Development of the TRANUS Land-use and Transportation Integrated (LUTI) Model to Evaluate the Feasibility of California-style Regional Climate Plan Targets for the Greater Toronto Metropolitan Region

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Special Thanks to Tomás de la Barra

JCCTRP Webinar: Modeling Low-Carbon Urban Transportation in Toronto
Webinaire JCCTRP : Modélisation du transport urban à faible émission de carbone à Toronto

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Outline of Presentation

• Introduction
• Research Question
  • What changes to the transportation system of the Toronto metropolitan region would be necessary to reduce greenhouse gas (GHG) emissions per vehicle mile traveled below a targeted level, as is currently required in California?
• Background on California metropolitan regional climate policy
• Background on Toronto regional climate policy
• Overview of the TRANUS model
  • Land-use model components
  • Transport model components
• Modeling Challenges
  • Calibration challenge
  • Application of the model for GHG emission modeling
• Conclusion and Next Steps
Goal

- To identify technical, economic and political factors shaping the potential for environmentally effective, economically efficient, and politically viable low-carbon transport and climate mitigation policy. The JCCTRP is addressing this goal by bringing together modeling and policy researchers in various jurisdictions into engagement with decision-makers.

Partner organizations

- Leading universities, private research institutions, businesses and non-profit organizations
- Quebec, California, Ontario and Vermont
- Includes jurisdictions of the WCI, RGGI and TCI

Funding

- Recipient of a Partnership Development Grant from the Canadian Social Sciences and Humanities Research Council (SSHRC)
Working Groups

1) Carbon Pricing and Policy Sequencing
   • Modeling Policy Sequencing: carbon pricing, ZEV Mandates, LCFS, VES
   • Ontario and Quebec
   • Economic Advantages of Linking State/Provincial Carbon Markets

2) Urban Transit
   • California Sustainable Communities and Climate Protection Act
   • Model Regional Plan Climate Targets for California in Toronto using TRANUS transport and land-use change model

3) Transport-Energy Nexus
   • Modeling the impact of electric vehicle penetration on energy demand in Quebec using UVMermond transport-energy model

4) Low-Carbon Fuel Standard (LCFS)
   • LCFS comparison of California, Canada, BC, including modeling differences

5) Comparative Policy
   • Investigating role of modeling urban transport through comparison of Montreal, Toronto and Los Angeles
Regional Transport Planning in California (before climate policy)

- **Metropolitan Planning Organizations (MPOs)**
  - Since 1962, large US metropolitan areas must create an MPO to facilitate a “continuing, comprehensive, and cooperative” transportation planning process in order to obtain federal transportation funds
- **Regional Transportation Plans (RTPs)**
  - MPOs fulfill its mandate by creating regional transportation plans (RTPs) every five years which define transportation investments over the next twenty years
- **Important Role for Transport System Modeling**
  - Bulk of day-to-day operations of MPOs involves assessing the impact of planned investments for the RTP using transportation forecasting models
California Sustainable Communities and Climate Protection Act (2008)

- Requires that MPOs adopt “Regional Plan Climate Targets”
  - Expressed as a percent change in per capita passenger vehicle GHG emissions relative to 2005
  - In practice, these focus on reductions in vehicle miles traveled (VMT)
    - 18 MPOs currently plan for a 9.6% reduction by 2020 relative to 2005 levels of per capita passenger vehicle GHG emissions on average and an 18% reduction by 2035
- Also requires that a Sustainable Communities Strategy (SCS) be incorporated into the RTP
  - A land use element that accommodates forecasted population growth
  - A transportation network to meet all regional needs
  - Transportation forecasting models have become critical to the demonstration of RTP compliance with federal and state air pollution and GHG reduction requirements.
  - CARB determines SCS compliance

