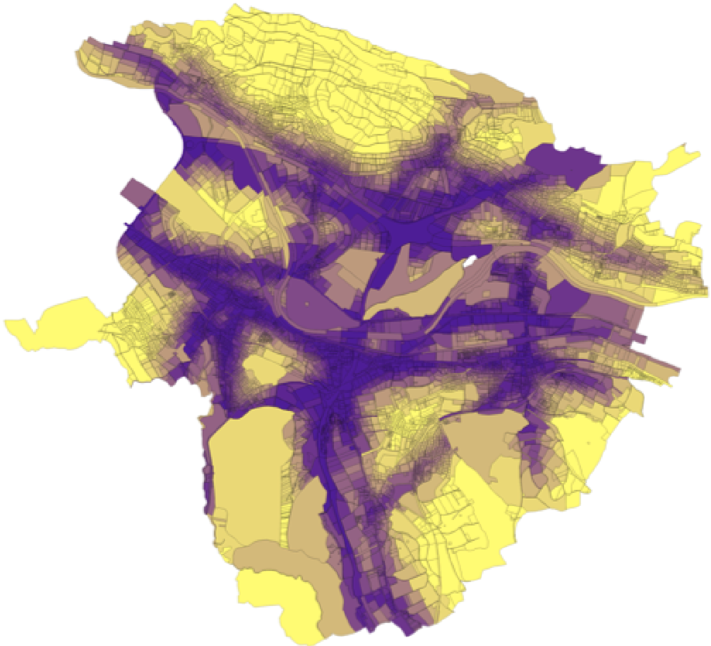


Agent-Based Indicators Analysis in the Context of Policy Evaluation

Dimitrios Efthymiou

Bilal Farooq

Michel Bierlaire

Constantinos Antoniou

Transp - OR, EPFL

April 2013

STRC | 13th Swiss Transport Research Conference

Monte Verità / Ascona, April 24 – 26, 2013

Transp - OR, EPFL

Agent-Based Indicators Analysis in the Context of Policy Evaluation

Dimitrios Efthymiou
Visiting Scholar
Transp - OR, EPFL
1015 Lausanne
phone: +41 21 693 93 29
fax: +41 21 693 80 60
defthym@mail.ntua.gr

Bilal Farooq
Research Associate
Transp - OR, EPFL
1015 Lausanne
phone: +41 21 693 93 27
fax: +41 21 693 80 60
bilal.farooq@epfl.ch

Michel Bierlaire
Professor
Transp - OR, EPFL
1015 Lausanne
phone: +41 21 693 25 37
fax: +41 21 693 80 60
michel.bierlaire@epfl.ch

Constantinos Antoniou
Assistant Professor
LoTE, NTUA
15780 Athens
phone: +30 210 772 27 83
fax: +30 210 772 26 29
antoniou@central.ntua.gr

April 2013

Abstract

The need for forecasting the direct and indirect effects of land use and transport policies, on the society, environment and local economy, has led to the development of many different Integrated Land-Use and Transport Models (LUTI) around the globe. In this paper, the Land-Use Model UrbanSim is applied integrated with the agent-based traffic simulation model MATSim, on the suburban area Limmattal of Zurich, for the purposes of the Sustainable Urban Patterns (SUPat) project of NRP65. UrbanSim applies sequentially, agent (households or jobs) location/relocation choice and transition models, building development and real estate price models, and forecasts their distributions in different time and space dimensions. The agent-based nature of the integrated model, broadens the scope of the analysis. We are interested in taking full advantage of the strengths of agent based microsimulation in the context of policy evaluation.

Currently, the evaluation of transport and land use policies (e.g. cordon charging, public transport investment, land use regulation) is based on economic indicators usually computed at an aggregate level (e.g. the Social Welfare). In this paper, a methodology based on the strength of microsimulation in three dimensions (space, time, and agents) is presented. By multiple runs of the simulation, we analyze the variance in the indicators in space and time. Moreover, we generate the distribution of these indicators by various types of agents. This methodology is applied to the base-case scenario (where the current trend is going on) of Limmattal region at the year 2030. Proposed policy scenarios are then simulated and the distribution of indicators are computed. The policies are then compared based on these distributions rather than the mean values of the indicators. The proposed methodology differs from the current policy evaluation framework, regarding the level of aggregation that is applied, and will support the decision making in the future.

Keywords

Integrated land-use and transport models, Limmattal, policy evaluation

1 Introduction

The need for forecasting the direct and latent effects of urban planning policies, on the society, the environment and the economy, in order to evaluate their sustainability, has led to the development of the agent-based Integrated Land-Use and Transport Models (Land-Use Transport Interaction - LUTI). Among the last few years, more than 20 LUTI models have been developed. Their characteristics differ in terms of the level of aggregation, required data and equilibrium approach.

UrbanSim is one of the most applied LUTI models. It was first developed at the Department of Urban Design and Planning of the University of Washington in the end of 1990 (Waddell, 2002). UrbanSim differs from the other models as it adopts an approach of dynamic disequilibrium, it makes predictions in different time scales, and requires extremely disaggregate spatial information (Waddell, 2002). Its open source, under the General Public Licence, allows to its users to access, interfere and adjust it according to their needs, but also contribute to its further development. It takes as input household, employment, building and real estate data, georeferenced in different spatial levels, such as zones, parcels or grids. Location choice, transition and price models can be estimated in UrbanSim; more specifically: 1) Economic Transition Model; 2) Demographic Transition Model; 3) Employment Relocation Model; 4) Household Relocation Model; 5) Employment Location Choice Model; 6) Household Location Choice Model; 7) Real Estate Development Model; 8) Land Price Model; 9) Workplace Location Choice Model, and others, according to the needs of each case study (Waddell, 2002). Until now, UrbanSim has been applied in many cities, such as: Honolulu (Hawaii), Springfield (Oregon), Houston (Texas), Salt Lake City (Yutah), Paris (France), Zurich (Switzerland), Seattle (Washington) and San Francisco (California) (www.urbansim.org). The European FP7 funded project named SustainCity, aims to improve UrbanSim by integrating the agent-based traffic simulation model MATSim, developing a new Sustainability sub-model, and generally adjust it in order to correspond to the local characteristics of three European capitals: Paris, Brussels and Zurich.

The general improvement of the methodological component of the LUTI models, but also the efforts to render them more easily applicable and their results more understandable, increases the perspectives of being used more actively in sustainable planning and policy evaluation. This paper aims to contribute to the literature of microsimulation and distribution analysis, which is currently very limited (eg Farooq and Miller, 2011, Miller *et al.,* 2011).

The objective of this research is to develop a methodology that, by exploiting the strengths of the microsimulation in three dimensions (space, time and agents), analyzes the actual distributions rather than point estimates of the policy evaluation indicators. This methodology is applied to the base-case scenario (where the current trend is going on) and a public transport investment scenario of Limmattal region (in Zurich) at the year 2030. The policies are then compared based on time and space distributions rather than the mean values of the indicators. The rest of the paper is structured as follows: following the introduction, the indicators for policy evaluation, such as the social welfare function, the accessibilities and the inequality indexes, are presented. Chapter 3 begins with the definition of the examined scenarios and continuous with the presentation of the methodology and the results of the analysis. Chapter 4 outlines the conclusions and makes suggestions for further research.

2 Indicators for policy evaluation

The Integrated Land-Use and Transport Models are employed for the evaluation of transport and land-use policies (e.g. road pricing, parking charging, hard shoulder running, land-use regulation, housing subsidy) by forecasting different scenarios. Until now, this is being achieved by using single indicator measurements belonging to one of the following four categories: 1) sustainability indicators (Litman, 2011), 2) economic indicators (Grazi *et al.,* 2007), 3) accessibilities (Baradaran and Ramjerdi, 2001) and 4) inequality measurements (Ramjerdi, 2005).

2.1 Sustainability indicators

The general interest around sustainability and livability in transport developmnet is growing. A report published by Litman (2011) distinguishes the meanings of these two words, as: Livability refers to the objectives of sustainability that affect the members of the community, in a small scale (e.g. local pollution), while sustainability refers to a larger scale, such as climate change emmisions.

The role of transport development in this aspect is of major importance, because of the size of transportation infrustructure and investments and their effects on economic, social and environmental development of both small and large scale environments. The cooperation of different scientific groups and sectors is needed in order to achieve the social, economic and environmental goals of sustainable transport.

Litman (2011) indicates that the transport objectives that support the sustainability goals, are: 1) Transport system diversity, 2) System integration, 3) affordability, 4) Resource (energy and land) efficiency, 5) efficient pricing and prioritization, 6) land use accessibility (smart growth), 7) operational efficiency and 8) comprehensive and inclusive planning. In more detail, the goals are: 1) economic productivity, 2) economic development, 3) energy efficiency, 4) affordability, 5) operational efficiency, 6) equity/Fairness, 7) safety, security and health, 8) community development, 9) heritage protection, 10) noise prevention, 11) water pollution, 12) openspace preservation, 13) good planning and 14) efficient pricing.

