Simulation of Land Use and Transport: State of the Art

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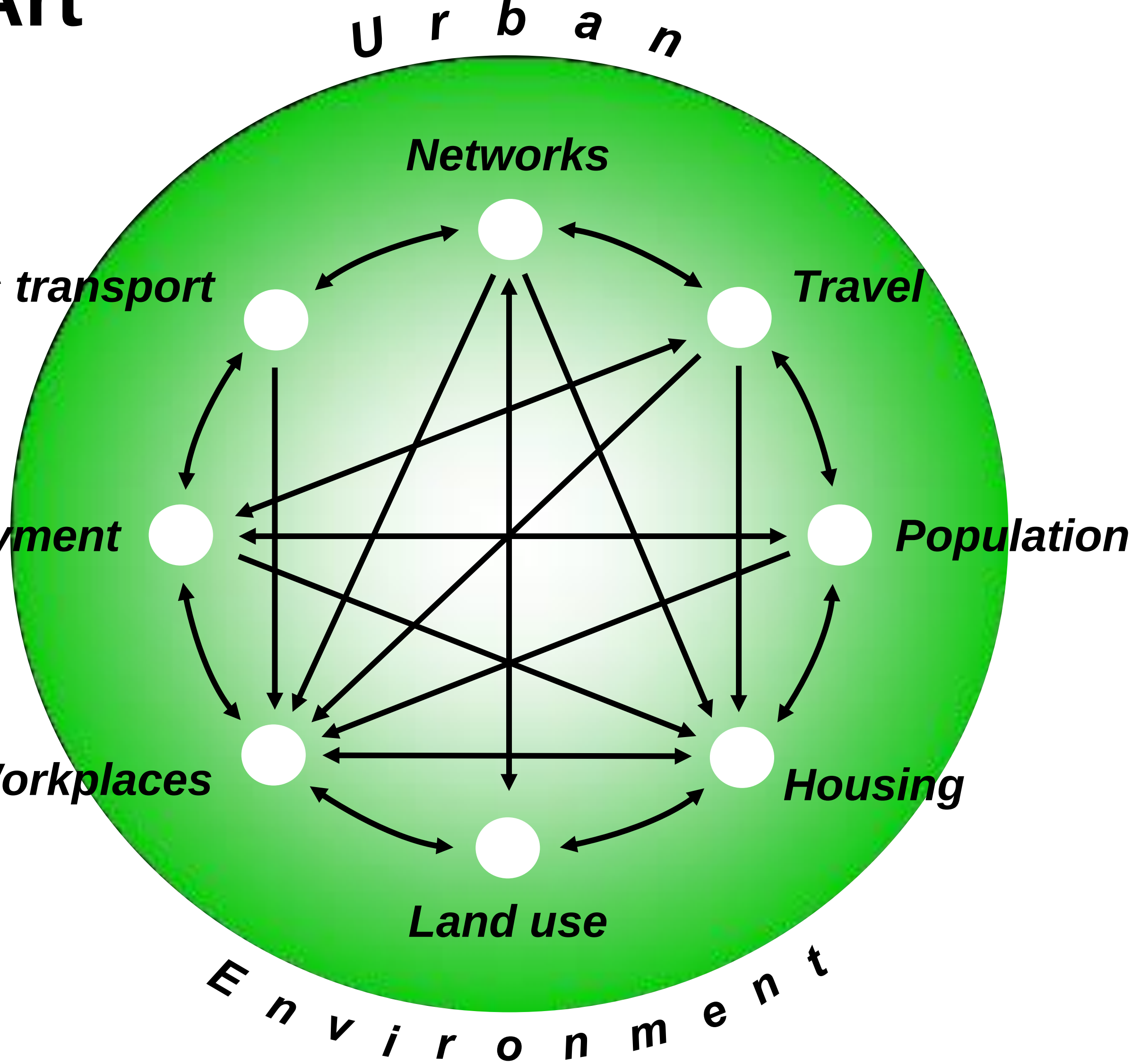

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Urban models in the 1960s

Integrated mathematical models of urban land use and transport appeared first in the United States in the early 1960s. In particular the ***Lowry model*** (1964) stimulated modelling efforts in many large metropolitan areas.

However, many of these efforts failed to deliver because of unexpected difficulties in ***data collection***, ***calibration*** and ***computing***.

Moreover, the models were focused on ***growth allocation*** and ***transport efficiency*** and did not address new ***social*** and ***ethnic*** urban ***conflicts***.

In addition, the ***synoptic rationalism*** planning paradigm the models were based on was replaced by incremental, participatory ways of planning.

Urban models in the 1970s

In his ***"Requiem for large-scale models***" , Douglass B. Lee (1973) accused the models of "seven sins":

- ***hypercomprehensiveness***
- ***grossness***
- ***mechanicalness***
- ***expensiveness***
- ***hungriness***
- ***wrongheadedness***
- ***complicatedness***

The urban modelling community retreated into the base-ments of academia.

Urban models in the 1980s

The requiem was premature. Some of the technical problems were relieved by better data availability and faster computers.

The models became ***more disaggregate*** and were based on ***better theory***, such as ***bid-rent theory*** or ***discrete choice theory*** and ***user equilibrium*** in urban networks.