<table>
<thead>
<tr>
<th>Metropolitan Region</th>
<th>Sacramento</th>
<th>San Diego</th>
<th>San Francisco</th>
<th>Los Angeles</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPO</td>
<td>Sacramento Area Council of Governments (SACOG)</td>
<td>San Diego Association of Governments (SANDAG)</td>
<td>San Francisco Bay Area Metropolitan Transportation Commission (MTC)</td>
<td>Southern California Association of Governments (SCAG)</td>
</tr>
<tr>
<td>Regional Population (Approx, 2010)</td>
<td>2,323,000</td>
<td>3,096,000</td>
<td>7,375,000</td>
<td>18,075,000</td>
</tr>
<tr>
<td>Regional Land Area</td>
<td>6,193 sq. mi.</td>
<td>4,230 sq. mi.</td>
<td>7,000 sq. mi.</td>
<td>38,000 sq. mi.</td>
</tr>
<tr>
<td>No of Counties in Region</td>
<td>6</td>
<td>1</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>No. of Cities in Region</td>
<td>22</td>
<td>7</td>
<td>101</td>
<td>191</td>
</tr>
<tr>
<td>Size of RTP-SCS (latest)</td>
<td>2016 MTP-SCS ($35 billion)</td>
<td>San Diego Forward 2050 ($204 billion)</td>
<td>Plan Bay Area 2040 ($303 billion)</td>
<td>2016 RTP-SCS ($556.5 billion)</td>
</tr>
<tr>
<td>CARB Approved GHG Emission Reduction Target</td>
<td>2020 : 7%</td>
<td>2020 : 15%</td>
<td>2020 : 10%</td>
<td>2020 : 8%</td>
</tr>
<tr>
<td></td>
<td>2035 : 19%</td>
<td>2035 : 19%</td>
<td>2035 : 19%</td>
<td>2035 : 19%</td>
</tr>
</tbody>
</table>

Four Largest MPOs in California and their Regional Climate Plan Targets

Ontario Climate Policy

• A Made-in-Ontario Environment Plan
  • Presented in November 2018
  • Relaxed 2030 target
    • 21% reduction the province’s GHG emissions relative to 1990 by 2030
    • Significant rolling back of relative to the previous government target, which was a 37% reduction by 2030 relative to a 1990 baseline
  • Repealed cap-and-trade and replaced with regulatory framework for industrial emitters
  • No links to modelling or other substantiation to support the claimed reductions

https://marksw.blog.yorku.ca/2018/12/03/the-ontario-climate-change-plan-an-assessment/
Toronto Metropolitan Region Climate Policy

• Greater Toronto and Hamilton Area
  • 49.2 MtCO2e in 2017
  • 41% of Ontario's carbon emissions
  • Emissions fell 3.3% between 2015-2016, then remained flat between 2016-2017

https://taf.ca/gtha-carbon-emissions/
Comparing Transportation Emissions in California, Ontario and Quebec

Road Transport as % Total GHG Emissions

Road Transport GHG Emissions per Capita
Background on TRANUS Model
Study Area

• Transportation Aspects
  • Road transportation account for 29.3% of the GHG area emissions produced in Ontario 13% Transit ridership (TTS 2016)
  • 86% of households own private vehicles (TTS 2016)
  • On average, each household has 2.6 persons and makes 5.3 trips/day (TTS 2016)
  • 0.74 daily worker trips / worker (TTS 2016)
Study Area

• Characteristics
  • 65% of residential land is zoned for single-family residential. (TTS 2016)
  • The GGH has a large central city (Toronto), representing about 37.2% of the total population
  • Residential land use account for 13.2% of the GHG area emissions produced in Ontario
  • High transit ridership in North America and relatively high population density (12 transit agencies and 1 inter regional transit system)
Path to LUTI Modeling (USA case)

Federal-Aid Highway Act of 1962
- Goal: Accessibility
- Result: Traffic Growth & Residential land and firms dislocation -> Environmental degradation, Social equity

3C Planning progress
- Goal: Continuing, Comprehensive, Cooperative planning process
- Result: Continuing independent development plans.

LUTI Modeling
Addressing:
- Interdependence
- Multi-objective modeling
- Dynamic
- Comprehensive goal based boundaries
- Supply / Demand / Pricing models all together
Similar Approaches

• Most work centered in Europe
  • Ruhrgebiet model in Germany
  • Tyndall Centre model in UK
  • LUMAS in Netherlands

• New Zealand's Wellington Integrated Land Use-Transport-Environment Model (WILUTE)

• ABAG in San Francisco uses UrbanSim

• Sacramento, Southern California, and San Diego Metropolitan Planning Organizations have versions of a PECAS model
Toronto’s TRANUS Model
Land Use Sectors