Indicators are quantitative tools / variables, used to evaluate the different transport policies. They are used to show whether these policies fulfil the objectives of sustainability and achieve their goals. However, while the use of a particular set of indicators can enlighten the latent effects of a policy, proving them positive for sustainable development, another set (or even the same, computed after different simulation runs) could show it harmful.

The multidimensional differentiation of the policy packages available at the policy maker, increase the difficulty of proper decision on urban planing. As a result, the selection of suitable indicators for urban transport policy evaluation becomes very significant.

2.2 Economic indicators

Two widely used sustainability, economic indicators are the Ecological Footprint (EF) and the Social Welfare. The second overpasses the weaknesses of the first in failing to consider externalities (Grazi *et al.,* 2007). The SW is computed by the Social Welfare Function (SWF). This measurement is used to rank the alternative policies suggested by policy makers, in order to select the optimal. The SWF has be developed, analyzed and critisized by a number of concrete research papers, such as: (Arrow, 1953, Samuelson, 1954, Coleman, 1966).

While the SW refers to the societal preference at an aggregated level, the term 'cardinal social welfare' is an individual level measurement, computed by the agent's utility, which is usually the income.

Other indicators in the same context are the Gross Domestic Product (GDP) and the monetary income. Economic indicators of this kind have been criticized and they should be used carefully. Comparing the amount of the wealth, without considering the way followed to be created (the level of environmental harm, the inefficiently spent of the wealth etc), could lead to miscalculations and miscosiderations.

2.3 Inequality measurements

The term 'equity' refers to the fairness of the policy impacts distribution, over the population. The impacts are indicated by the benefits and costs generated by a policy, and are usually measured by the change of the population's wealth. The inequality measurements are equity indicators that quantify the difference of the fairness within the population. They are employed to evaluate policy scenarios, simulated by the Integrated Land Use and Transport Models. However, the literature related with their use in the context of the agent-based LUTI models is limited, if not absent.

According to Ramjerdi (2005), the inequality measurements are classified into the following three categories: 1) statistical, which measure the distribution of a characteristic in the population; these are the range, variance, the measure of variation, the log variance, the Gini coefficient and the Theil's index; 2) welfare, which are based on the welfare economics and functions; these are the Kolm and Atkinson messurements; and 3) axiomatic. Ramjerdi used these measurements to assess the effects of transport policies in Oslo. She concluded that the results can be interpreted differently when using different indicators. Talen (1998), recognized early the potential benefits of visualizing the output of the inequality measurements in Geographical Information Systems, for the planners. Viegas (2001) suggested wider perspective of equity when planning congestion charging schemes, in order to cover both horizontal and longitudinal dimensions. Franklin (2006) evaluated road pricing scenarios using among others, inequality measurements in the mode choice models.

Levinson (2010), published a theoretical work where he is trying to understand the effects of road pricing policies on equity. He concludes that the revenues of road pricing schemes can be used accordingly, to achieve the desired equity results. Santos *et al.* (2008) integrated equity objectives into accessibility maximization function for a road network design model.

The most applied inequality measurement is probably the Gini coefficient, which measures the statistic dispersion. It takes values between zero, where the characteristic that is measured (income or wealth) is equal everywhere, and one. A value higher than one may imply the negative income. The Gini coefficient is derived from the Lorenz curve, which plots the cumulative share of income of a population (y axis) over the share of people from lowest to highest income at the (x axis). The Gini is the ratio of the difference between the line of equality and the Lorenz curve, over the total area shaped by the line of equality. Moreover, it can be computed by the following formula:

$$G = \frac{\sum_{j\in 1}\sum_{k\in 1}|X_j(y) - X_k(y)|}{2n^2\overline{X}} \tag{1}$$

where n is the number of groups that belong to N and $\overline{X}$ is the characteristic that is being measured.

Although Gini is the most popular and widely cited inequality measurement, in this study we focus on the Theil index. In its general form it is equal with the difference between the maximum possible entropy of the data, and the observed. It takes values from zero (perfect equality) to ln(x). The Theil index importance, lies in the fact that it can be decomposed in different subgroups, for instance spatial units. This means that it can be applied separately to each zone of an area, measuring the inequality at a disegregate level, and then cumulate the resulted values to compute the total inequality of the region. Novotny (2007) suggested a decomposed Theil index for cross-country comparison of regional inequality. Elbers *et al.* (2005) and Dikhanov (1996) analyze decomposed indices to measure the income inequality in and between countries. Kemel *et al.* (2008) used the decomposed Theil index to measure the inequality of accessibility for people in California, suggesting that this method should be used for fairer allocation of transportation investments in the area.

The decomposable formulation of the Theil index is:

$$T = \sum_{g\in G}\widehat{X}_m \cdot T_g + \sum_{g\in g}\widehat{X}_g \cdot ln\left(\frac{\overline{X}_g}{\overline{X}}\right) \tag{2}$$

where,

$$T_g = \frac{1}{N}\sum_{j\in N}\left(\frac{X_j}{\overline{X}}\right) \cdot ln\left(\frac{X_j}{\overline{X}}\right) \tag{3}$$

G is the number of groups
$\widehat{X}_g$ is the weighted characteristic of group g over all the G
$\overline{X}$ is the average value of the measured characteristic to all groups
$\overline{X}_g$ is the average value of the measured characteristic of each group
T_g is the Theil index of each group

N are the centers of region g

In this study, we compute the Theil index in three different decompositions, respective to three spatial levels of aggregation. Kemel *et al.* (2008) suggested a similar approach, starting from a 'track' level and resulting to the whole California. Our case is different in the fact that for the preliminary level of decomposition (within the parcel), we compute the inequality between the individual agents (households) and not groups.

Parcel level (decomposition of each parcel by each agent/household within the parcel):

$$T_{\text{Parcel j}} = \sum_{\text{Household k of Parcel j}} \frac{a_k}{A_{\text{Parcel j}}} \cdot log\left(\frac{\frac{a_k}{A_{\text{Parcel j}}}}{\frac{n_k}{N_{\text{Parcel k}}}}\right) \tag{4}$$

Zone level (decomposition of each zone by each parcel within the zone):

$$T_{\text{Zone i}} = \sum_{\text{Parcel j of Zone i}} \frac{a_j}{A_{\text{Zone i}}} \cdot log\left(\frac{\frac{a_j}{A_{\text{Zone i}}}}{\frac{n_j}{N_{\text{Zone i}}}}\right) + \sum_{\text{Parcel j of Zone i}} \frac{a_j}{A_{\text{Zone i}}} \cdot T_{\text{Parcel j}} \tag{5}$$

Limmattal level (decomposition of whole Limmattal by each zone within the area):

$$T_{\text{Lim}} = \sum_{\text{i=1}}^{Lim} \frac{a_i}{A_{\text{Lim}}} \cdot log\left(\frac{\frac{a_i}{A_{\text{Lim}}}}{\frac{n_i}{N_{\text{Lim}}}}\right) + \sum_{\text{i=1}} \frac{a_j}{A_{\text{Lim}}} \cdot T_{\text{Zone i}} \tag{6}$$

All the components together:

$$T_{\text{Lim}} = \sum_{\text{i=1}}^{Lim} \frac{a_i}{A_{\text{Lim}}} log\left(\frac{\frac{a_i}{A_{\text{Lim}}}}{\frac{n_i}{N_{\text{Lim}}}}\right) + \sum_{\text{i=1}} \frac{a_j}{A_{\text{Lim}}} \left[\sum_{\text{Parcel j}} \frac{a_j}{A_{\text{Zone i}}} log\left(\frac{\frac{a_j}{A_{\text{Zone i}}}}{\frac{n_j}{N_{\text{Zone i}}}}\right) + \sum_{\text{Parcel j}} \frac{a_j}{A_{\text{Zone i}}} \left(\sum_{\text{Hh k}} \frac{a_k}{A_{\text{Parcel j}}} log\left(\frac{\frac{a_k}{A_{\text{Parcel j}}}}{\frac{n_k}{N_{\text{Parcel k}}}}\right)\right)\right] \tag{7}$$

2.4 Accessibility

The accessibility indicators are gaining an increasing interest in policy evaluation, because they measure the ease with which the activities can be reached. The accessibility affects the household location choice (Vandenbulcke *et al.,* 2009) and as a result the house prices (Medda, 2012). Gutiérrez and Urbano (1996) tried to forecast the resulted increase of accessibility in Europe, after the implementation of the Trans-European road network, using an indicator that is based on the impedance from country to country and the GDP. Linneker and Spence (1996) measured the impact of of the M25 London Orbital Motorway on the accessibilities at a regional level. Geurs and Wee (2004) review the accessibility indicators used for land-use and transport strategies and identify four types of components: 1) land-use (e.g. the supply and demand of the opportunities distributed spatially); 2) transportation (e.g. travel time); 3) temporal (e.g. availability of the opportunities in day); 4) individual (e.g. personal characteristics). Moreover, they identify four basic perspectives on measuring the accessibility: 1) infrastructure-based; 2) location-based; 3) person-based; 4) utility-based. According to the same research, accessibility is being used as a way of measuring the operationalization, the interpretability and communicability, as a social or economic indicator.

