Anticipating the impacts of transformative transportation technologies on urban sustainability

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Witnessing the making of a future of disruptive emergence of “high tech” transportation,

Transformative technologies are changing transportation faster than we are able to understand, let alone predict or manage,

Bold vision for the future of transportation and cities, but equally high risks and potential for crises,

Need to develop quantitative tools to guide the evolution of our cities in the era of disruptive technologies,

Empower people and business, protect the environment, harness and maximize potential and minimize risks.

Credits: iCity-CATTS, B. Abdulhai
Societal Ripple Effects

- The environment and health
- Cities and land use
- Energy
- Transportation Systems: Demand, Supply and Performance
- Transformative Trends: Driverless, TaaS
- Automation & e-sharing innovations

Credits: iCity-CATTS, B. Abdulhai

TaaS = transportation as a service
The Boldest Vision:
Automated, Green, Shared
But if unplanned, will automation also mean healthy and sustainable?
ANTICIPATING THE IMPACTS OF CONNECTED AND AUTOMATED VEHICLES ON ENERGY CONSUMPTION, GHG EMISSIONS, AIR POLLUTION

*Neighborhood effects*

*Regional effects*
End-to-End (E2E) dynamic routing control with connected and autonomous vehicles (E2ECAV)
End-to-end distributed control on autonomous vehicles (E2ECAV)

- Up to date real time traffic information
- Single integrated view of the network
- Responsive to changes
- Objective: Maximize capacity & minimize travel time
Application in downtown Toronto

Various scenarios for congestion and penetration of connected and automated vehicles

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Network demand level</th>
<th>E2ECAV market penetration rate (MPR)</th>
<th>on-road vehicle type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low (LOS1)</td>
<td>0</td>
<td>HDV</td>
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<tr>
<td>2</td>
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<td>E2ECAV+HDV</td>
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<td>E2ECAV</td>
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<td>6</td>
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<td>High (LOS3)</td>
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<td>9</td>
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<td>E2ECAV</td>
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<tr>
<td>10</td>
<td>High</td>
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<td>AV</td>
</tr>
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</table>

LOS = level of service
HDV = heavy-duty vehicles
E2ECAV = end-to-end connected autonomous vehicles
AV = autonomous vehicles

30% base demand
70% base demand
100% base demand
Traffic throughput increases

- CAV = connected autonomous vehicles
- AV = autonomous vehicles

Bar chart showing clearance time in seconds for different percentages of CAV (0%, 5%, 100%) under low, medium, and high demand conditions.
GHG emissions are reduced but reductions in NO$_x$ emissions are minor.
Under the E2ECAV scenario, vehicles are spending more time at operating modes associated with higher emission rates.

**Graph:**
- High demand, 0% CAV
- High demand, 5% CAV
- High demand, 100% CAV

*E2ECAV = end-to-end dynamic routing control with connected and autonomous vehicles*
Dispersion modeling with a street canyon model: SIRANE
Flow along the street
Recirculation which confines pollutants
Exchange with layer above roof level
NO$_2$ concentrations across the network

Higher maxima in CAV scenario but network clears faster

NO$_2$ = nitrogen dioxide
CAV = connected autonomous vehicles
Energy consumption under full electric vehicle (EV) environment

- Electric energy consumption model

  Electric power: \( P_{electric}(t) = f(v(t), a(t)) \)

  Electric energy: \( E_{electric} = \int P_{electric}(t) \, dt \)

- Model calibration is based on the data from Downloadable Dynamometer Data (D3) collected by Argonne National Laboratory(*)

(*) Acknowledgement: The data used for the calibration of electric energy consumption model is from the Downloadable Dynamometer Database and was generated at the Advanced Mobility Technology Laboratory (AMTL) at Argonne National Laboratory under the funding and guidance of the U.S. Department of Energy (DOE).
Energy consumption

![Bar chart showing energy consumption for different percentages of CAV (connected autonomous vehicles) and AV (autonomous vehicles) under low, medium, and high demand.

- **0% CAV**:
  - Low demand: ~2000 kWh
  - Medium demand: ~6000 kWh
  - High demand: ~10000 kWh

- **5% CAV**:
  - Low demand: ~2500 kWh
  - Medium demand: ~6500 kWh
  - High demand: ~11000 kWh

- **100% CAV**:
  - Low demand: ~3000 kWh
  - Medium demand: ~7000 kWh
  - High demand: ~12000 kWh

- **100% AV**:
  - Low demand: ~3500 kWh
  - Medium demand: ~7500 kWh
  - High demand: ~13000 kWh

CAV = connected autonomous vehicle
AV = autonomous vehicle
EV = electric vehicle
This analysis does not include latent demand
Automated, electric, or both?
Anticipating regional effects
Distribution of transport emissions in the region

- **GHG = greenhouse gas**
- **PM$_{2.5}$ = fine particulate matter**
- **NOx = oxides of nitrogen**
Comparison with Public Transit

❖ Green bar illustrates the range of private vehicle emission intensities

❖ Boxes illustrate the ranges of public transit emission intensities

CO₂eq/PKT = carbon dioxide equivalent per passenger kilometer traveled
Modal Split – Base Case

WAT: Walk Access Transit

- WAT: 20%
- Auto: 48%
- Walk: 7%
- Schoolbus: 3%
- RideShare: 0%
- Passenger: 12%
Modal Split – Autonomous vehicle (AV) adoption (15%)

WAT: Walk Access Transit
## Lifecycle GHG emissions of passenger travel if AVs were EVs

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Efficiency</th>
<th>Fuel Options</th>
<th>Lifecycle Emissions (tonne)</th>
<th>VKT (millions)</th>
<th>Emission Intensity (g CO₂eq/PKT)</th>
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<tbody>
<tr>
<td>A0 (Base Case)</td>
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<td>Gasoline</td>
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<td>Electric AV Mix4</td>
<td>33,500</td>
<td>116</td>
<td>251</td>
</tr>
</tbody>
</table>

GHG = greenhouse gas; AVs = autonomous vehicles; EVs = electric vehicles; VKT = vehicle kilometers traveled; CO₂eq/PKT = carbon dioxide equivalent per passenger kilometer traveled
ELECTRIC VEHICLE (EV) CHARGING PATTERNS CAN AFFECT GHG EMISSIONS

Introducing Marginal Emission Factors (MEF) for electricity production
Marginal Emissions of Electricity Generation

Hourly Electricity Supply by Fuel Type
( Ontario June 9th – 15th 2017)
NO$_2$ concentrations generated by a chemical transport model – assuming all additional electricity production by natural gas

<table>
<thead>
<tr>
<th>Base Case</th>
<th>100% EV</th>
<th>25% EV</th>
</tr>
</thead>
</table>

NO$_2$ = nitrogen dioxide
EV = electric vehicles
Black carbon (BC) concentrations generated by a chemical transport model – assuming all additional electricity production by natural gas
Comparison with electrification of heavy-duty diesel vehicles – exposure

BC = black carbon
EV = electric vehicles
Fundamental Dilemma

- Travelers face new choices
- Users will do what is best for them even if detrimental to the system

- Policy makers, planners, operators, engineers and researchers must mind the user but must also mind the system

- What is our vision for the city we want to live in?