Better ***visualisation*** tools made the model results more understandable by citizens and decision makers.

A new generation of models was more sensitive to issues of ***social equity***.

Urban models in the 1990s

The 1990s brought a new interest in integrated urban land-use transport models:

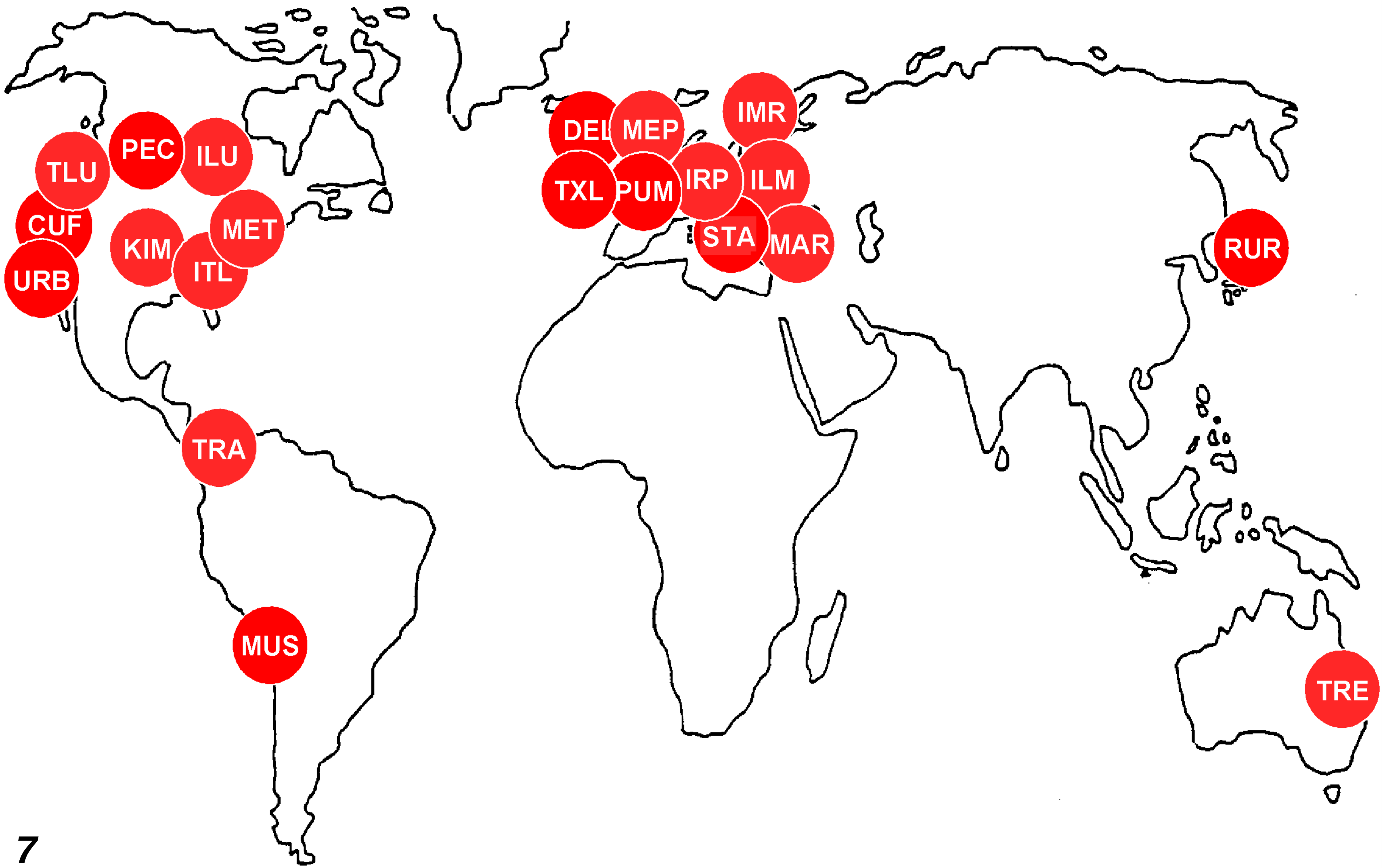
- ***Environmental legislation*** in the USA triggered a new wave of applications of urban land-use transport models
- In Europe, the ***European Commission*** funded a number of studies employing urban land-use transport models.
- Integrated urban land-use transport models were applied to a ***growing number*** of metropolitan areas (TRANUS, MEPLAN, METROPILUS, IMREL, RURBAN, UrbanSim, DELTA and PECAS.
- The first urban models (TRANUS and UrbanSim) were made available as ***Open Source*** software.

Urban models today

The most recent developments have opened a seemingly unlimited ***golden future*** for urban modelling:

- New developments in data availability through geographic information systems ***(GIS)*** and computer science ***(parallel computing)*** have reduced former technical limitations.
- New developments in modelling theory and methodology, such as ***activity-based*** and ***agent-based*** models, have widened the range of issues that can be addressed.
- A global community of urban modelling experts meets at conferences, such as ***WCTR***, ***CUPUM*** and ***TRB***.