In its simplest form, the accessibility is measured by the ease that each land-use unit can be accessed by each transport mode.

$$A_i = \sum_{j \in L} \frac{1}{f(c_{ij})} \tag{8}$$

Where A_i is the accessibility at location i, c_{ij} is the cost of travel from location i to location j.

The most applied accessibility measurement is the gravity model. In this form, accessibility is measured by considering the number of opportunities that are available to travelers, by the equation:

$$A_i = \sum_{j \in L} \frac{W_j}{f(c_{ij}, \beta)} \tag{9}$$

Where W_j is the number of opportunities at the location j, and β is the coefficient of the cost.

Moreover, there is another way to measure the accessibility based on the utility. Currently there are two types of utility-based accessibility measurements. Ben-Akiva and Lerman (1985) suggested the *logsum*, which uses the denominator of the multi-nomial logic model in order to measure the accessibility of the complete choice set. The second, is based on the doubly constrained entropy model (Martinez, 1995). Banister and Berechman (2001) suggest that the accessibility is the engine behind the economic growth of an area after the implementation of a policy, because it leads to increase of the employment and productivity. More recently, Martinez and Viegas (2013) applied a methodology that is widely used in Botany, to model the distance-decay functions for accessibility assessment.

De Jong *et al.* (2005) review the current policy evaluation measurements, emphasizing on the rule-of-the-half and the consumer surplus, which is computed by the difference between the logsums of different scenarios. The benefits of using the rule of the half as a policy evaluation measure have been analyzed by Bates (2003). Cherchi *et al.* (2009) evaluated the impacts of alternative policy scenarios using the compensating variation (CV), a term that according to Small and Rosen (1981) indicates the minimum amount of money that a consumer has to be compensated after the implementation of a policy, in order to be at the same level of utility as before. Later, Cherchi *et al.* (2004) measured the welfare using the compensating variation by resampling, the logsum and the rule-of-a-half, and found that the results are biased when compared with the correct values, resulted by a simulation of disaggregate compensating variation.

Odec and Hamre (2003) used the logsum of the generalized cost instead of the rule-of-the-half in the consumer surplus function, and computed the welfare resulting from a congestion pricing policy in Oslo. Gupta *et al.* (2006) and later Kalmanje and Kockelman (2004), measured the compensating variation as the difference in the maximum utility between two transport policy scenarios in Austin, Texas, where the utility is the logsum of the generalized cost. Zhao *et al.* (2008) concluded that the mean compensating variation resulted of transport policy cannot be estimated accurately even after 1 million simulations. They also suggest that the confidence intervals of the welfare measures should be computed, since they are necessary for policy analysis.

The compensating variation is computed by the formula:

$$CV_n = (1/\mu_n) ln\left(\sum_{j=1}^{J} e^{V_{nj}}\right) + C \tag{10}$$

Where μ_n is equal to dU_{nj}/dY_n, Y_n is the income of person n and U_n is the overall utility, and C is the constant that represents the unknown factors.

The difference of the logsums between a policy (J=1) and the base case (where J=0):

$$\Delta CS_n = (1/\mu_n)\left[ln\left(\sum_{j=1}^{J^1} e^{V_{nj}^1}\right) - ln\left(\sum_{j=1}^{J^0} e^{V_{nj}^0}\right)\right] \tag{11}$$

In UrbanSim, the logsum accessibilities per zone are computed by MATSim (Nicolai, 2012, Nicolai and Nagel, 2011), as follows:

$$A_i = \frac{1}{\beta_{Scale}} \cdot ln(\sum_{j=1}^{J}(W_j \cdot exp(-\beta_{Scale} \cdot c_{ij}))) \tag{12}$$

where, A_i is the workplace accessibility at location i, $i \in I$ the origins, $j \in J$ the destinations, β_{Scale} is a scale factor related to the scale of a logic model, W_j is a weight giving the number of jobs at location j, $exp(-\beta_{Scale} \cdot c_{ij})$ is a deterrence function, c_{ij} is the generalized travel cost from location i to location j.

The generalized travel cost c_{ij} is:

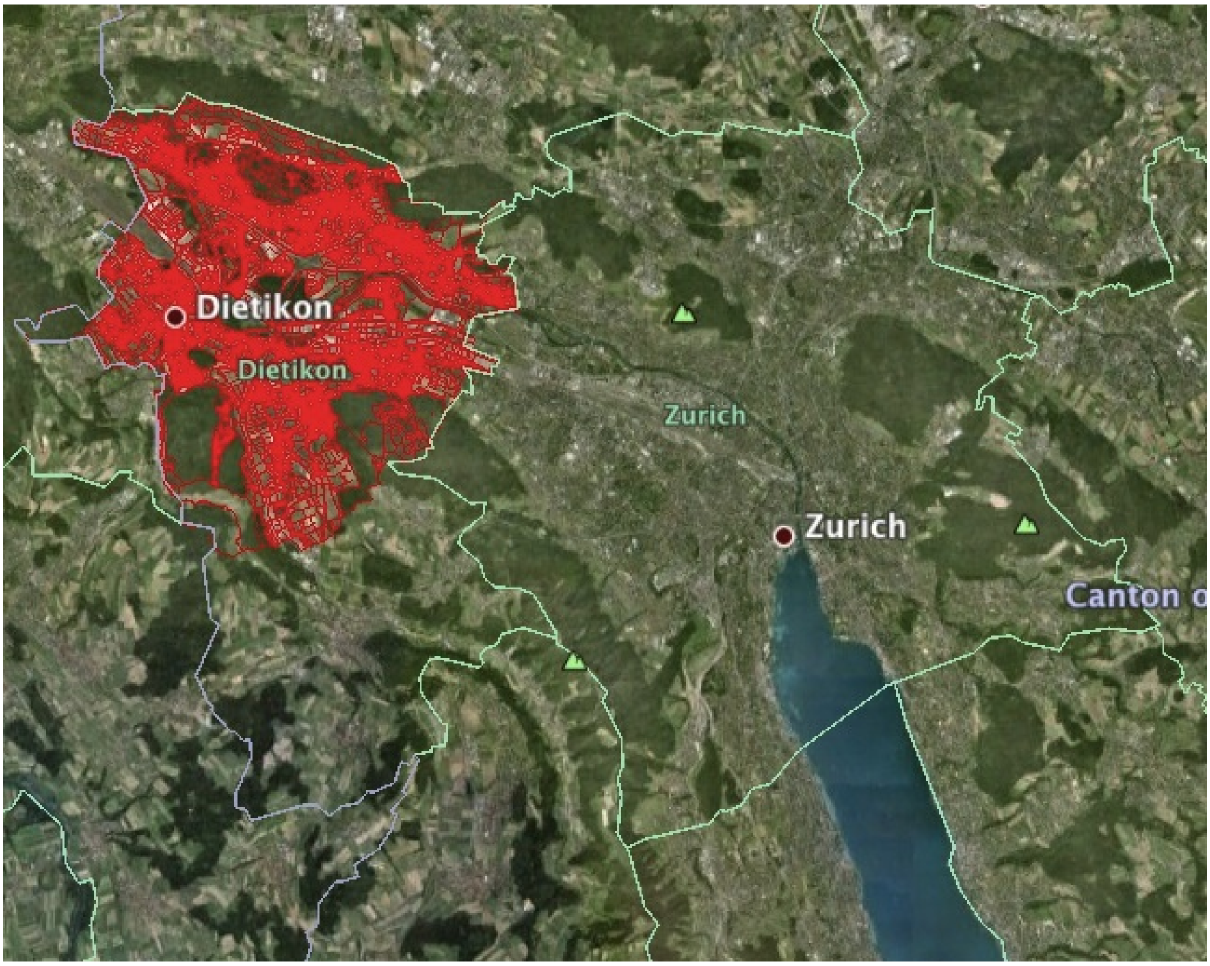
$$\begin{aligned} c_{ij} = (\alpha \cdot ttime) + (\beta \cdot ttime^2) + (\gamma \cdot ln(ttime)) + (\delta \cdot tdistance) + (\epsilon \cdot tdistance^2) + \\ (\zeta \cdot ln(tdistance)) + (\eta \cdot tcost) + (\theta \cdot tcost^2) + (\iota \cdot ln(tcost)) \end{aligned} \tag{13}$$

where *ttime* is the travel time in minutes, *tdistance* is the distance in meters, *tcost* is the monetary travel cost, α to ι are the marginal utilities

In this study, the default values of MATSim were used: $\beta_{Scale} = 1$ and $\alpha = -12$. The other values were set to zero.

