Measuring the Performance of Urban Models

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PROBLEM DESCRIPTION

"It is not the precise numerical path, but faith to the dynamic behavior generated by the model" (Meadows et al. 2005) that matters. Nevertheless, the only objective way to evaluate the performance of a model is through the accuracy of its results. In this respect, there is a great number of numerical error and fitting indicators that are used to evaluate the outcomes of urban growth and Land-Use change models. However, accurate results may not necessarily imply an accurate model and as a result comparing the accuracy of models' results is not a valid mean to compare the different models.

Among existing fitting indicators, the *Lee-Sallee* (*LS*) index of agreement and the *Kappa* (*K*) coefficient are commonly used to measure the similarity between the model's results (layer A) and the reality (layer B). The *LS* index is essentially the quotient of the two layers' union divided by the two layers' intersection and shows how correctly coincident are the results of modeling with the spatial shape of the actual urban area (Kim et al. 2006). Its values range from 0, indicating no fitting at all, to 1 indicating a perfect match. The *K* coefficient is also used to make pair wise comparisons between layers A and B while its values range from -1, indicating the absence of any similarity, to 1 indicating that layers A and B are identical. The value 0 represents the special case where the agreement is exactly equal to the agreement as can be expected by chance.

It should be noted that *K* coefficient is sensitive to the amount of change present in the maps (Hagoort et al. 2008) while the same applies to *LS*. This means that if the changes are small, any simulation may lead to very good results. *"A high agreement therefore does not necessarily indicate an accurate model"* (Jasper 2009). At the same time, previous studies showed that in a selection of published applications, the average LU change is less than 10% (Pontius & Malanson 2005) which means that (in average) the no-change model would score a similarity index greater than 90%. Actually, in some cases, the no-change model may appear to be more accurate than the model's results (Pontius & Malanson 2005, Jasper 2009). It is evident that new indicators should be used; indicators that measure the performance of urban models taking into account the specific characteristics of each case study. To this end, these indicators should conduct pair wise comparisons between the initial reference map, the final reference map and the map resulting from the model's simulation (Pontius et al. 2007).

THE *GAIN* & *FIDELITY* FACTORS

Towards this direction, certain indicators have been proposed such as $K_{simulation}$ (Jasper 2009). In this paper, we introduce the notion of the *Gain* and the *Fidelity* factors that are calculated based on the classical definition of *LS*. Let U_1 and U_2 be the urban cover of an area under study in t_1 and t_2 ($t_1<t_2$) respectively and U_m a model's estimation of U_2 based on U_1. Additionally, let LS_{null} be the *LS* indicator calculated for the null model which assumes no change/growth (the coincidence between U_1 and U_2) and LS_m the *LS* indicator calculated for the model's result (the coincidence between U_m and U_2). Finally, note that for the case of a *perfect* model, *LS* would equal *1*. Using the above notions we may give the following definitions:

$$LS_{gain} := (LS_m - LS_{null})/LS_m$$

$$LS_{fidelity} := (LS_m - LS_{null})/(1 - LS_{null})$$

The *Gain* factor depicts how much of the results' accuracy (using *LS*) is attributed to the model used or in other words how much accuracy we gain by applying the model instead of using the no-model approximation. The *Fidelity* factor on the other hand, compares the performance of the model to the performance of a perfect model, measuring hence how much of the change simulated by the model is actually accurate and trustworthy. Assuming that $LS_m \geq LS_{null} > 0$, both factors' values range from 0, indicating that the model used is no better than the null model, to 1 which indicates a perfect performance. On the other hand, if $LS_m < LS_{null}$, both factors are negative implying thus that the model used is worse than the null model. The *Gain* and *Fidelity* factors can be applied upon the *K* coefficient as well, if both K_m and K_{null} are greater than zero, which is usually - but not always - the case.

In order to illustrate further the use of the herein proposed factors, we use them to measure the performance of the CaFe urban growth model (Mantelas et al. 2010). Specifically we use the simulations produced by CaFe for the east Attica region for three periods during which significant changes in urban cover occurred (Table 1 & 2 – Figure 1). Using only the classical *LS* and *K* indicators (LS_m and K_m in tables) it would appear that the model performs better for periods *A* and *B* rather than period *C*. Nevertheless, despite the fact that the results of the model for the periods *A* and *B* are closer to reality than the results for period *C*, this is not a valid conclusion. The *Gain* factors reveal that the end user has less information to gain by applying the model for periods *A* and *B* while for period *C* the gain in information is tripled. At the same time, the *Fidelity* factors indicate that the model, when applied for period *C*, performs 50% percent more accurately than when applied for period *A* and *B*.

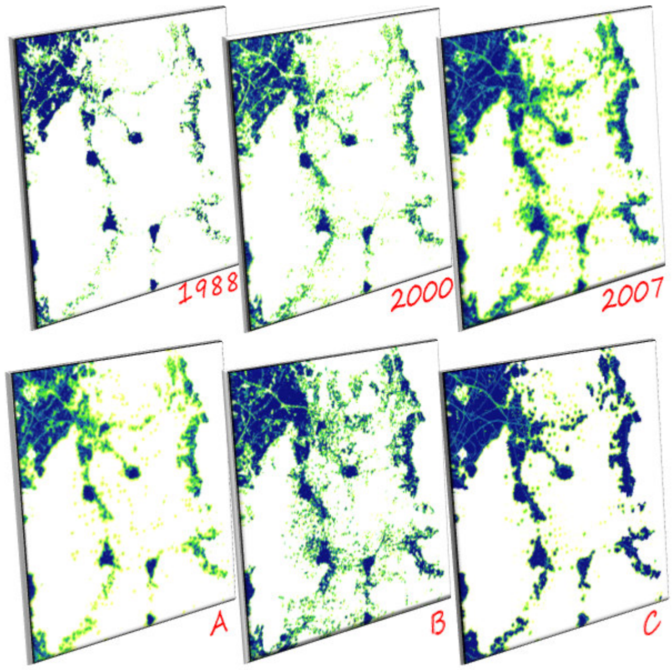

***Figure 1**:* The actual urban cover layers and the correspondent estimations of them used

Period	t_1	t_2	*Change%*	LS_{null}%	LS_m%	LS_{gain}%	$LS_{fidelity}$%
A	1988	2000	66	61	72	15	28
B	2000	2007	66	60	72	27	30
C	1988	2007	177	36	63	43	42

Table 1: The *Gain* and *Fidelity* based on *LS*

Period	t_1	t_2	*Change%*	K_{null}%	K_m%	K_{gain}%	$K_{fidelity}$%
A	1988	2000	66	74	82	10	31
B	2000	2007	66	71	80	11	31
C	1988	2007	177	48	72	33	46

***Table 1**:* The *Gain* and *Fidelity* based on *K*

CONCLUSIONS

While *LS* and *K* are advisable indicators to measure the fitting of a model's result to reality, they fail to evaluate the model's performance itself. For this reason, we propose two indicators that are very easy to calculate based on the classical definitions of the *LS* and *K* indicators under certain numerical assumptions. The *Gain* factor measures how much information the end user can gain by applying the model while the *Fidelity* factor evaluates the ability of the model to simulate the occurred change.

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