Quantifying the Quality of Mobility: Development of a Comprehensive Mobility Metric

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Motivation

• Vision of U.S. DOE’s Energy Efficient Mobility Systems (EEMS) Program
  ○ *Maximum mobility and minimum energy*

• What is mobility?

• How to quantify the quality of mobility?

• No well accepted, quantifiable, and practical ‘Mobility’ metric
Existing Mobility Related Measures

• Road network measures: travel time, travel time reliability, level of service, volume capacity ratio
  o Relative health of a link on the roadway
  o Does not reflect the ability of a system to connect people to the goods, services and jobs

• ‘Accessibility’ research literature
  o Only consider travel time and employment opportunities
  o One mode is evaluated

• Web-based metrics: walk score, bike score, transit score
  o Methodology behind these metrics is seldomly made public
  o Uni-modal
  o Coarse geographical resolution
Properties of a Good Mobility Metric

• Reflects access to goods, services, and employment
• Spatially scalable (neighborhood, district, city)
• Factors need to be included
  o Travel time
  o Number of opportunities accessible
  o Energy consumption
  o Mode of travel
• Based on established research
• Data supportable
Objective

• Develop a comprehensive mobility metric
  o Quantify the quality of mobility
  o Effectively incorporate different travel modes and trip purposes
  o Reflect energy efficiency
  o Able to quantify the impact of changes on mobility
  o Enable the comparison between different locations
  o Easily adaptable to different data sources and different geographical resolutions
Development of a Comprehensive Mobility Metric

Mobility = \( f \) (travel time, land use, energy efficiency, travel demand)
Geographic Area for Analysis

- Metropolitan area of Columbus, OH
- Divided into 1830 1km×1km cell blocks
- Mobility is evaluated at the centroid of each 1km×1km cell block
• Quantify the number of opportunities that people can reach within a certain travel time threshold by different transportation modes

• The opportunity measures is weighted by the energy efficiency metrics of different transportation modes

• Average the energy-weighted mobility values across all activities
Land Use Data

- Acquired from Mid-Ohio Regional Planning Commission (MORPC)
Isochrone

- Isochrone: a polygon formed by a line connecting all points where travelers can reach from the same origin within the same travel time
- Data source: OpenStreetMap and TransitLand

Isochrones of 10, 20, 30, and 40 minutes travel time by biking
Cumulative Opportunities

- Count the opportunities that can be accessed within travel time of 10, 20, 30, 40 minutes for all modes in every cell

A example of opportunities accessible by biking
Let $o_{ijkt}$ denote the number of opportunities of activity $j$ by mode $k$ within the travel time threshold $t$ at the $i$th cell block.

Travel time-weighted cumulative opportunities, $O_{ijk}$, are calculated as following:

$$O_{ijk} = \sum_t (o_{ijkt} - o_{ijk(t-10)}) \cdot e^{\beta t}$$

where $\beta=-0.08$.

Travel time $\in [10, 20, 30, 40]$.
Travel Time-Weighted Cumulative Opportunities

<table>
<thead>
<tr>
<th>Mode</th>
<th>WORK</th>
<th>SHOPPING</th>
<th>GROCERY</th>
<th>PARK</th>
<th>SCHOOL</th>
<th>RELIGIOUS</th>
<th>MEDICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVING</td>
<td>804681</td>
<td>433</td>
<td>1952</td>
<td>291</td>
<td>499</td>
<td>612</td>
<td>98</td>
</tr>
<tr>
<td>TRASIT</td>
<td>24628</td>
<td>8</td>
<td>109</td>
<td>4</td>
<td>76</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>BIKING</td>
<td>120292</td>
<td>40</td>
<td>676</td>
<td>36</td>
<td>239</td>
<td>204</td>
<td>61</td>
</tr>
<tr>
<td>WALKING</td>
<td>24410</td>
<td>7</td>
<td>102</td>
<td>4</td>
<td>77</td>
<td>25</td>
<td>27</td>
</tr>
</tbody>
</table>

Each cell has travel-time weighted cumulative opportunities for all activities and all modes.
Opportunities that can be reached by more energy efficient modes, such as walking, biking, and transit, are assigned more weights.