Home and work locations are distributed within a given radius from the centroid of each zone, in order to avoid that all the household and workplace locations are attached at the same link of the road network. Because of the uneven sizes of zones in our case, a radius of 500 meters was selected, representative of an average situation.

Figure 1: Limmattal area



3 Methodology

3.1 Case Study Setup

The Municipality of Limmattal comprises from 15 communities, including a part of the city of Zurich. It takes its name from the river 'Limmat' which extends from Zurich city center to Baden, in a valley called 'Plateau' or 'Mittelland' in Switzerland. The transit planing of Limmattal is nationally significant, as it serves the gateway to Zurich. Moreover, it offers a relief function for the agglomeration of Zurich, as it is a popular leisure destination. From an urban development perspective, Limmattal is characterized by high migration rates, not only in the ethnic-cultural mix, but also in the in -and out-commuters. The base year data used in this research, were collected and managed by Zöllig and Axhausen (2011).

3.2 Definition of the Scenarios

For the purpose of this research, we examined two scenarios of development for the region, with time horizon the year 2030: A base-case, where the current trends are going on, and a 'Charming Valley' scenario, where the region is characterized by a robust and cross-linked system of green spaces. The Charming Valley scenario assumes that the development of massive high blocks of buildings leads to settlement densification. The flexible open spaces and urban squares allow for temporary uses. The river Limmat is been highlighted and becomes an attraction, while the waterfront area becomes more recreational, and is integrated into a walk and bike network, as well as parks and squares. The main differences comparing with the base-case scenario, is the construction of the light train 'Limmattalbahn' in 2019, which runs underground through the region, and the higher rate of immigration in the area. The private transport is expected to decline, due to higher densification at infrastructure intersections and optimized provision of cross-linked walkways. The reduction of private transport and the set of energy standards on buildings implies high energy efficiency. This scenario assumes that the increase of housing settlement facilitates people of all the social classes to live and work locally. Limmattal becomes very attractive to businesses and employees, because of the increase of the accessibility. The different communities cooperate and are networking in a very conductive way (Wissen *et al.,* 2012).

3.3 Results

The pre-step of the three dimensional analysis (space, time and agents), was to simulate the current situation in the next 30 years, using the Integrated Land-Use and Transport model UrbanSim. In order to generate the distribution of the spatial indicators in time, we run more than 10 simulations for each of the scenarios (base-case and Charming Valley), using different seeds.

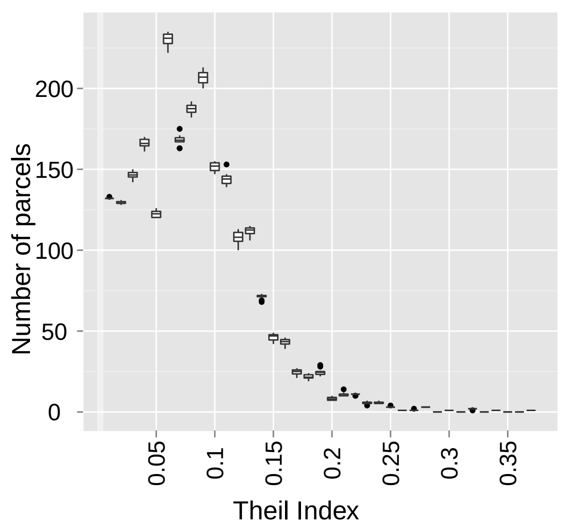
The inequality in the parcels with only one household is zero, and for that reason they were not-considered in the analysis. Figures 2(a), 2(b), 3(a) and 3(b), show the distribution of Theil at the base-year (2000) and in 2030. The variance is increasing in time, reaching values up to 1%, which is normal, because of the cumulative yearly changes of the distribution. We observed that the resulted distribution of parcels' Theil index can be approximated by a gamma distribution which we fitted, and the rate and shape parameters are depicted in figures 2(c), 2(d), 3(c) and 3(d). After fitting a loess curve, we observe that the rate and shape parameters of the base-case scenario decrease in time. However, the shape parameter decreases with lower rate between 2009 and 2015, something that needs to be investigated further. On the other hand, those of the Charming Valley scenario seem to be stabilizing after the year 2020, which is the year of implementation for the new metro line. Since a demographic model is still absent from the current LUTI model for Limmattal, a repetition of the analysis when it will be available, will shed more light on the effect of the new metro line on the inequality.

Figures 4(a) and 4(b) show the spatial distribution of the accessibilities at the base-year, and 4(c), 4(d), 4(e) and 4(f), show the spatial distribution of the car and public transport accessibilities at the year 2030 for the base-case and the Charming Valley scenarios. As in the case of Theil index, the inter-simulation variance is not very high. In figures 5(a) and 5(b) we see the car and public transport accessibilities of the whole area per year. The accessibilities increase linearly in time. What is interesting in the accessibility analysis, is the sudden increase of the public transport accessibility after the year of implementing the new metro line, which is caused by the decrease of the public transport travel time, because of the new line.

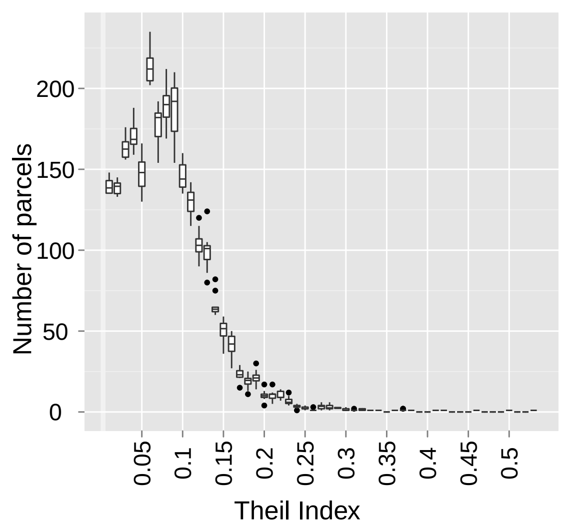
As before, we observed that the distribution of the car accessibilities can be approximated by beta, in this case, which we fitted. The computed parameters (shape1 and shape2) are depicted in figures 6(a), 6(b), 6(c) and 6(d). Similarly, the beta parameters of the public transport accessibility are presented in the figures 7(c), 7(d), 7(c) and7(d). The effect of the new metro line is made clear at the shape2 parameter of the beta distribution in the Charming Valley scenario (7(d)). The parameters for both scenarios are decreasing in time. This raise some questions about the trust that one should have to the results of long-term simulated scenarios.

