OUTLINE

- Setting the stage
- Traditional transport planning modelling approach
- The interaction between land use and transport developments
- Urban growth modelling
- Integrating the accessibility notion in the CA model
- Application for the city of Jeddah, Saudi Arabia
- Conclusions
Global trends: rapid urbanization

World population will increase from 7 billion today to more than 9 billion in 2050.

That translates into an average 1 million more city dwellers every week for the next 38 years.

These trends are impossible to stop, so the question is not whether or not urbanization should take place, but how best to urbanize.

Source: Planet under pressure, 2012
Impacts of urbanization:
Urbanization and economic growth are inextricably linked

Source: UNDESA, 2007
Impacts of urbanization

Urban sprawl

Environmental degradation

Severe accessibility problems

Poor living conditions
Global trends: rapid motorization

Rapid increase in car ownership and use (timing and rate of change differs).

Extensive expansion of (urban) road networks, thereby supporting suburbanization.

Marginalization of alternative modes of transport.

Urban divide in transport opportunities.

Source: Planet under pressure, 2012
### Historical trend of worldwide vehicle registrations 1960-2010 (thousands)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Car registrations(^{(1)})</td>
<td>98,305</td>
<td>193,479</td>
<td>320,390</td>
<td>444,900</td>
<td>548,558</td>
<td>617,914</td>
<td>684,570</td>
<td>707,764</td>
</tr>
<tr>
<td>Truck and bus registrations</td>
<td>28,583</td>
<td>52,899</td>
<td>90,592</td>
<td>138,082</td>
<td>203,272</td>
<td>245,798</td>
<td>295,115</td>
<td>307,497</td>
</tr>
<tr>
<td>World total</td>
<td>126,888</td>
<td>246,378</td>
<td>410,982</td>
<td>582,982</td>
<td>751,830</td>
<td>863,712</td>
<td>979,685</td>
<td>1,015,261</td>
</tr>
</tbody>
</table>

Note (1) Cars registrations do not include U.S. light trucks (SUVs, minivan and pickups) that are used for personal travel. These vehicles are accounted among trucks.


### Comparison of motorization rates by region 1999 and 2009 (vehicles per 1000 people)

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>1999</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>20.9</td>
<td>24.9</td>
</tr>
<tr>
<td>Asia, Far East</td>
<td>39.1</td>
<td>157.7</td>
</tr>
<tr>
<td>Asia, Middle East</td>
<td>66.2</td>
<td>101.2</td>
</tr>
<tr>
<td>Canada</td>
<td>560.0</td>
<td>620.9</td>
</tr>
<tr>
<td>Central and South America</td>
<td>133.6</td>
<td>169.7</td>
</tr>
<tr>
<td>Europe, East</td>
<td>370.0</td>
<td>363.9</td>
</tr>
<tr>
<td>Europe, West</td>
<td>528.8</td>
<td>583.3</td>
</tr>
<tr>
<td>Pacific</td>
<td>513.9</td>
<td>560.9</td>
</tr>
<tr>
<td>United States</td>
<td>790.07</td>
<td>828.04</td>
</tr>
</tbody>
</table>

Source: Automobile and Truck Trends, 2011
Impacts of motorization

Congestion

Emissions (climate change, pollution, noise)

Traffic casualties

Fragmentation (barriers, road space)

Degradation of livability in cities
Land use and transport planning challenge

Cities place tremendous strains on natural resources and the environment.

Land use and transport planning are crucial for giving direction to urban developments.

Dense cities designed for efficiency offer one of the most promising paths to sustainability.

New ways of thinking about how to make cities more self-sufficient and sustainable, along with advances in a wide range of technologies and heightened environmental awareness is leading to a reformulation of urban planning and development.
POPULAR TRANSPORT PLANNING MODELLING APPROACH

- Unit of analysis is trip (movement from origin to destination)
- Classification of trip purposes
- Characteristics of trip makers
- Characteristics of trip destinations
- Identification of travel modes and associated network characteristics
- Aggregation in traffic analysis zones (TAZ)
URBAN TRANSPORT MODELING SYSTEM (UTMS)

“The 4-stage Travel Demand Model”