Lowry Model

Spatial Input-Output Supply & Demand Equilibrium

Arrow ≡ Consumes

<table>
<thead>
<tr>
<th>Sector ID</th>
<th>Sector Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AS4M</td>
<td>Agriculture and Mining</td>
</tr>
<tr>
<td>2</td>
<td>UC3C</td>
<td>Utilities and Construction</td>
</tr>
<tr>
<td>3</td>
<td>MfBrk</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>4</td>
<td>RW</td>
<td>Retail and Wholesale</td>
</tr>
<tr>
<td>5</td>
<td>Whs</td>
<td>Warehousing</td>
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<tr>
<td>6</td>
<td>Ps</td>
<td>Professional Services</td>
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<td>7</td>
<td>EHR</td>
<td>Health and Education services</td>
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<tr>
<td>8</td>
<td>Usi</td>
<td>Utility Services</td>
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<tr>
<td>9</td>
<td>Gm</td>
<td>Government</td>
</tr>
<tr>
<td>10</td>
<td>HihPp</td>
<td>Population with high income</td>
</tr>
<tr>
<td>11</td>
<td>Mishi</td>
<td>Population with medium-high income</td>
</tr>
<tr>
<td>12</td>
<td>Mili</td>
<td>Population with medium income</td>
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<tr>
<td>13</td>
<td>Mili</td>
<td>Population with low income</td>
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<tr>
<td>14</td>
<td>Lwinc</td>
<td>Population with low income</td>
</tr>
<tr>
<td>15</td>
<td>Silo</td>
<td>Silos floor space in m2</td>
</tr>
<tr>
<td>16</td>
<td>Lrfr</td>
<td>Low rise framed buildings floor space in m2</td>
</tr>
<tr>
<td>17</td>
<td>Hrfr</td>
<td>High rise framed buildings floor space in m2</td>
</tr>
<tr>
<td>18</td>
<td>Smfr</td>
<td>Semi-detached floor space in m2</td>
</tr>
<tr>
<td>19</td>
<td>Det</td>
<td>Detached floor space in m2 (100 factor real area/3)</td>
</tr>
<tr>
<td>20</td>
<td>Town</td>
<td>Townhouses floor space in m2</td>
</tr>
<tr>
<td>21</td>
<td>Inland</td>
<td>Industrial &amp; Resources land in hec</td>
</tr>
<tr>
<td>22</td>
<td>Comland</td>
<td>Commercial &amp; Institutional &amp; Government land in hec</td>
</tr>
<tr>
<td>23</td>
<td>SuRedLand</td>
<td>Single unit Residential land in hec (100 factor real area/3)</td>
</tr>
<tr>
<td>24</td>
<td>MuRedLand</td>
<td>Multi unit Residential land</td>
</tr>
<tr>
<td>25</td>
<td>AgrLand</td>
<td>Agriculture &amp; Open Area land in hec (100 factor Green/100 &amp; Red10)</td>
</tr>
</tbody>
</table>
Lowry Model

Disutility of product of sector \( n \) demanded by zone \( i \) located in zone \( j \)

\[
P_{ij}^n = \frac{(A_i^n)^{\alpha_n} \cdot \exp(-\beta_i^n U_{ij}^n)}{\sum_j (A_i^n)^{\alpha_n} \cdot \exp(-\beta_i^n U_{ij}^n)}
\]

\( P(\text{production of sector } n \text{ demanded by zone } i \text{ and located in zone } j) \)

Two elements make the disutility function: price and transport disutility. The price scale weights the price element within the disutility function.

A logit scale parameter sets the degree of scaling of utilities in the logit model. Must be a value from zero to one (recommended value = 1).

The attractor factor is an exponent applied to the attractor function of the sector in the distribution logit model (default=1).

Elasticity is the distribution parameter that multiplies the disutility function of the logit or powit model. Non-transportable sectors are defined by setting a value of zero to the distribution parameter. This also applies to fully exogenous sectors, whose production is not consumed in the study area.
Lowry Model in Simple Words

• External sectors consumes population (Example: agriculture employment opportunities attract a family of three in that zone)
• Population induce internal sectors (Example: household members need health care which induce internal health employments)
• Internal sectors consume population (Health care employments will attract new population)
• ...

Toronto’s Lowry Model

- Info Canada 2011 (to know employment distributions in the region)
- Validation with Stats Canada’s 2011 Census for aggregate data
Land Sectors

• Same procedure applies to land sectors with the following constraint:

• Min production = Production = Max production

• All the flexibility go to land price

• Data Source: TREB 2011
The Input-Output Model

- Lowry gives us a balance inside each zone for economy sectors and population sectors.

- How about the equilibrium the sectors across zones? how the interactions between sectors are simulated?

<table>
<thead>
<tr>
<th>Consumption Sectors (Buying)</th>
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<tbody>
<tr>
<td>✔️ ✔️ ✔️ ✔️ ✔️</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Production Sectors (Selling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔️ ✔️ ✔️ ✔️ ✔️</td>
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- Stats Canada’s 2011 Census
The challenge of Input-Output model

• Input-Output is an aggregate urban economics model which gives total input and outputs by sectors for the GGH.