Figure 2: Spatial distribution of Theil index - Basecase

(a) Distribution of Theil in 2000



(b) Distribution of Theil in 2030



(c) Rate in time

(d) Shape in time

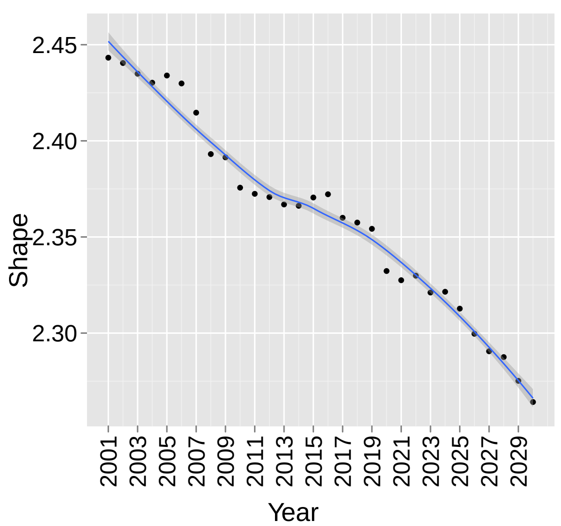


Figure 3: Spatial distribution of Theil index - Charming Valley

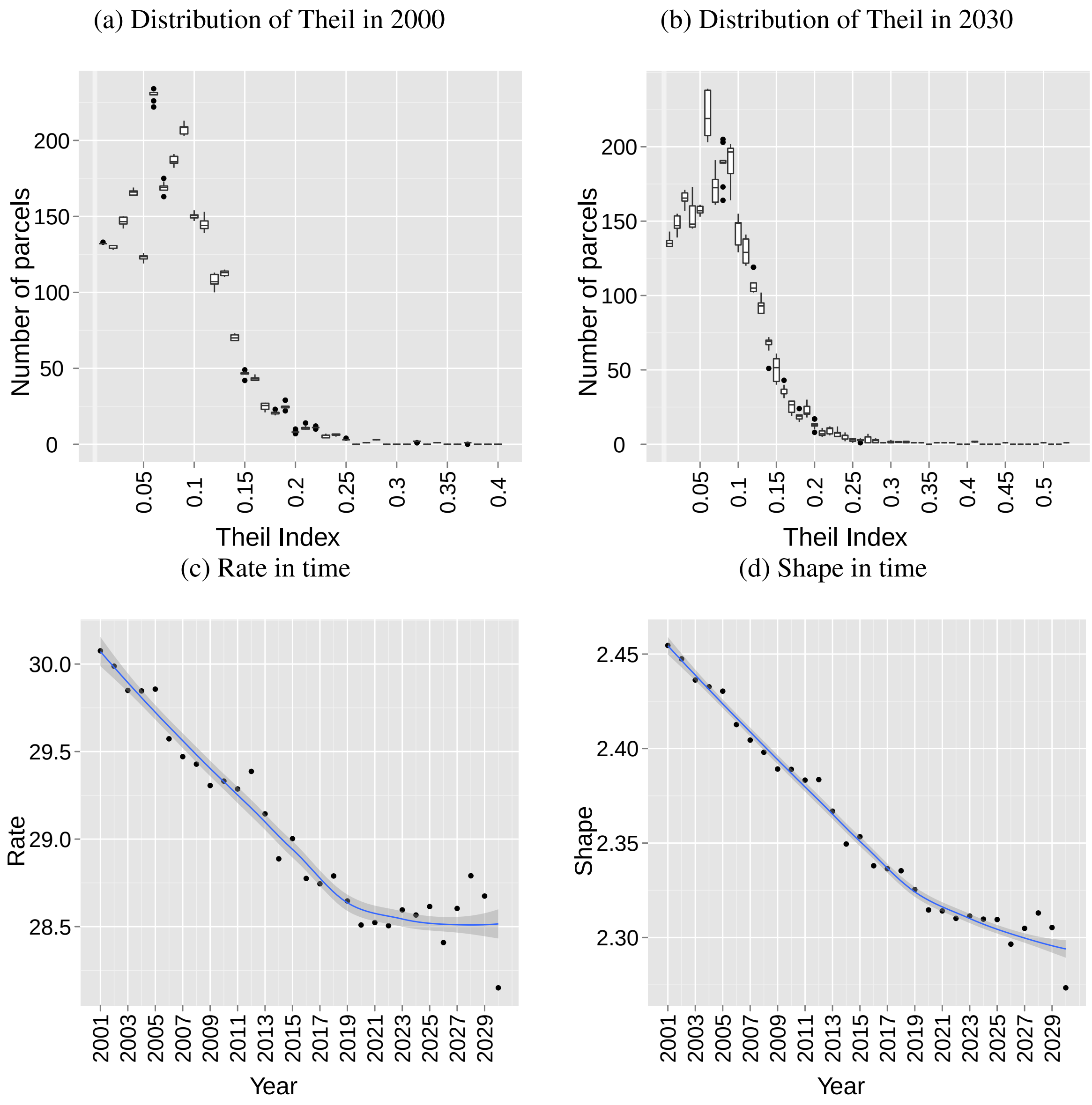
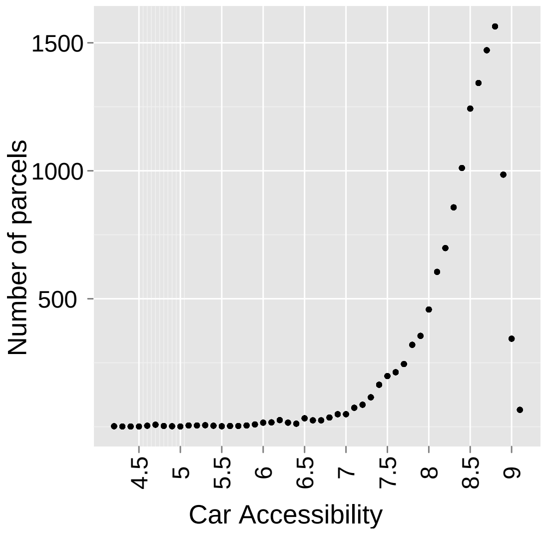
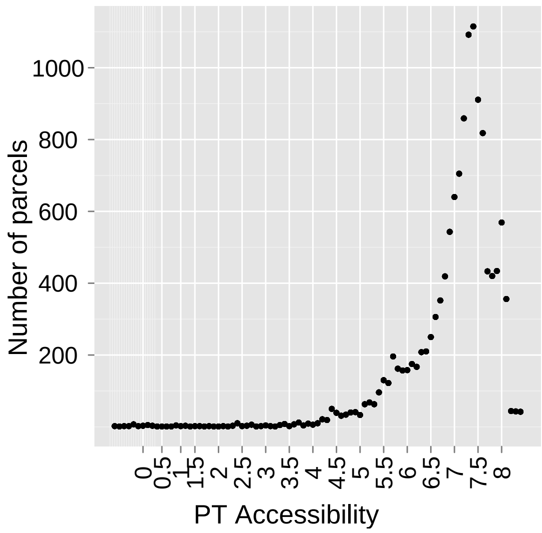


Figure 4: Spatial distribution of accessibilities

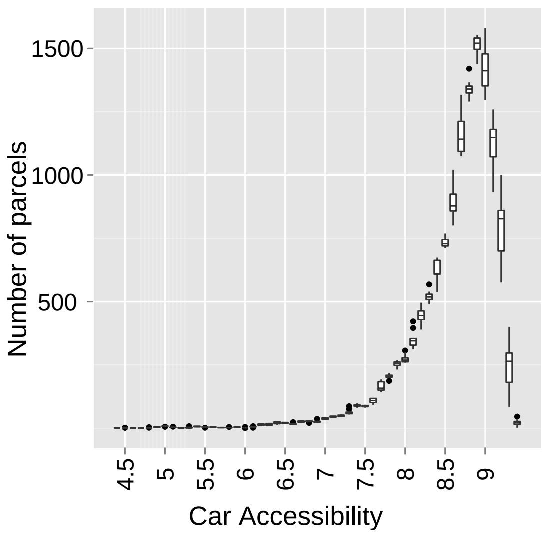
(a) Distribution of Car accessibility in 2001



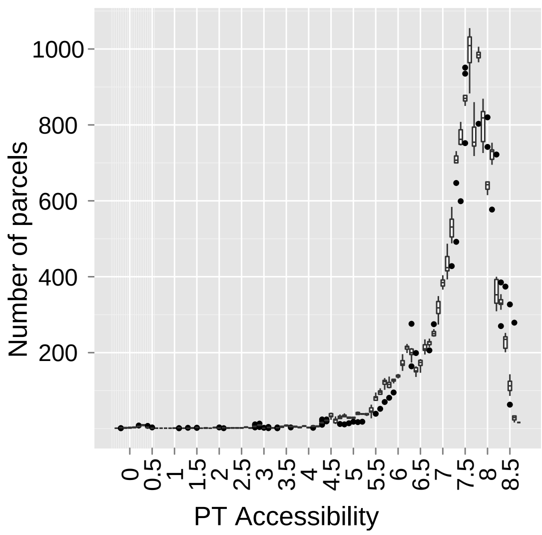
(b) Distribution of PT accessibility in 2001



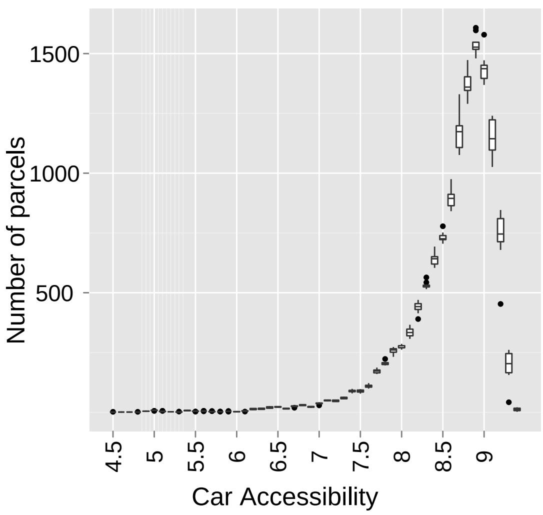
(c) Distribution of Car accessibility in 2030 - BC



