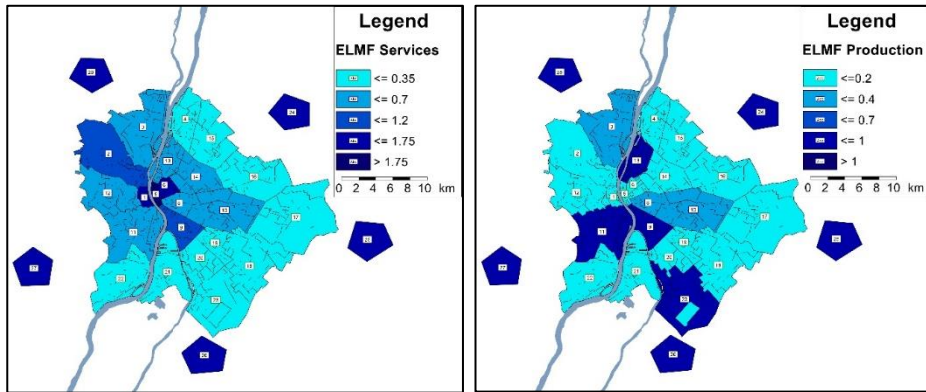

Figure 9: Values of the external utility factors in the labour market module for services (left) and production sector (right)

In terms of the other, complementary parameters there are also some interesting results. First of all the travel time budget calculated from the base year (2014) model is around 58 mins/day. This is slightly lower than those international values reported by Schafer and Victor [18] (spread from 60 to 80) and values for Budapest by Fleischer and Tir [19] (around 75). An obvious explanation can be that walking as a transport mode is not included. In addition to this, suburban areas are also not fully covered. Within the model only those residents are included who make a trip to or through Budapest. The number of these residents is also taken into consideration in the calculation of the travel time budget. However, those trips are excluded that these people have towards other destinations which are not affect the capital city. The mentioned two factors can reduce the travel time budget by around 20-25%. Secondly, the values of average time-span of living in the same place (ATSL) and life-span of businesses (ALSB) were also calibrated. There was not any official or strongly reliable data on these values, however, during the calibration 25 and 20 years were found to be fit to the observed changes. It provides some background to ATSL that according to some national statistics on the housing market an average resident moves 3.4 times during a lifetime [20], which implies a value around 22-25 years. In terms of ALSB the only relevant data based on private business information systems (Opten statistics) that the fluctuation is nearly 50% among companies in every 5 years. That would imply a value below 10 years. However, the ALSB value is much more complicated and it is also common that there is a fluctuation in terms of companies but the workplace and its location remains in its previous state.

Table 6 provides some details on the coefficients of the land-use modules. All of the variables found to be significant at the 95% level apart from the rent rate in the housing module which is significant at the 85% level.

Table 6: Details of the calibration results for the land-use modules

Explanatory variable	Coefficient	Exp(Coeff.)	Standard Error	Significance
Housing market module				
Accessibility	0.015	1.015	0.007	0.045
Housing quality	0.382	1.466	0.061	~ 0.0
Green spaces	0.169	1.184	0.037	~ 0.0
Institutional environment	0.101	1.106	0.049	0.038
Rent	-0.125	0.883	0.081	0.121
Utility corr. (size)	0.775	2.171	0.124	~ 0.0
Labour market module - Services				
Accessibility	0.032	1.033	0.006	~ 0.0
Cost of building	-0.057	0.944	0.014	~ 0.0
Utility corr. (size)	1.22	3.387	0.075	~ 0.0
Labour market module - Production				
Accessibility	0.040	1.040	0.04	~ 0.0
Cost of building	-0.024	0.976	0.12	0.008
Utility corr. (size)	1.25	3.490	0.068	~ 0.0