Opportunities that can be reached by less energy efficient modes, such as driving, are assigned less weights.

Energy-weighted mobility for activity $j$ at $i$th cell block, $a_{ij}$

$$a_{ij} = \sum_{k} O_{ijk} \cdot e^{\alpha(E_k/ \min_k E_k)}$$

where $\alpha = -0.3$

$E_k$ – energy use per passenger-mile for transportation mode $k$
Passenger travel and energy use data was obtained from *True Cost Blog*

<table>
<thead>
<tr>
<th>Mode</th>
<th>Gallon per passenger-mile</th>
<th>$E_k/ \min_k E_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biking</td>
<td>0.0010</td>
<td>1</td>
</tr>
<tr>
<td>Walking</td>
<td>0.0014</td>
<td>1.4</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>0.0261</td>
<td>26</td>
</tr>
<tr>
<td>Driving</td>
<td>0.0280</td>
<td>28</td>
</tr>
</tbody>
</table>
Energy-Weighted Mobility

Energy Weighted Cumulative Opportunities

<table>
<thead>
<tr>
<th></th>
<th>WORK</th>
<th>SHOPPING</th>
<th>GROCERY</th>
<th>PARK</th>
<th>SCHOOL</th>
<th>RELIGIOUS</th>
<th>MEDICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>105344</td>
<td>35</td>
<td>568</td>
<td>29</td>
<td>228</td>
<td>168</td>
<td>63</td>
</tr>
</tbody>
</table>

Energy Weighted Mobility (0-100 score)

<table>
<thead>
<tr>
<th></th>
<th>WORK</th>
<th>SHOPPING</th>
<th>GROCERY</th>
<th>PARK</th>
<th>SCHOOL</th>
<th>RELIGIOUS</th>
<th>MEDICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>84</td>
<td>32</td>
<td>67</td>
<td>50</td>
<td>67</td>
<td>50</td>
<td>53</td>
</tr>
</tbody>
</table>

- Each cell has energy-weighted cumulative opportunities for all activities
- Then normalized to the scale of 0 to 100 mobility score
Aggregating Activity

- Average across all activities weighted by trip frequency
- Final aggregated mobility for the $i$th cell block, $A_i$

\[
A_i = \frac{\sum_j a_{ij} \cdot f_j}{\sum_j f_j}
\]

where $f_j$ is the trip frequency of activity $j$
Trip Frequency Data

- Acquired from National Household Travel Survey (NHTS)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Estimated Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>9.9%</td>
</tr>
<tr>
<td>Shopping</td>
<td>1.7%</td>
</tr>
<tr>
<td>Grocery</td>
<td>17.7%</td>
</tr>
<tr>
<td>Park</td>
<td>2.4%</td>
</tr>
<tr>
<td>School</td>
<td>4.6%</td>
</tr>
<tr>
<td>Religious</td>
<td>0.5%</td>
</tr>
<tr>
<td>Medical</td>
<td>1.6%</td>
</tr>
</tbody>
</table>
Final Mobility Metric

Final Mobility Metric (0-100 score)

68
Mobility Metric in Columbus

• Higher score means easy, fast, and energy efficient access to services/employment opportunities
Mobility Metric by Activity

- Work
- Shopping
- Park
- Grocery
- School
- Medical
Summary

- Developed a comprehensive mobility metric
  - Evaluate quality of mobility
  - Reflects energy efficiency
  - Aggregate different trip activities
  - Enables the comparison between different locations
  - Able to quantify the impact of changes on mobility
    - Add new services or infrastructure
    - Improvement on travel time
    - Increase transit ridership
    - Emerging technology: sharing, electrification, Automation, Connectivity
  - Easily adaptable to different data sources and different geographical resolutions
Issues – Future Steps

• Scale mobility metric by cost of travel and travel time reliability
  – Method extendable by cost of travel – ‘fundamental mobility metric’
  – Travel time reliability – acceptable approaches to add to travel time

• Data supportable
  – Travel time data (isochrones) available nationwide
  – Land use data is available per city – no national source/standard
Thank you!
Questions?