1. Trip generation
2. Trip distribution
3. Modal split
4. Traffic assignment

- Socio-economic & land-use forecast
- Transport network & services attributes

- Link, Origin/Destination flows, time, costs, etc.
TRANSPORT PLANNING MODEL

Conceptual model

Transport system performance = f (land use)

Land use = input
THE TRANSPORT / LAND USE SYSTEM

- Infrastructures (Supply)
  - Accessibility
  - Traffic assignment models
  - Transport capacity

Friction of Space (Impedance)

- Spatial interaction models
  - Distance decay parameters
  - Modal split

Spatial Accumulation (Demand)

- Economic base theory
  - Location theory
  - Traffic generation and attraction models

Transport System

Spatial Interactions

Land Use

Spatial Accumulation (Demand)
Understanding the mutual interaction between the land use and transport systems is crucial for urban planners and transport planners.

Source: Dantas and Ribeiro, Impacts of transport infrastructure policies, 2006
LAND USE – TRANSPORT INTERACTION

Conceptual model

Land use = f\textsubscript{1} (transport system performance)

\[
\text{Transport system performance} = f\textsubscript{2} (\text{land use})
\]
RECIPROCAL RELATIONSHIP OF URBAN GROWTH AND TRANSPORTATION

Transport

Travel demand

Transport infrastructure

Population

Land use

Urban growth

Induce

Catalyze
URBAN GROWTH/LAND USE CHANGES

Urban growth
Chengdu, China
1991
1995
2000
2002
URBAN GROWTH MODELLING APPROACHES

- Spatial Logistic Regression models
- Cellular Automata (CA) models
- Agent Based models (ABM)
- Spatial System Dynamics

CA-based Urban Growth Model in Beijing: 1975-1997

A CELLULAR AUTOMATA MODEL

“A CA may be defined as

- (1) a discrete cell space, together with
- (2) a set of possible cell states and
- (3) a set of transition rules that determine the state of each cell as a function of the states of all cells within
- (4) a defined cell-space neighbourhood of the cell;
- (5) time is discrete and all cell states are updated simultaneously at each iteration.”

(White, 1998)
CA Model example:
Land Use Transport Interaction (LUTI) Model

- A Cellular Automata (CA) is a regular grid of cells, where a neighbourhood is defined relative to a cell, and where the state of the neighbourhood determines the probability of transition of the cell at t+1.

- CA has the capability to mimic the spatial and temporal processes of urban systems.

- It allows to simulate and predict complex geographical phenomena.
CELL STATES $\equiv$ LAND USE CLASSES

Finite set of discrete states, e.g.

<table>
<thead>
<tr>
<th>code</th>
<th>Land use class</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Vacant</td>
<td>Vacant</td>
</tr>
<tr>
<td>1</td>
<td>Residential low density</td>
<td>Function</td>
</tr>
<tr>
<td>2</td>
<td>Residential medium density</td>
<td>Function</td>
</tr>
<tr>
<td>3</td>
<td>Residential high density</td>
<td>Function</td>
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<tr>
<td>4</td>
<td>Commercial</td>
<td>Function</td>
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<tr>
<td>5</td>
<td>Industrial</td>
<td>Function</td>
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<tr>
<td>6</td>
<td>Airport</td>
<td>Feature</td>
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<td>7</td>
<td>Port</td>
<td>Feature</td>
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<td>8</td>
<td>Public place</td>
<td>Feature</td>
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<tr>
<td>9</td>
<td>Green area</td>
<td>Feature</td>
</tr>
<tr>
<td>10</td>
<td>Informal settlement</td>
<td>Feature</td>
</tr>
<tr>
<td>11</td>
<td>Outside simulation</td>
<td>Feature</td>
</tr>
</tbody>
</table>
CELL-SPACE NEIGHBOURHOOD

Depends on

- Cell size
- States considered
- Strength of the (spatial) relationships

Is outcome of

- Spatial statistical analysis
- Experimentation
CA MODEL TYPES

- In a pure CA model, the automaton state depends **only** on what is happening in the neighborhood.