Urban models today



A fragmented field

Yet despite this success, the urban modelling community is separated along two fundamental dividing lines:

- ***Equilibrium v. dynamics***. Are urban areas modelled best as in equilibrium or as dynamic systems?
- ***Macro v. micro***. What is the best level of aggregation of urban models?

There is only little communication between the camps with different paradigms.

Equilibrium v. Dynamics

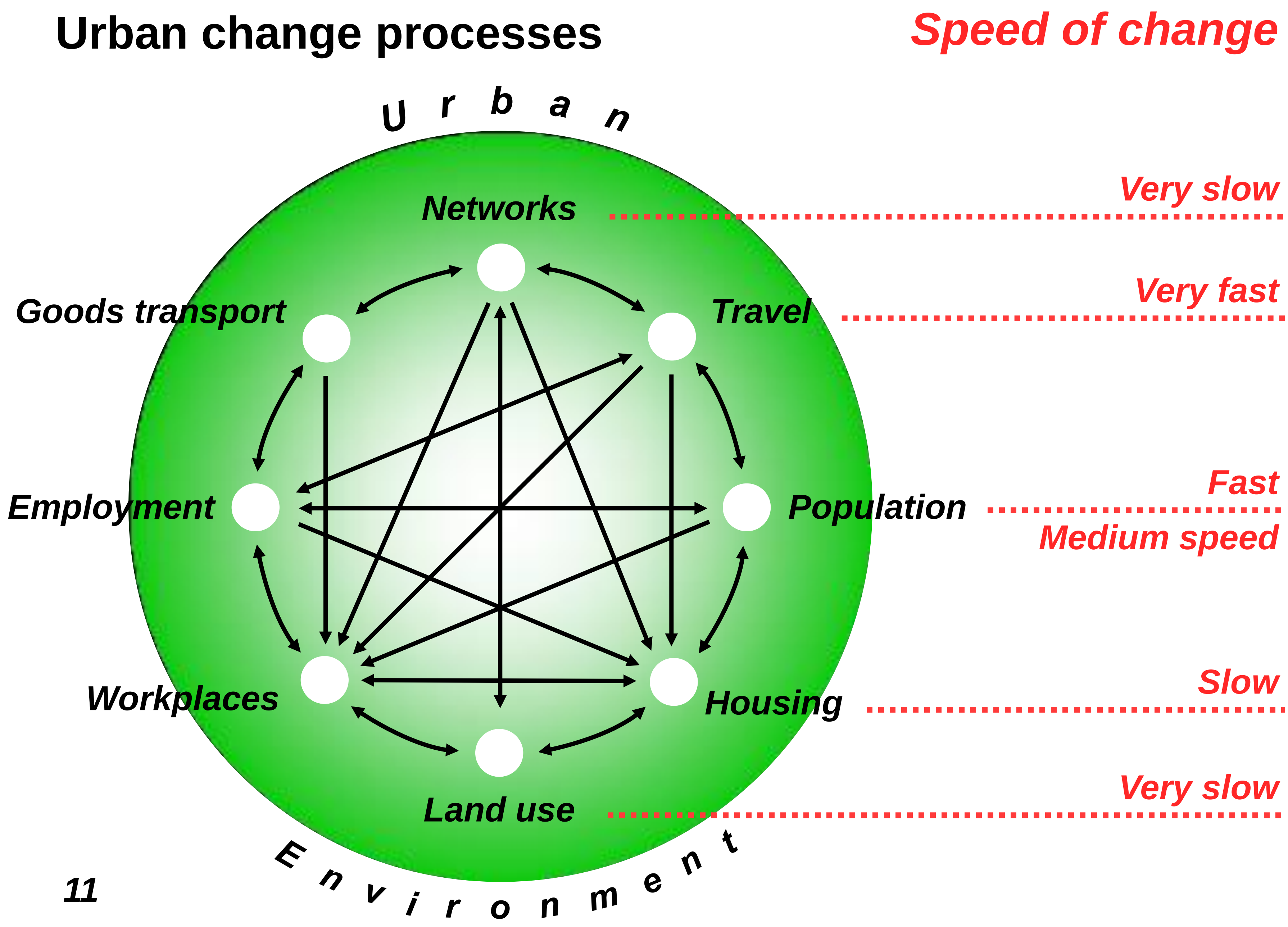
Equilibrium v. dynamics (1)

Human settlements evolve over a long time span by the cumulative efforts of ***many generations***. The resulting physical structure of cities displays a remarkable ***stability*** over time prevailing even after major devastations such as wars, earthquakes, or fires, and changing only in relatively ***small increments*** in normal times.

However, there are ***more rapid*** changes in the way the ***buildings*** are ***used***.

Even ***faster*** changes occur in the ***spatial interactions*** between activities.

Urban change processes



Equilibrium v. dynamics (2)

These different ***time scales*** of urban change have long attracted the attention of urban historians, theorists and planners.

Geddes (1915) used the Darwinist paradigm of ***evolution*** to explain urban development.

Urban historians like Mumford (1938; 1961) or Gutkind (1964-1972) aimed at understanding growth and decline of cities as ***constellations of causes and effects***.