• However, the Input-Output model does not produce transport flows, so TRANUS divides it into separate production and consumption equilibriums for each zone.
Supply & Demand Equilibrium

\[ a_i^{mn} = \min^{mn} + (\max^{mn} - \min^{mn}) \cdot \exp \left( - \delta^{mn} U_i^n \right). \]
Land Use Calibration

• Equilibrium between consumption and production between each zone.

• Pairwise equilibrium among 105 zones * 30 interactions
TRANUS Model

Land use Model
- Lowry Model
- Spatial Input-Output Model
- Supply & Demand Equilibrium

Transport Model
- Path Search
- Random Utility Based Discrete Choice model for mode choice and assignment
### Activities to transportation demand

<table>
<thead>
<tr>
<th>Endogenous sectors in land use model</th>
<th>Transport categories in transport model</th>
</tr>
</thead>
<tbody>
<tr>
<td>High income population</td>
<td>work based trips income 1</td>
</tr>
<tr>
<td>Medium-high income population</td>
<td>work based trips income 2</td>
</tr>
<tr>
<td>Medium income population</td>
<td>work based trips income 3</td>
</tr>
<tr>
<td>Medium-low income population</td>
<td>work based trips income 4</td>
</tr>
<tr>
<td>Low income population</td>
<td>work based trips income 5</td>
</tr>
</tbody>
</table>

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<td>Utilities and Construction</td>
<td>Trips to Services</td>
</tr>
<tr>
<td>Retail and Wholesale</td>
<td></td>
</tr>
<tr>
<td>Finance, holdings and technical services</td>
<td></td>
</tr>
<tr>
<td>Health and Education services</td>
<td>Trips to Health or Education Centers</td>
</tr>
<tr>
<td>Entertainment and Food and Shopping</td>
<td>Trips for entertainment and shopping</td>
</tr>
</tbody>
</table>
Path building

\[ c_{ijp}^{k\alpha} = \sum_{m=1}^{z} RT_m^z + RD_m^z + TR_{m-1,m}^z, \]

- K-shortest path
- Overlapping factor

\[ P_{ijp}^{ks} = \frac{\exp(-\gamma^z c_{ijp}^{k\alpha})}{\sum_p \exp(-\gamma^z c_{ijp}^{k\alpha})}, \]
Preparing Transport Characteristics

• Defining modes
• Defining operators
• Defining Transfers and transport costs and Tariffs
• Defining Link types and right of way
The Lowry Model

- Exogenous Sectors
- Basic Population
- Induces endogenous sectors
- Induces population

Land Price Model

- Population Competes over Land
- Change in Price
- Change in Land Use
- Land Development
- Relocation of Population and sectors in form of ± Vectors

Transport Model

- Trip Generation
- Trip Distribution
- Operator Split
- Multi Operator Assignments
- Path Search
- Network’s Capacity

Flowchart per Time unit & mode

Output: For each end. Sector generation of the population or employments in the form of PD matrices

Categorizing flows to trips by keeping, splitting or combining

Transportation costs
Calibration & Validation
TRANUS Model Preliminary Findings
TRANUS Outputs & GHG Emissions

- Traditional transportation demand output is traffic volumes on roads, which are fed into an emissions model (MOVES, MOBILE, etc.)
- What about building emissions?
- Integrated models help us better include the full range of GHG impacts from transportation and land use policy.

[Graph showing the source of Toronto's Greenhouse Gas Emissions, 2014: 33% Transportation, 48% Buildings, 19% Waste]
Future Scenarios

➢ California style regional climate plan target
➢ Autonomous Vehicle mode (~16% more 1 hour+ commutes in an Austin, TX study)
➢ Eglinton Crosstown LRT / Yonge North extension / Relief Line
➢ Active mode dominated downtown
➢ Urban form changes around Metrolinx mobility hubs & Green Belt
Conclusions

• Our goal has been to fill a gap in the Toronto region by developing a strategic model to assess regional climate plan targets for transportation and land use.

• The model will be transferred the new TRANUS 3 interface, which makes it simple for policy analysts to explore outputs and build maps.

• We are currently in the calibration stage for 2011 Census data.

• Overall, there is sufficient technical capacity in the Toronto metropolitan region to develop a LUTI model similar to that used in the regional climate policy process in California.
Thank you! Merci!

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