- Two common ways of relaxing this assumption:
  - **Other factors** are mixed with the neighborhood, e.g. accessibility to urban centralities (White, 1998).
  - A **global constraint** may be applied: the total amount of change is externally defined (an exogenous land demand is set).
Relaxation of a pure CA model
Example: a LUTI model

- Other factors: Zoning, Land Suitability, Proximity
- External demand: National/regional spatial claims
The potential $P_{k,i}$ for land use class $k$ in cell $i$ is given by

$$P_{k,i} = r_{k,i} \cdot A_{k,i} \cdot S_{k,i} \cdot Z_{k,i} \cdot N_{k,i}$$

where

- $r_{k,i}$ is a scalable random perturbation term for land use $k$ in cell $i$,
- $A_{k,i}$ is the proximity to road infrastructure of land use $k$ in cell $i$,
- $S_{k,i}$ is the physical suitability of land use $k$ in cell $i$,
- $Z_{k,i}$ is the zoning status of land use $k$ in cell $i$,
- $N_{k,i}$ is the influence of the neighborhood of cell $i$ on land use $k$. 
## RULES DERIVED FROM SPATIO-TEMPORAL STATISTICAL ANALYSIS

### Table 8
The maximum likelihood estimation result of the spatial lag model: dependent variable—ln residential development.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lag</td>
<td>Lag</td>
<td>Lag</td>
<td>Lag</td>
</tr>
<tr>
<td>Ln (Highways)</td>
<td>-0.091 (0.091)</td>
<td>0.205 (2.01) '*'</td>
<td>0.0215 (0.213)</td>
<td>0.119 (1.06)</td>
</tr>
<tr>
<td>Ln (Main roads)</td>
<td>-0.069 (0.579)</td>
<td>0.376 (3.16) '*'</td>
<td>0.129 (1.33)</td>
<td>0.146 (1.41)</td>
</tr>
<tr>
<td>Ln (Secondary roads)</td>
<td>0.458 (4.15) '*'</td>
<td>0.104 (0.947)</td>
<td>0.261 (2.43)</td>
<td>0.394 (2.97) '*'</td>
</tr>
<tr>
<td>ρ</td>
<td>0.81 (18.10) '*'</td>
<td>0.752 (14.72) '*'</td>
<td>0.839 (22.18)</td>
<td>0.78 (16.67) '*'</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.70</td>
<td>0.69</td>
<td>0.71</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Notes: Absolute values of z-statistics in parentheses.

* Significant at 5%.

** Significant at 1%.
Transport infrastructure = input

Conceptual model

Urban growth development = f (transport infrastructure)
INTEGRATING TRANSPORT PLANNING IN URBAN GROWTH MODELLING APPROACH

Replacing proximity by accessibility
ACCESSIBILITY INSTEAD OF PROXIMITY

- The ability and ease of people to overcome the friction of distance in order to utilize services at fixed points in space

- It concerns (1) people, (2) the activities or opportunities that they require, and (3) the transport or communication link between the two

Point of Origin   Transport network (Impedance)   Point of destination (Utility/Benefit)
1. **Infrastructure based**, i.e. the amount of effort for a person to reach one or more locations
   
   ... *observed or simulated performance of the transport system*

2. **Activity-based**, i.e. the opportunities for activity available in a geographical location
   
   ... *distribution of activities in space and time*

3. **Utility-based**, i.e. the freedom of individuals to participate in activities in the urban environment
   
   ... *the benefits people derive from access to activities*
METRONAMICA LUTI MODEL

National / Regional spatial claims

Zoning

Land suitability

Accessibility

CA-Spatial interaction model

Demand

Simple transportation model

Cellular Automata land use model

Production & Attraction

Distribution & Mode Choice

Route Assignment

Generalized Cost

Travel costs & Accessibility

Route choice & Allocation

Exogenous Land use

Production & Attraction

Distribution & Modal split

Route choice & Allocation

www.metronamica.nl
RELAXATION OF THE CA-MODEL

- Other factors:
  - Zoning
  - Land suitability
  - Accessibility (Generalised costs)

- Global constraint
  - Population dynamics (e.g. land use volume)
AN EXAMPLE OF A CA-MODEL
A LUTI MODEL FOR JEDDAH

Characteristics:

- Both land-use and transport are endogenous
- The model is dynamic: starting from a base year the model calculates annually developments in land-use and transport
- Future states are simulated using scenario analysis
THE CITY OF JEDDAH, SAUDI ARABIA

Jeddah is the second largest city in the Kingdom of Saudi Arabia.
Jeddah city started as a small fishing village within a wall. After the discovery of oil in about 1938 and the destruction of the fortified wall of Jeddah in 1947, the city started to grow rapidly.
<table>
<thead>
<tr>
<th>Urban area (km²)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.54</td>
<td>before 1947</td>
</tr>
<tr>
<td>2.8</td>
<td>1948</td>
</tr>
<tr>
<td>32.5</td>
<td>1958</td>
</tr>
<tr>
<td>56</td>
<td>1968</td>
</tr>
<tr>
<td>367</td>
<td>1986</td>
</tr>
<tr>
<td>1507</td>
<td>2007</td>
</tr>
</tbody>
</table>

Jeddah’s urban expansion
JEDDAH’S LAND USE CHANGES
JEDDAH’S TRANSPORT INFRASTRUCTURE EXPANSION

![Graph showing the expansion of Jeddah's transport infrastructure from 1964 to 2007. The graph illustrates the increase in total road length, distinguishing between all roads, primary roads, secondary roads, and highways.](image)

- **Total roads length (km):**
  - **All Roads**
  - **Primary roads**
  - **Secondary roads**
  - **Highways**

**Legend:**
- Black solid line: All Roads
- Red dotted line: Primary roads
- Yellow solid line: Secondary roads
- Blue dashed line: Highways
Urban spatial expansion (residential area growth) and transport infrastructure expansion in the city have gone hand-in-hand.
Yet, Jeddah has not been able to accommodate increases in travel demand, hence causing high levels of congestion.
METRONAMICA LUTI MODEL FOR THE CITY OF JEDDAH

- Base year 1980
- 11 land use classes
- 5 land uses are dynamic (function class)

<table>
<thead>
<tr>
<th>code</th>
<th>Land use class</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Vacant</td>
<td>Vacant</td>
</tr>
<tr>
<td>1</td>
<td>Residential low density</td>
<td>Function</td>
</tr>
<tr>
<td>2</td>
<td>Residential medium density</td>
<td>Function</td>
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<td>Port</td>
<td>Feature</td>
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<tr>
<td>8</td>
<td>Public place</td>
<td>Feature</td>
</tr>
<tr>
<td>9</td>
<td>Green area</td>
<td>Feature</td>
</tr>
<tr>
<td>10</td>
<td>Informal settlement</td>
<td>Feature</td>
</tr>
<tr>
<td>11</td>
<td>Outside simulation</td>
<td>Feature</td>
</tr>
</tbody>
</table>

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METRONAMICA LUTI MODEL FOR THE CITY OF JEDDAH

- Validation: 2007 – 2011
- Prediction: 2011 – 2030
Calibration and validation scheme

Stage 1
Calibration of the CA-based land-use model

Stage 2
Calibration of the four-step transport model

Stage 3
Calibration of the feedback from transport to land use

Stage 4
Independent validation of the CA-based land-use/transport interaction model
Land use change over time

Time Loop

Land use at time $T+1$

Suitability

Interaction & weights

Zoning & Accessibility = Potential for change

Transition Rule

Cells change to land-use with highest potential until regional demands are met.
Several workshops in Jeddah

Land use and transport policy scenarios:

1. Business As Usual (BAU)

2. Encouraging Public Transport (PT) – travel cost, car restraint etc

3. Transit Oriented Development (TOD) – strict zoning policies etc

4. Integrated Land use Transport Intervention (ILUT) – combined 2 + 3
Land-use change prediction 2011-2030

1. Business As Usual (BAU)
2. Encouraging Public Transport (PT)
3. Transit Oriented Development (TOD)
4. Integrated Land use Transport Intervention (ILUT)
Compact urban development scenarios will limit the ongoing urban expansion most