The Chicago school of urban sociology interpreted cities as multi-species ***ecosystems*** in which socio-economic groups ***fight for survival*** (Park, 1936).

Equilibrium v. dynamics (3)

However, in the 1960s emerging ***urban economics*** and ***regional science*** became more and more preoccupied with ***space*** and less with ***time***.

Location theory (Alonso, 1964) was almost exclusively based on accessibility and ***equilibrium*** of supply and demand and lost sight of the ***adjustment processes*** to achieve that equilibrium.

The Lowry (1964) model successfully stripped this theory of its last ***behavioural***, i.e. economic, ***content***, leaving ***distance*** as the one and only explanatory variable of the distribution of activities in space.

Equilibrium v. dynamics (4)

This narrowing down in scope of urban theory contrasted with the growing interest in temporal processes taken by related disciplines.

Since Schumpeter (1939), economists tried to explain why economies develop in ***cycles*** or ***wave-like*** patterns.

Dynamic spatial theories encompassing ***cumulative*** or ***positive feedback*** (Myrdal, 1957; Hägerstrand,1966) challenged the neo-classical location theory.

Suggestions were made to address the space ***and*** time dimensions of social phenomena in a ***spatio-temporal*** framework (Hägerstrand, 1970; Isard, 1970).

Equilibrium v. dynamics (5)

All of these ideas remained ***without*** effect on urban theory and model building.

Mainstream urban theory-building and modelling adopted the most restricted engineering perception of the urban system as a system of movements as represented by the ***spatial interaction*** or ***Lowry*** (1964) model.

The spatial interaction paradigm (the myth that workers choose their place of residence on their way home from work) ***forces*** things together that should be analysed ***separately***, i.e. the decision to move, change job, make trips, etc., although these are interrelated, but only in a lagged and indirect way.

Static equilibrium models (1)

Equilibrium models are based on the assumption that interdependent model variables, such as prices, supply and demand, adjust to equilibrium ***instantaneously*** and with no ***path-dependence***.

Time is abstracted out of equilibrium models: they do not represent chronological time.

There are only few urban models determining a ***general*** equilibrium of ***transport*** and ***land use*** with endogenous prices and congestion costs.

Other models are equilibrium models of ***transport*** only or of ***transport*** and ***activity location*** separately.

Static equilibrium models (2)

No considerations of time enter the rationale of ***spatial interaction*** models:

- They weld together change processes with different time behaviour: ***medium-speed*** changes of activities and ***fast*** daily movements.
- They predict a ***slow*** and ***inert*** process, ***location***, from a ***volatile*** process, ***travel***.

In the real world, daily ***travel*** decisions are ***subordinate*** to ***location*** decisions.

Accessibility is relevant for location in an ***aggregate*** and ***lagged*** way, as one location factor among others.

Dynamic models (1)

Dynamic models make the representation of movement through time explicit.

Early efforts to model ***spatial dynamics*** of cities treated time as continuum (Harris and Wilson, 1978; Beaumont et al., 1981; Allen et al., 1981).

Today the most common form of temporal representation in dynamic urban models is through ***recursive*** or ***quasi-dynamic*** models in which the ***end state*** of one time period, usually in time steps of one year, serves as the ***initial state*** of the subsequent time period.

Dynamic models (3)

Recursive quasi-dynamic models typically operate with a ***combination*** of ***different submodels*** for different urban subsystems or change processes.

Such ***composite*** models have the advantage of ***flexibility*** in the selection of ***variables***, ***relationships*** and ***modelling*** techniques, but they have to solve the ***additional problem*** of ***consistently linking*** the submodels.

It is here where the consideration of ***time*** becomes critical.