(d) Distribution of PT accessibility in 2030 - BC



(e) Distribution of Car accessibility in 2030 - CV



(f) Distribution of PT accessibility in 2030 - CV

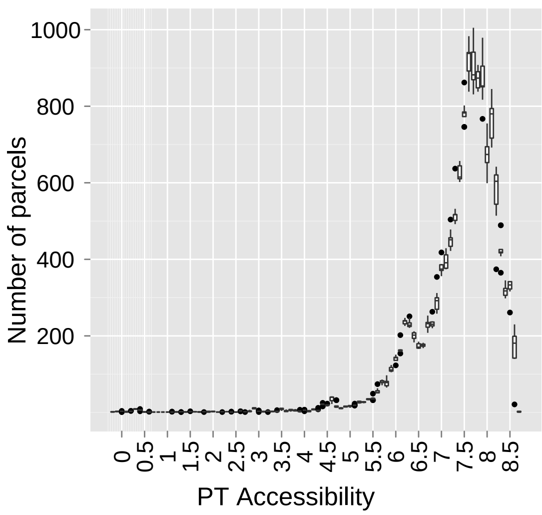
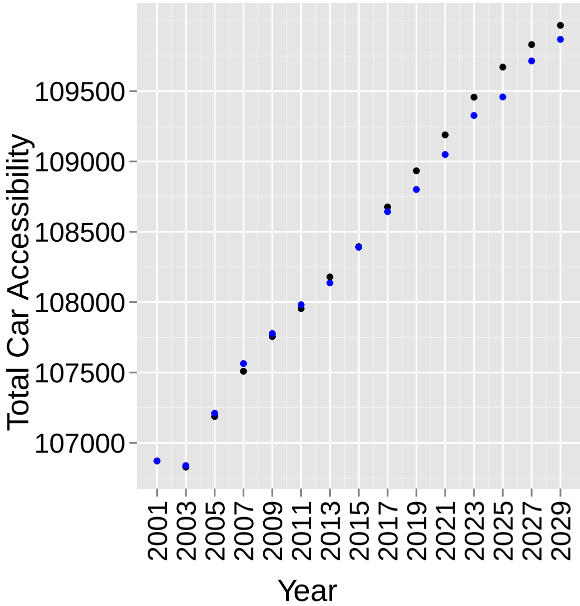


Figure 5: Spatial distribution of accessibilities

(a) Distribution of Car accessibility in 2030
Black points: Basecase scenario
Blue points: Charming Valley scenario



(b) Distribution of PT accessibility in 2030
Black points: Basecase scenario
Blue points: Charming Valley scenario

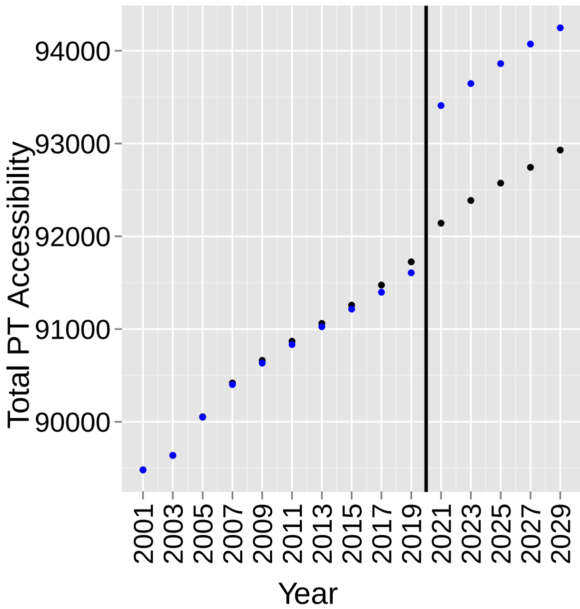
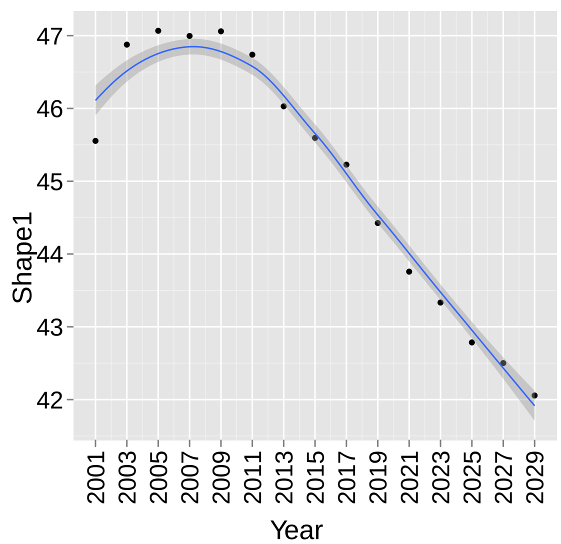
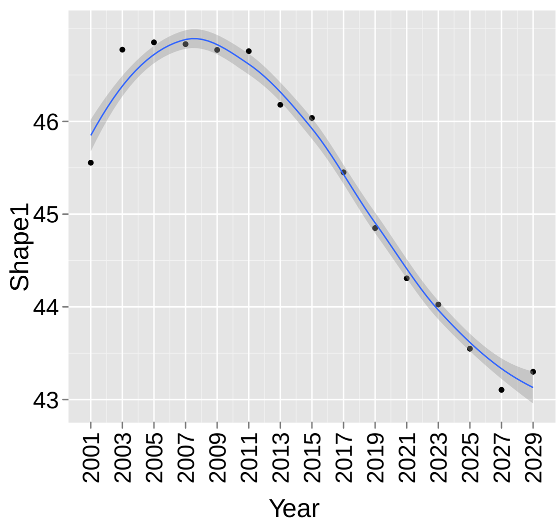


Figure 6: Parameters of beta distribution for Car Accessibilities

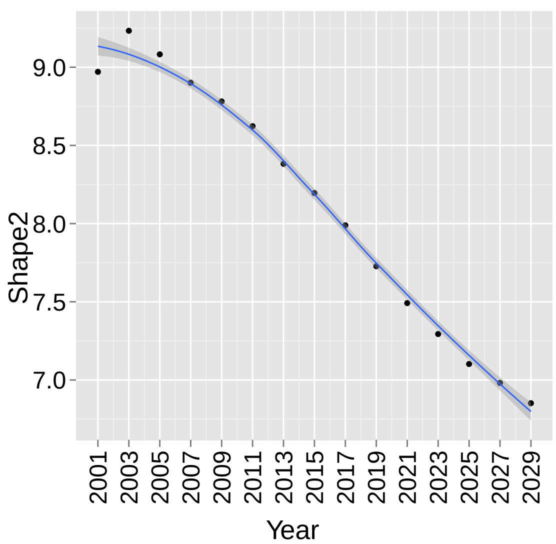
(a) Shape 1 in time - Basecase



(b) Shape 1 in time - Charming Valley



(c) Shape 2 in time - Basecase



(d) Shape 2 in time - Charming Valley

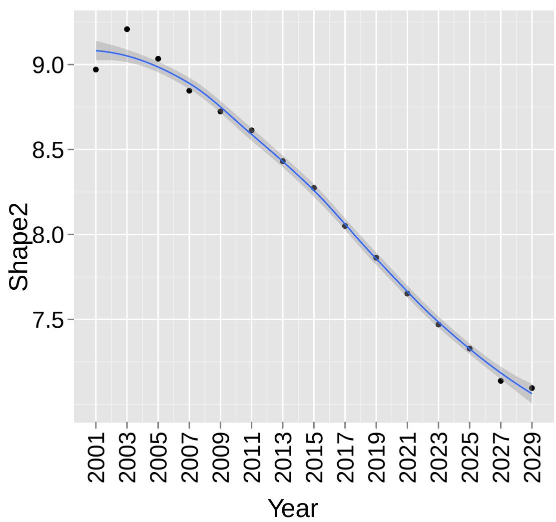
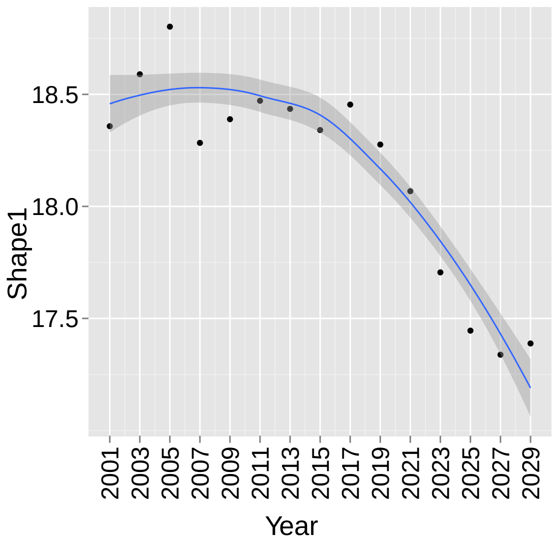
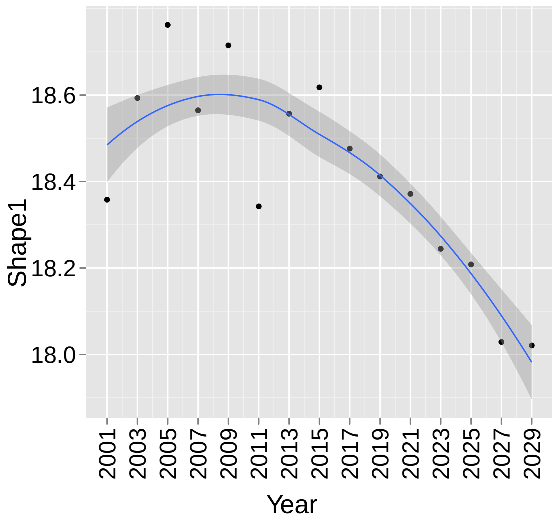