<table>
<thead>
<tr>
<th>Land use</th>
<th>2011</th>
<th>BAU 2031 change%</th>
<th>PT2031 change%</th>
<th>TOD2031 change%</th>
<th>ILUT2031 change%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacant</td>
<td>67930</td>
<td>-19.94</td>
<td>-19.91</td>
<td>-12.2</td>
<td>-12.1</td>
</tr>
<tr>
<td>Residential Low Density</td>
<td>12370</td>
<td>40.5</td>
<td>41.8</td>
<td>-13.6</td>
<td>-13.6</td>
</tr>
<tr>
<td>Residential Medium Density</td>
<td>7041</td>
<td>71.8</td>
<td>71.9</td>
<td>75.3</td>
<td>75.3</td>
</tr>
<tr>
<td>Residential High Density</td>
<td>3426</td>
<td>47.0</td>
<td>48.1</td>
<td>106.6</td>
<td>106.8</td>
</tr>
<tr>
<td>Commercial</td>
<td>3045</td>
<td>7.8</td>
<td>7.8</td>
<td>41.2</td>
<td>42.4</td>
</tr>
<tr>
<td>Industrial</td>
<td>7826</td>
<td>20.3</td>
<td>20.3</td>
<td>20.1</td>
<td>20.1</td>
</tr>
<tr>
<td>Airport</td>
<td>9629</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Port</td>
<td>760</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Public place</td>
<td>8172</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Green area</td>
<td>300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Informal settlement</td>
<td>4395</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spatial expansion %</td>
<td>56964</td>
<td>23.7</td>
<td>24.0</td>
<td>14.5</td>
<td>14.6</td>
</tr>
</tbody>
</table>
Traffic congestion 2011-2030

Volume over Capacity ratios
Sustainable transport scenarios seem to limit the increase in congestion most, while increasing the share of public transport.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>2011</th>
<th>BAU 2031</th>
<th>Change %</th>
<th>PT 2031</th>
<th>Change %</th>
<th>TOD 2031</th>
<th>Change %</th>
<th>ILUT 2031</th>
<th>Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of trips</td>
<td>5,752,719</td>
<td>10,251,583</td>
<td>78.2</td>
<td>10,315,472</td>
<td>79.3</td>
<td>10,556,314</td>
<td>83.5</td>
<td>10,623,114</td>
<td>84.7</td>
</tr>
<tr>
<td>Car %</td>
<td>92.0</td>
<td>87.0</td>
<td>-5.4</td>
<td>69.7</td>
<td>-24.2</td>
<td>87.0</td>
<td>-5.4</td>
<td>69.0</td>
<td>-25.0</td>
</tr>
<tr>
<td>Public transport %</td>
<td>8.0</td>
<td>13.0</td>
<td>62.5</td>
<td>30.3</td>
<td>278.8</td>
<td>13.0</td>
<td>62.5</td>
<td>31.0</td>
<td>287.5</td>
</tr>
<tr>
<td>Average accessibility</td>
<td>0.57</td>
<td>0.47</td>
<td>-17.5</td>
<td>0.46</td>
<td>-19.3</td>
<td>0.56</td>
<td>-1.8</td>
<td>0.55</td>
<td>-3.5</td>
</tr>
<tr>
<td>Average trip distance car (km)</td>
<td>7.9</td>
<td>8.3</td>
<td>5.1</td>
<td>8.4</td>
<td>7.0</td>
<td>6.9</td>
<td>-12.1</td>
<td>7.1</td>
<td>-9.6</td>
</tr>
<tr>
<td>Average trip duration car (min.)</td>
<td>37.8</td>
<td>44.4</td>
<td>17.5</td>
<td>40.4</td>
<td>6.9</td>
<td>48.7</td>
<td>28.8</td>
<td>38.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Daily Congestion (km)</td>
<td>556.0</td>
<td>825.0</td>
<td>24.0</td>
<td>723.0</td>
<td>30.0</td>
<td>690.0</td>
<td>24.1</td>
<td>627.0</td>
<td>12.8</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- Because of the evident mutual interactions between land use developments and transport infrastructure and performance, the traditional four stage travel demand model has severe shortcomings in case of applications to fast growing cities.
- In these cases treatment of land use developments as an exogenous variable is inappropriate and should be avoided.
- A dynamic land-use transport interaction model, such as the adapted CA urban growth model, allows to simulate and predict the complex interaction between land use and transport, and assist to reshape cities.
Thank you for your attention

Reference