A Multidimensional Analysis of Agent-Based Policy Evaluation Indicators

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1 Motivation

The general interest around sustainability and livability in urban development is growing. The role of transport in this direction is of major importance, because of the size of transportation infrastructure projects and their effects on the economy, society and environment.

In order to evaluate the different transportation policies and show whether they fulfill the objectives of sustainability in the entirety of the area, econometric indicators that are usually computed at an aggregate level are employed. However, while a particular set of indicators based on a single simulation, can characterize a policy positive for sustainable development, another set, or the same computed by multiple simulation runs, could show it harmful. The complex way of interaction between the indicators, and the multidimensional differentiation of the policy packages available at the policy maker, increase the difficulty of proper decision on urban planing, rendering the selection of suitable indicators for urban transport policy evaluation, very significant.

2 Objective

The objective of this research is to develop a methodology that will employ the output of the microsimulation in three dimensions, agents, space and time, to support the evaluation of transportation policies and compute the confidence intervals of their success. By multiple runs of the integrated land-use and transport model for Limmattal (Zurich), we measure the variance and generate the distributions of the indicators in space and time. The methodology is applied to a base-case and a public transport investment scenario, which assumes the construction of a new underground rail in the year 2020, and the results are compared. The proposed methodology differs from the current policy evaluation framework regarding the level of aggregation that is applied, and will support the highly complex decision making in the future.

3 Policy Evaluation Indicators

3.1 Inequality Measurements

The difference of the fairness within a population after the implementation of a policy, is measured by the inequality metrics. Ramjerdi [1], classified them in statistical, such as the Gini coefficient and the Theil's index, welfare, such as the Kolm and Atkinson indexes, and axiomatic. She used them to measure the effects of transportation policies in Oslo, and concluded that the results can be interpreted differently when different indicators are being used. Viegas [2] suggested wider perspective of equity when planning congestion charging schemes, to cover both horizontal and longitudinal dimensions. Santos et al. [3] integrated equity objectives into accessibility maximization function for a road network design model.

The Theil index equals 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's index advantage comparing with the Gini, lies in the fact that it can be decomposed in groups of agents or spatial levels. This means that it can be applied separately to each zone of an area, measuring the inequality at a disaggregate level, and then cumulate the resulted values to compute the total inequality of the region. This is an important property that renders it suitable for our research.

3.2 Accessibilities

The effect of the accessibility on the household location choice and as a result the house prices has been identified by many studies in the past [4, eg]. The accessibility is measured by indicators that gain an increasing interest in policy evaluation, since they count the ease with which the activities can be reached. The most applied accessibility measurement is the gravity model, while the most sophisticated is the utility-based, which we are using in this research. Ben Akiva and Lerman [5] proposed the *logsum* term, which uses the denominator of the multi-nomial logic model to measures the accessibility of the complete choice set. They suggest that accessibility is similar to the consumer surplus, and equals with the maximum expected utility of the travelers.

In the Integrated Land-Use and Transport model UrbanSim [6], the logsum accessibilities per zone are computed by the agent-based traffic simulation model MATSim [7], as follows:

$$Acc = \frac{1}{\mu} \cdot ln(\sum_{j=1}^{j} (D_j \cdot exp(\mu \cdot \beta \cdot c_{ij}))) \tag{1}$$

Where: Acc is the accessibility, j are all job locations, D_j is the number of jobs at location j, c_{ij} is the travel time in minutes to get from location i to j, μ is the logit scale, β is the travel time. Here, the default values described in [8] were used: μ=2, β=-12.

4 Methodology and Results

For the purpose of this research, we use the Land - Use model UrbanSim integrated with the agent-based traffic simulation model MATSim, for the region Limmattal in Zurich. The first step of our three-dimensional analysis (space, time and agents), was to measure the inter-simulation variance of the Theil index, car accessibility and public transport accessibility, for a base-case and a public transport investment scenarios. We found that the maximum spatial variance after 30 simulated years, using data from 10 runs, remains at low level ($\sim$ 2%), despite the fact that we considered using different starting seeds. As a result, we based our further analysis on the mean values of the indicators per spatial unit (parcel).

Moreover, we observed that the spatial distributions of the Theil index and the accessibility measurements, can be approximated by gamma and beta distributions respectively, therefore we computed their shape and scale parameters in time. While in the base-case scenario the parameters decline continuously over time –throughout the simulation period– we noticed that concerning the public transport investment scenario, the parameters of gamma (Theil's index distribution) are stabilizing at the same value after the year 2020, which is the first year of operation for the new underground rail. At the same year of the simulation, it is observed a major shift in the value of the shape2 parameter of the beta distribution fitted on the public transport accessibility, which was a first indication that further investigation was needed at a scenario level.

Following the inter-simulation analysis, we compared the indicators' distributions between the scenarios. In order to do so, we composed subsets of the population (parcels) based on the eucledian distance from the new underground rail stations. Since we have already shown that the distributions were non-normal, we applied the following non-parametric tests: Anderson-Darling, Levene's, Kruskal Wallis, Mann Whitney and Sign. Concerning the Theil and car accessibility, the results show that the difference between the variances of their distributions in the two scenarios is zero, since the null hypothesis that both groups are coming from the same population is not rejected ($p > 0.05$). On the other hand, the null hypothesis for the public transport accessibility is rejected, indicating the relocation of the mean between the two scenarios, which we measure (Table 1).

	<=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

Table 1: Inter-scenario analysis of variance

5 Conclusions

In this paper, the authors develop a methodology that exploits the strengths of microsimulation in three dimensions: agents, space and time. By multiple runs, they measure the variance and generate the distributions of policy indicators, such as the inequality measurement Theil index and the utility-based accessibility. The results show that while the inter-simulation variance of the selected indicators is low, their distribution changes sharply when a large-scale transportation infrastructure investment is taking place. The distributions means' distance between a base-case and a public transport investment scenario is being measured, assuming varying euclidian distances from the newly constructed stations of an underground rail. The results are expected to support the transport policy evaluation.

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