Macro v. Micro

Disaggregation trend

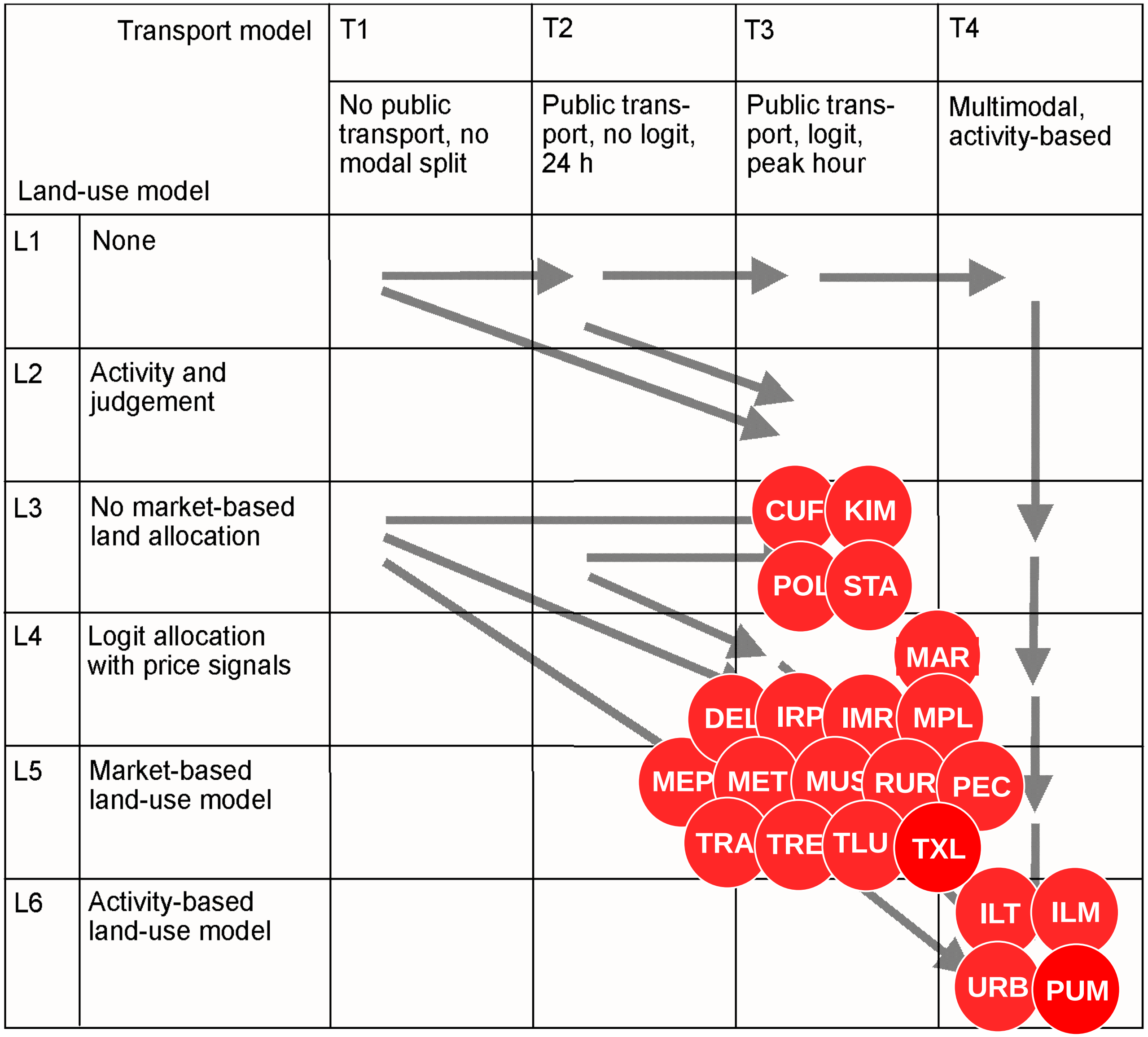
The mainstream trend in ***urban transport and land use modelling*** is ***disaggregation***.

Activity-based travel models have become the state of the art. ***Agent-based land use models*** are proliferating.

There are persuasive *reasons* for this trend:

- With growing individualisation of society, urban life styles, location and mobility patterns are becoming more diversified. Disaggregate models capture this ***heterogeneity***.
- New model extensions addressing environmental issues, such as air quality, noise, landscape and water require ***high-resolution*** grid-cell models

Disaggregation trend



(adapted from Miller et al., 1998)

Development path

However ...

To date, no full microsimulation model of urban land use, transport and environment has become operational.

- Many large modelling projects ***failed to deliver*** in the time available or had to reduce their ambitious goals.
- Many applications of established models by others than their authors did not become ***operational***.
- Many projects got lost in data collection and calibration and did ***not*** reach the state of ***policy analysis***.
- Many projects remained in the ***academic*** environment and produced only PhD theses.

Computing time

The ***computing time*** for existing microsimulation models is calculated in terms of ***weeks*** or ***days,*** not ***hours***.

In particular ***activity-based transport models*** are much too slow to be executed ***several times*** for different years in integrated land-use transport models.

Microsimulation land-use transport models are too slow to allow the examination of the ***large number of scenarios*** required for the composition of ***integrated strategies***.

Stochastic variation

Serious problems of ***calibration***, ***stability*** and ***stochastic variation*** of microsimulation models are unsolved.

In particular the problem of ***stochastic variation*** has been largely ignored in recent modelling projects:

- The results of microsimulation models ***vary*** between runs with different ***random number seeds*** as a function of the number of ***choices*** and the number of ***alternatives***.
- This can be overcome by ***averaging*** their results to a level of aggregation they were initially designed to overcome or by ***averaging*** their results over several model runs; but for this most microsimulation models are too slow.