Figure 7: Parameters of beta distribution for PT Accessibilities

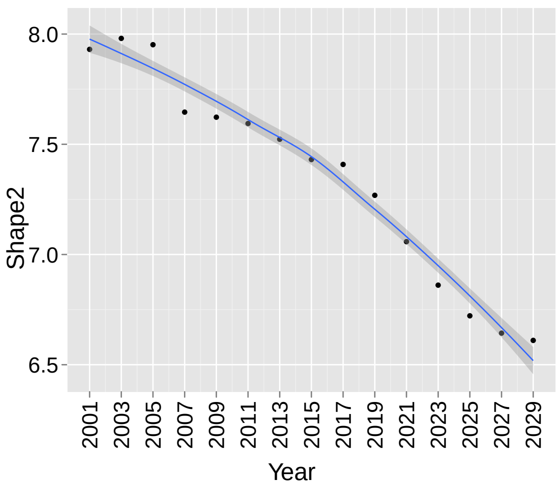
(a) Shape 1 in time - Basecase



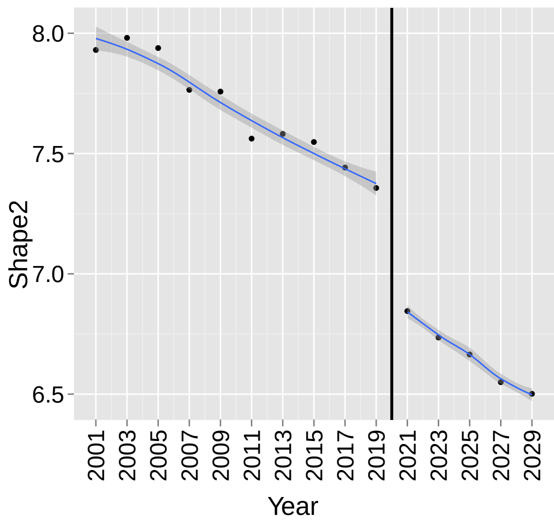
(b) Shape 1 in time - Charming Valley



(c) Shape 2 in time - Basecase



(d) Shape 2 in time - Charming Valley



3.4 Inter-simulation analysis

In the previous paragraph we made a first step by measuring the inter-simulation variance of the indicators. Here we are attempting to measure the variance of the indicators between the base-case and the Charming Valley scenarios, comparing their spatial distributions. Since the indicators follow non-normal distributions, we employed non-parametric tests for their comparison. These tests, which examine whether the samples originate from the same distribution, are the:

Kruskal Wallis test (null hypothesis: population variances are equal) (Kruskal and Wallis, 1952)

$$K = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_i - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - r)^2} \tag{14}$$

where n_i is the number of observations per group i, r_{ij} is the rank of j from group i, N is the total number of observations, $\bar{r}_i = \frac{\sum_{j=1}^{n_i}}{n_i}$ and $\bar{r}_i = 1/2(N+1)$ is the average

Anderson - Darling test (null hypothesis: all samples come from a common population) (Anderson and Darling, 1954)

$$A^2 = -n - S \tag{15}$$

where A is the test statistic, $S = \sum_{k=1}^{n}\frac{2k-1}{n}[ln(F(Y_k)) + ln(1 - F(Y_{n+1-k}))]$, where F is the cumulative distribution.

Levene's test (null hypothesis: population variances are equal) (Brown and Forsythe, 1974)

$$W = \frac{(N-1)}{(k-1)}\frac{\sum_{i=1}^{k} n_i(\bar{z}_{i\cdot} - \bar{z}_{\cdot\cdot})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(z_{ij} - \bar{z}_{i\cdot})^2} \tag{16}$$

where $\bar{z}_i = \sum z_{ij}/n_i$ and $\bar{z}_{i\cdot} = \sum\sum z_{ij}/\sum_{n_i}$

Mann Whitney test (Null hypothesis: true location shift of means is equal to 0) (Mann and Whitney, 1947)

$$U_2 = R_2 - \frac{n_2(n_2+1)}{2} \tag{17}$$

where $n1$ is the sample size for sample1, R_1 is the sum of the ranks in sample 1.

Sign test (Null hypothesis: true median difference equal to 0) (Mendenhall *et al.,* 1989), which assumes that is the null hypothesis is true then the W (the test statistic, number of pairs for $y_i - x_1 > 0$ y where y and x the observation for each population respectively) follows a binomial distribution.

We applied these tests assuming different Euclidean distances (<100, 250, 500 meters and the whole area) from the new metro stations, which is planned to be constructed in 2020. The results indicate that the null hypothesis that the distributions of the Theil index and car accessibility are same is not rejected, in all tests and for every distance from the stations. On the other hand, the null hypothesis that the public transport accessibility distributions are similar, is rejected. The Mann-Whitney test measured the distance between the means of the distributions from 0.30, for the purples up to 100 meters form the stations, to 0.13 when the parcels of the whole area are considered.

Figure 8: Inter-scenario analysis of variance

	<=100				<=250				<=500				Whole area			
	test	p	CI	Dif.	test	p	CI	Dif.	test	p	CI	Dif.	test	p	CI	Dif.
THEIL																
Anderson - Darling	-1.19	0.68			-1.27	0.70			-1.28	0.70			-1.24	0.69		
Levene's (ANOVA)	0.01	0.93			0.00	0.99			0.00	0.95			0.04	0.84		
Levene's (Kruskal - Wallis)	3.56	0.06			10.64	0.00			96.15	0.00			1164.42	0.00		
Mann Whitney	11542	0.99	99%	0.00	321651	0.93	99%	0.00	1716416	0.94	99%	0.00	16511652	0.93	99%	0.00
Sign - test	16	1.00	99%	0.00	104	0.38	99%	0.00	199	0.28	99%	0.00	435	0.04	99%	0.00
Car accessibility																
Anderson - Darling	-0.89	0.60			-0.29	0.42			0.11	0.30			-0.05	0.34		
Levene's (ANOVA)	0.00	0.99			0.01	0.93			0.05	0.82			0.00	0.97		
Levene's (Kruskal - Wallis)	0.01	0.92			0.00	0.95			0.01	0.92			0.91	0.34		
Mann Whitney	11348	0.79	99%	0.00	317629	0.61	99%	0.00	1696068	0.49	99%	0.00	16608875	0.64	99%	0.00
Sign - test	34	0.00	99%	0.00	246	0.00	99%	0.00	557	0.00	99%	0.00	915	0.00	99%	0.00
PT accessibility																
Anderson - Darling	10.25	0.00			68.87	0.00			94.81	0.00			71.05	0.00		
Levene's (ANOVA)	16.59	0.00			14.62	0.00			22.06	0.00			5.64	0.02		
Levene's (Kruskal - Wallis)	12.07	0.00			9.37	0.00			17.77	0.00			0.14	0.71		
Mann Whitney	14330	0.00	99%	0.30	416086	0.00	99%	0.28	2105906	0.00	99%	0.24	18190122	0.00	99%	0.13
Sign - test	152	0.00	99%	0.23	797	0.00	99%	0.23	1806	0.00	99%	0.22	2921	0.00	99%	0.08

4 Conclusions

The evaluation of transport and land use policies is based on various sustainability (e.g. Carbon Footprint), econometric (e.g. Social Welfare Function), inequality (e.g. Theil, Gini) and accessibility (e.g. Gravity model, logsum) indicators, which are computed at an aggregate spatial level (usually city of country). Moreover, the evaluation is based on the results of an individual simulation run, without utilizing the full potential of microsimulation. In this paper, we exploit the strengths of microsimulation in three dimensions, space, time and agents, and analyze the variances of policy evaluation indicators within them. For the purpose of this research, we use the Integrated Land-Use and Transport Model UrbanSim with the agent-based traffic simulation model MATSim in Limmattal area, in Switzerland.

The analysis is performed in three steps. First of all, we simulate the area in the future via two scenarios: a base-case, where the current trends are going on, and a 'Charming Valley' scenario, which assumes the implementation of a new metro line in the year 2020. The second step is the inter-simulation analysis of variance using 10 runs starting from different seeds. The results show that the variance increases in time, but this is normal because of the accumulated variance per year of simulation. We observed that the distribution of the Theil index in space can be approximated by a gamma distribution, and the car and public transport accessibility by beta. Moreover, we measured the impact of a new metro line on the public transport accessibility. The third and last step of the three dimensional analysis, is the comparison of the indicators' distribution between the scenarios, for the year 2030 (last year of the simulation). Since the distributions are non-normal, we applied non-parametric test, the: Kruskal Wallis, Anderson-Darling, Levene's, Mann-Whitney and Sign-test assuming different distances from the new metro stations. These tests examine the null hypothesis that the observations from the two samples (scenarios) belong to the same population (their variance is 0). The results show that the null hypothesis is not rejected when examining the Theil index and the car-accessibility distributions, but is rejected for the public transport accessibility. The difference between the means of the public transport accessibility distributions is 0.30, when assuming distance less or equal to 100 meters from the stations, and goes up to 0.13, when we examine the whole area. In the future we plan to extend this analysis to more indicators and scenarios.