Finally, a test running of the model has been carried out in order to demonstrate what LUTI modelling can bring in terms of differences in traffic volumes. Starting from 2007 as a base year the whole model run until 2013 and predicted the changes in the land-use and transport system annually. Another scenario was to give a prediction from 2007 up until 2013 without any change in the land-use system (that is what traditional transport modelling does). Then these modelling results were compared to that of the actual model for 2013 (used as a reference). Fig. 10 shows the differences in private (left side) and public transport (right side). On the top is the difference between the actual 2013 model and the model for 2013 derived from 2007 with the full LUTI model, while in the bottom it is the difference between the actual 2013 model and the model for 2013 derived from 2007 without land-use changes.
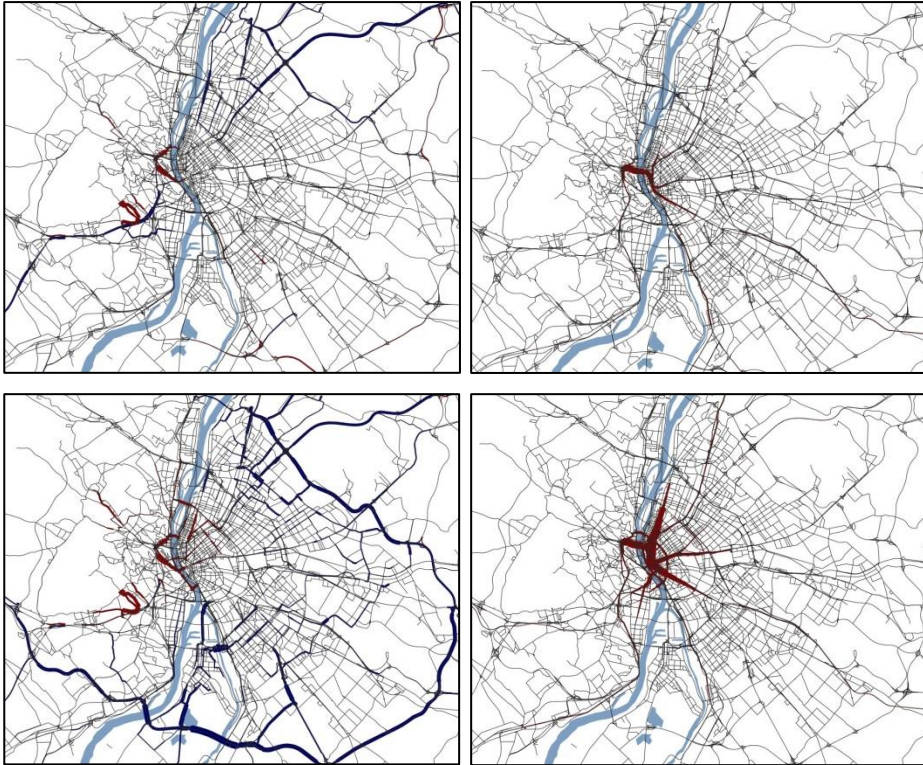
Figure 10: Differences in private (left side) and public transport (right side) traffic volumes between "model 2013" and the model for 2013 derived from 2007 with the full LUTI model (top), plus between "model 2013" and the model for 2013 derived from 2007 without land-use changes (bottom)

5.   Conclusions

Based on the results of this paper it is undeniable that excluding land-use effects of transport in modelling such schemes could cause a serious distortion even in a shorter time period (e.g. in 7 years). It is not the quantifiable indicators (total travel time, total distance covered or vehicle operating cost) that can have a considerable change, but the spatial differences can be significant, especially if the impacts of a certain project are under estimation. It seems that such land-use effects and feedbacks can no longer be disregarded as it is not in accordance with the desire of improving transport modelling practice. Moreover, it makes no sense to constantly develop better and better transport models or modelling parts (e.g. traffic assignment methods) while the gain with the improvement is far less then losses coming from neglecting land-use effect. From this point of view, an ideal solution might be to establish a modelling framework which takes into account every important aspect and then improve its parts in a way which ensures a sustained integrity. Otherwise there is an imminent risk that isolated best-practices are to be created which could be hardly integrated with each other.

This paper suggests that land-use effects can be included and semi-sophisticated (but still reliable) LUTI models could be created even if available data are narrow. This approach is also practical and can overcome general obstacles of time, cost and data availability issues. Besides if such a LUTI model is created and constantly used it can be a platform of further development and may also influence data collection which can aid further model development going forward.

Ultimately, further steps of this research are drafted. The next step should be to carry out case studies (tests) for the estimation of real transport investments (to see whether the model performs as expected) and compare the results with conventional and international ones. For the city of Budapest these case studies could be a following: impact of the recently implemented metro line M4, the planned traffic calming of the city centre (which may include congestion charging) and a scenario for a rapid fuel price increase.

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