Stochastic variation

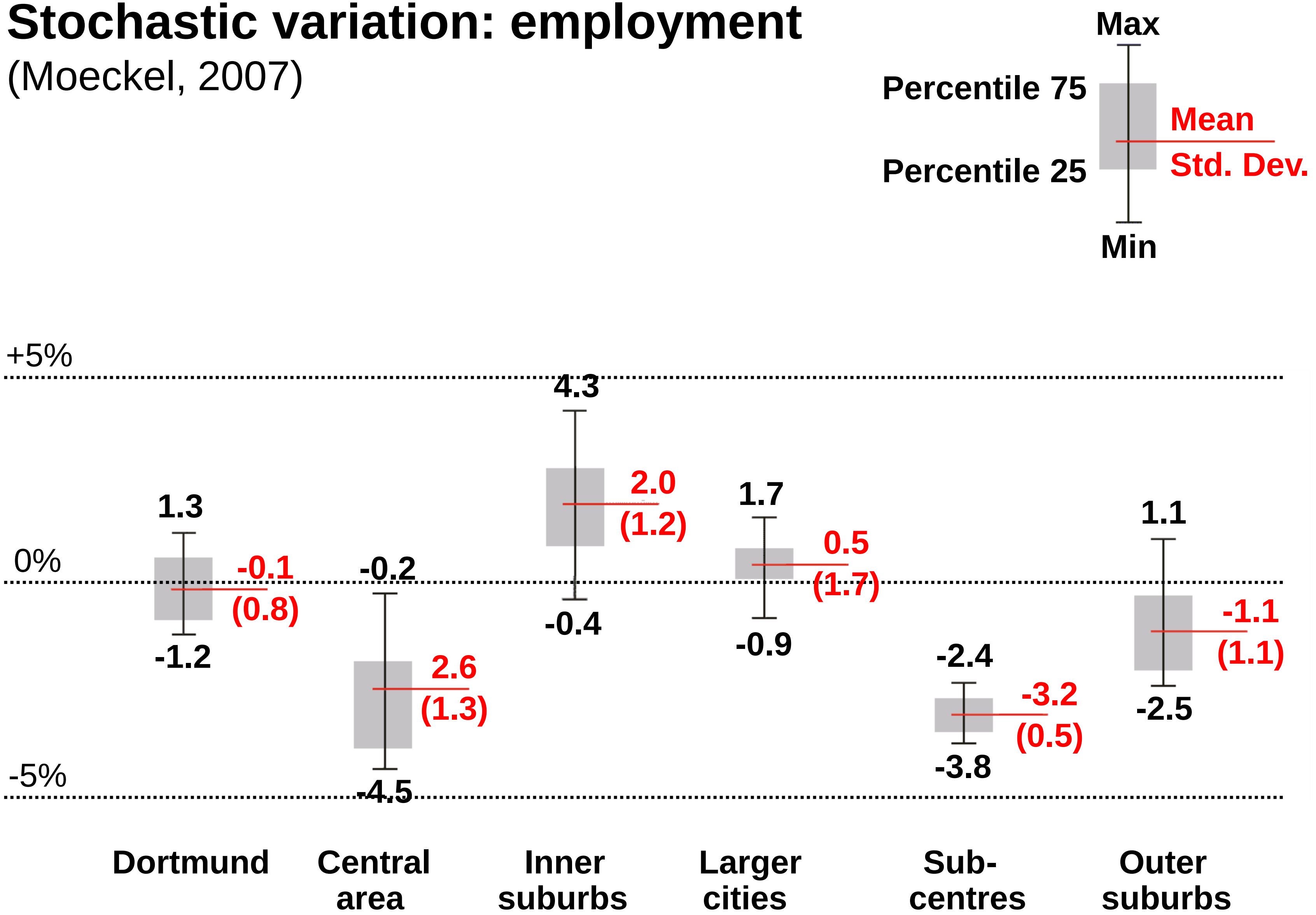
Moeckel (2007) analysed the effects of stochastic variation in his microsimulation model of ***firm location***.

He ran the model ***fifteen times*** over 30 years with different seeds of the random number generator:

- When aggregated to five subregions, the rates of change of ***population*** differed by only a few percent, whereas the rates of change of ***employment*** varied by up to more than 100 percent.
- The reason was that the microsimulation model processed ***1.2 million household***s but only ***80,000 firms***.