Acknowledgement

This research was partly funded through the SUPat project of the SNSF and the SustainCity project, co-financed by the European Commission within the FP7 program. The first author is grateful for the scholarships awarded by (i) the Special Fund for Research Grants of NTUA for his PhD studies, and (ii) the Swiss Government for his visit at EPFL in Switzerland. The authors are also grateful to the Institute of Transport Planning and Systems of ETH Zurich for providing the data for this research.

5 References

Anderson, T. W. and D. A. Darling (1954) A test of goodness-of-fit, *Journal of the Ameican Statistical Association*, **49**, 765–769.

Arrow, K. J. (1953) *Social Choice and Individual Values*, Cowles Foundation Monographs; New York: Wiley 1964.

Banister, D. and Y. Berechman (2001) Transport investment and the promotion of economic growth, *Journal of Transport Geography*, **9**, 209–218.

Baradaran, S. and F. Ramjerdi (2001) Performance of accessibility measures in europe, *Journal of Transportation and Statistics*, **4** (2-3) 31–48.

Bates, J. (2003) Economic evaluation and transport modelling: theory and practice, paper presented at the *paper for 10th International Conference on Travel Behaviour Research*, Luzern.

Ben-Akiva, M. and S. R. Lerman (1985) *Discrete Choice Analysis*, MIT Press.

Brown, M. B. and A. B. Forsythe (1974) Robust tests for the equality of variances, *Journal of the American Statistical Association*, **69** (346) 364–267, June 1974.

Cherchi, E., C. Cirillo and J. W. Polak (2009) Assessment of user benefits in presence of random taste heterogeneity, *Transportation Research Record: Journal of the Transportation Research Board*, (2132) 78–86.

Cherchi, E., J. Polak and G. Hyman (2004) The impact of income, tastes and substitution effects on the assessment of user benefots using discrete choice models, paper presented at the *European Transport Conference*, Strasbourg.

Coleman, J. S. (1966) The possibiliy of a social welfare function, *The American Economic Review*, **56** (5) 1105–1122, December 1966.

De Jong, G., M. Pieters, A. Daly, I. Graafland, E. Kroes and C. Koopmans (2005) Using the logsim as an evaluation measure: Literature and case study, *Technical Report*, RAND Corporation, May 2005.

Dikhanov, Y. (1996) Decomposition of inequality based on incomplete information, paper presented at the *IARIW 24th General Conference*, Lillehammer, Norway, August 1996.

Elbers, C., P. lanjouw, J. A. Mistiaen and B. Ozer (2005) Re-interpreting sub-group inequality decompositions, *Technical Report*, **3687**, World Bank Policy Research Working Paper.

Farooq, B. and E. Miller (2011) Towards integrated land use and transportation: A dynamic disequilibrium based microsimulation framework for built space markets, *Transportation Research Part A: Policy and Practice*.

Franklin, J. P. (2006) The equity effects of roadway tolls: An application of hicksian wealfare meassure with income effects, paper presented at the *The Expanding Sphere of Travel Behaviour Research, 11th International Conference on Travel Behaviour Research*, Kyoto, August 2006.

Geurs, K. T. and B. Wee (2004) Accessibility evaluation of land-use and transport strategies: review and research directions, *Journal of Transport Geography*, **12**, 127–140.

Grazi, F., C. v. d. B. Jeroen and P. Rietveld (2007) Spatial welfare economics versus ecological footprint: modeling agglomeration, externalities and trade, *Environmental and Resource Economics*, **38**, 135–153.

Gupta, S., S. Kalmanje and K. M. Kockelman (2006) Road pricing simulations: Traffic, land use and welfare impacts for austin, texas, *Transportation Planning and Technology*, **29** (1) 1–23.

Gutiérrez, J. and P. Urbano (1996) Accessibility in the european union: the impact of the trans-european road network, *Journal of Transport Geography*, **4** (1) 15–25.

Kalmanje, S. and K. M. Kockelman (2004) Credit-based congestion pricing: Travel, land value and welfare impacts, *Transportation Research Record: Journal of the Transportation Research Board*.

Kemel, E., S. Y. Yoon and K. G. Goulias (2008) An inequality assessment tool for urban development using gis-based accessibility measures and a fractal version of theil's index, paper presented at the *Transportation Research Board annual meeting*.

Kruskal and Wallis (1952) use of ranks in one-criterion variance analysis, *Journal of the American Statistical Association*, **47** (260) 583–621.

Levinson, D. (2010) Equity effects of road pricing: A review, *Transport Reviews: A Transnational Transdisciplinary Journal*, **30** (1) 33–57.

Linneker, B. and N. Spence (1996) Road transport infrastructure and regional economic development, *Journal of Transport Geography*, **4** (2) 77–92.

Litman, T. (2011) Developing indicators for sustainable and livable transport planning, Victoria Transport Policy Institute.

Mann, H. B. and D. R. Whitney (1947) On a test of whether one of two random variables is stochastically larger than the other, *Annals of Mathematical Statistics*, **18** (1) 50–60.

Martinez, F. J. C. (1995) Access: the transport-land use economic link, *Transportation Research Part B*, **29** (6) 457–470.

Martinez, L. M. and J. M. Viegas (2013) A new approach to modelling distance-decay functions for accessibility assessment in transport studies, *Journal of Transport Geography*, **26** (87-96).

Medda, F. (2012) Land value capture finance for transport accessibility: a review, *Journal of Transport Geography*, **25**, 154–161.

Mendenhall, W., D. D. Wackerly and R. L. Scheaffer (1989) *Mathematical statistics with applications (Fourth ed.)*, chap. Nonparametric statistics, 674–679, PWS-Kent.

Miller, E. J., B. Farooq, F. Chingcuanco and D. Wang (2011) Historical validation of integrated transport–land use model system, *Transportation Research Record: Journal of the Transportation Research Board*, **2** (2255) 91–99.

Nicolai, T. W. (2012) Integrating matsim to urbansim for the integrating matsim to urbansim for the sustaincity studies brussels and zurich, *Technical Report*, Technische Universität Berlin.

Nicolai, T. W. and K. Nagel (2011) Matsim4urbansim – guide on urbansim usage of the travel model plug-in, *Technical Report*, Transport Planning and Transport Telematics (VSP), Transport Planning and Transport Telematic (VSP), Technical University of Berlin (TUB).

Novotny, J. (2007) On the measurement of regional inequality: does spatial dimension of income inequality matter?, *Annals of Regional Science*, **41**, 563–580.

Odec, J., J. nd Rekdal and T. N. Hamre (2003) The socio-economic benefits of moving from cordon toll to congestion pricing: The case of oslo, paper presented at the *Transportation Research Board annual meeting*.

Ramjerdi, F. (2005) Equity measures and their performances in transport, *Transportation Research Record: Journal of the Transportation Research Board*.

Samuelson, P. A. (1954) The pure theory of public expenditure, *The Review of Economics and Statistics*, **36** (4) 387–389, November 1954.

Santos, B., A. Antunes and E. J. Miller (2008) Integrating equity objectives in a road network design model, *Transportation Research Record: Journal of the Transportation Research Board*, **2089**, 35–42.

Small, K. A. and H. S. Rosen (1981) Applied welfare economics with discrete choice models, paper presented at the *Econometrica*, vol. 49, 105–130.

Talen, E. (1998) Visualizing fairness: Equity maps for planners, *Journal of the American Planning Association*, **64** (1) 22–38.

Vandenbulcke, G., T. Steenberghen and I. Thomas (2009) Mapping accessibility in belgium: A tool for land0use and transport planning?, *Journal of Transport Geography*, **17**, 39–53.

Viegas, J. M. (2001) Making urban road pricing acceptable and effective: searching for quality and equity in urban mobility, *Transport Policy*, **8**, 289–294.

Waddell, P. (2002) Urbansim: Modelling urban development for land use, transportation and environmental planning, *Journal of the American Planning Association,*, **68** (3) 297–314.

Wissen, U., T. von Wirth, A. Kunze and N. Neuenschwander (2012) How does the limmattal present itself in the year 2030? four regional scenarios, *Technical Report*, Sustainable Urban Patterns, January 2012.

Zhao, Y., K. Kockelman and A. Karlström (2008) Welfare calculations in discrete choice settings: The role of error term corelation, paper presented at the *87th Transportation Research Board Annual Meeting*.

Zöllig, C. and K. W. Axhausen (2011) A conceptual, agent-based model of land development for urbansim, paper presented at the *51th ERSA Conference*, Barcelona, September 2011.