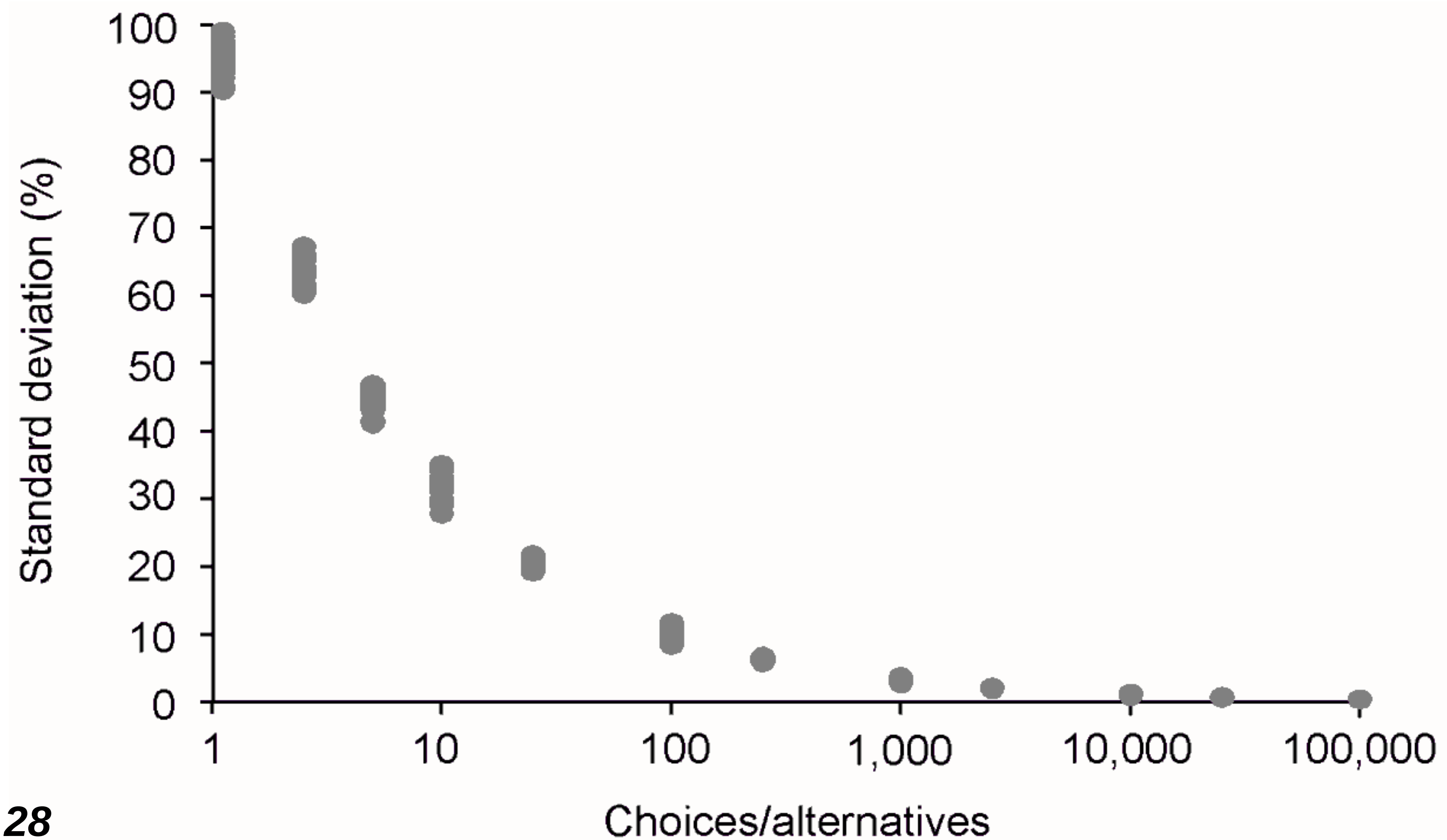
Stochastic variation: employment

(Moeckel, 2007)



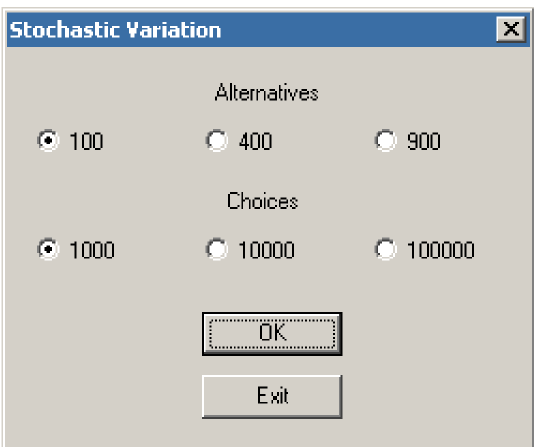
Stochastic variation

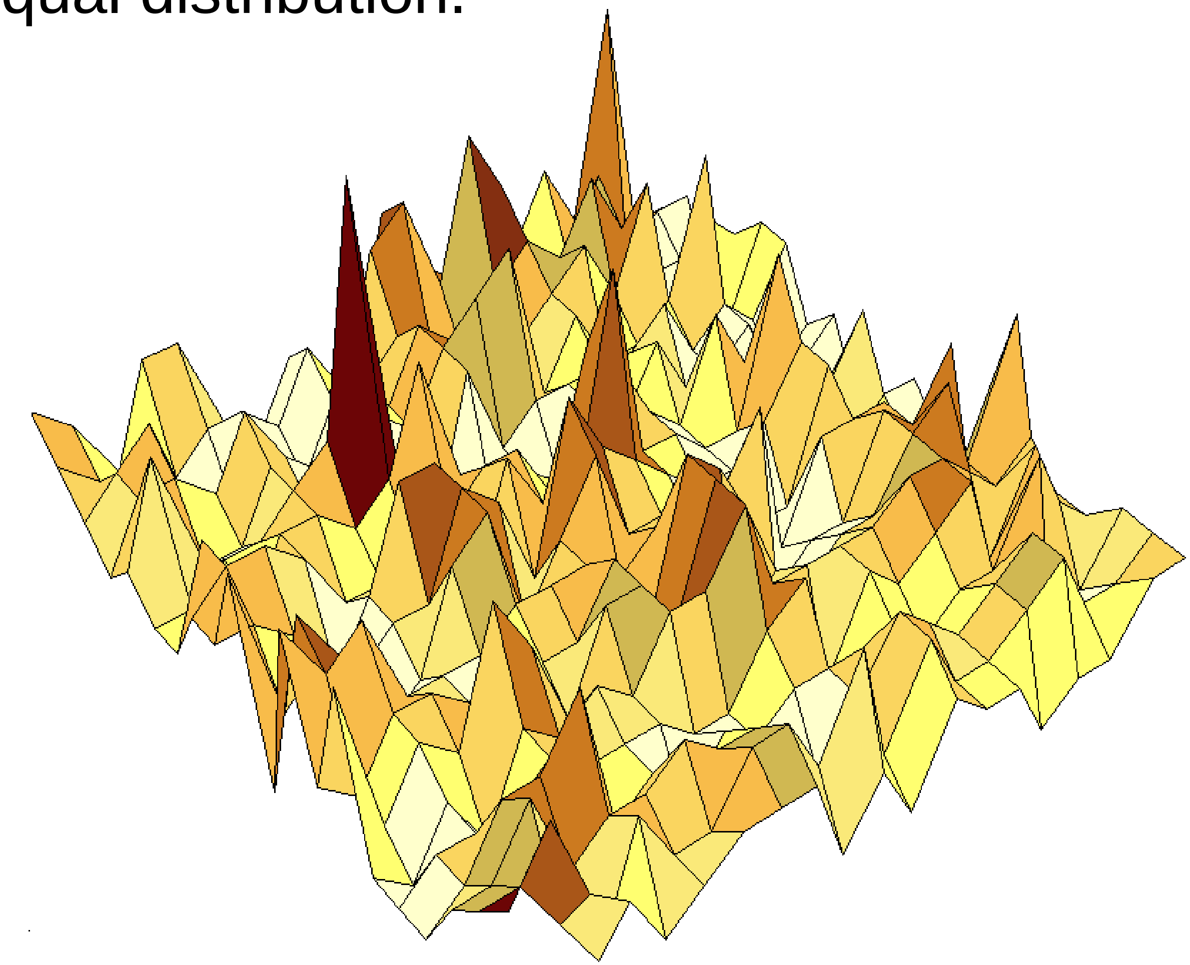
The magnitude of stochastic variation is a function of the ***ratio of choices and alternatives:***



Stochastic variation

The programme ***<stovar>*** shows the effects of the **number of *choices*** and the **number of *alternatives*** on stochastic variation from the equal distribution.





How much micro is enough?

Despite these problems, microsimulation modellers engage in ever more ambitious plans to further raise the complexity and spatial resolution of their models.

The common belief among most microsimulation modellers seems to be: the more micro the better.

This is the dream of the ***one-to-one Spitfire***.

The one-to-one Spitfire

"Simplifying assumptions are not an excrescence on model-building; they are its essence. Lewis Carroll once remarked that a map on the scale of one-to-one would serve no purpose. And the philosopher of science Russell Hanson noted that if you progressed from a five-inch balsa wood model of a Spitfire air plane to a 15-inch model without moving parts, to a half-scale model, to a full-size entirely accurate one, you would end up not with a model of a Spitfire but with a Spitfire".

Robert M. Solow (1973)

The Spitfire

The one-to-one model of the Spitfire

New Challenges for Urban Models

New challenges for urban models (1)

Beyond these technical difficulties, urban transport and land use models are facing ***new challenges***:

- Most experts agree that in the future ***energy scarcity*** and the imperative of ***reducing greenhouse gas emissions*** will make transport significantly more ***expensive***.
- This implies that in the future urban ***location*** and ***mobility*** will depend less on individual ***life styles*** and ***preferences*** but more on ***basic needs*** and ***constraints***.

New challenges for urban models (2)

Many current urban models cannot model the impacts of significant ***energy price increases***:

- Many travel models do not consider ***travel cost*** in their trip generation, trip distribution or modal split models.
- Many travel models do not model ***induced/suppressed*** travel demand.
- Many land-use and transport models work with elasticities ***estimated in times of cheap energy***.
- Many urban models do not consider ***household budgets*** for ***housing***, ***transport*** and other expenditures.
- Many urban models do not model ***car ownership*** as a function of household travel budgets.

A new requiem for large-scale models?

There is again the danger that urban models are ***rejected*** because they fail to address the new challenges and the resulting ***social conflicts***. This time the "seven sins of large-scale models" would be:

- too much ***extrapolation*** of past trends
- too much belief in ***equilibrium***
- too much reliance on ***observed*** behaviour
- too much attention to ***preferences***
- too much emphasis on ***calibration***
- too much effort spent on ***detail***
- too much focus on ***feasible*** solutions

Conclusions

Conclusions (1)

To avoid that urban models are again rejected, ***significant changes*** in the philosophy and method of urban modelling are needed:

- less ***extrapolation***, more ***fundamental change***
- less ***equilibrium***, more ***dynamics***
- less ***observed behaviour***, more ***theory on needs***
- less ***preferences*** and ***choices***, more ***constraints***
- less ***calibration***, more ***plausibility analysis***
- less ***detail***, more basic ***essentials***
- less ***forecasting***, more ***backcasting*** (don't ask what could be done but what needs to be done)

Conclusions (2)

Under constraints of ***data collection***, ***computing time*** and ***stochastic variation*** there is for each planning problem an optimum level of ***conceptual***, ***spatial*** and ***temporal*** model resolution.

This suggests to work towards a ***theory*** of balanced ***multi-scale models*** which are as ***complex as necessary*** for the planning task at hand and "***as simple as possible but no simpler***".

Future urban models will be ***modular*** and ***multi-scale*** in ***scope***, ***space*** and ***time***.