The Socio-Demographic and Built Environment Characteristics of Emissions in Neighborhoods Under Compactness and Sprawl
The Case of Charlotte, North Carolina

Daniel A. Rodríguez, Ph.D.
University of North Carolina, Chapel Hill
July 28, 2011
Presentation outline

- Motivation
- Study area
- Model development
- Design of futures
- Analysis of emissions
- Conclusions
Motivation

Differences in SES composition associated with differences in pollution exposure

§ Built environment, land markets, and discrimination as explanatory causal factors

$p$ Maryland, California (US), Hamilton (Canada), Christchurch (NZ), Malmo (Sweden), Birmingham (UK)
Key research questions

- How does population exposure to pollution (HC, CO, and NO\textsubscript{x}) change as a city grows more compactly?
- Are there differences in exposure by SES?
Modeling approach

- Classify built environment
  - Walking and transit-supportive environments

- Develop integrated models sensitive to built environments
  - Land and travel demand

- Create future scenarios compare travel and emissions spatially
  - Compact growth scenario
  - Business as usual scenario
Presentation outline

- Motivation
- Study area
- Model development
- Design of futures
- Analysis of emissions
- Conclusions
Study area—Mecklenburg County

- Growing metro area in NC
- Data-rich
- Designated 8-hour ozone non-attainment area
  - Likely in nonattainment for new ozone standards
- Future transit metropolis?

Charlotte in 2050?
Mecklenburg County

- Rapid population increase
  - 22% from 1990 to 2000
  - > 845k in 2008

- Even faster land consumption
  - Density
    - 1950: 6.98 persons/acre
    - 2000: 3.60 persons/acre
Urban form
Urban activity system

Translation demand models and county's economic structure into model parameters
Input-output model of Mecklenburg County

Translate demand models and county's economic structure into model parameters
Urban activity system

Integrated transport-land use model

Trips
Mode choice
Link-level traffic volumes and average speeds
Locations of employment centers and residences

Design/redesign future scenarios
Populate model's databases with baseline land use, employment, households, and transportation supply
Calibrate land and travel demand parameters

Emissions factors
Allocate emissions spatially

Stats analysis

Translate demand models and county's economic structure into model parameters
Input-output model of Mecklenburg County

Translate demand models and county's economic structure into model parameters
Urban activity system

Integrated transport-land use model

Trips
Mode choice
Link-level traffic volumes and average speeds
Locations of employment centers and residences

Design/redesign future scenarios
Populate model's databases with baseline land use, employment, households, and transportation supply
Calibrate land and travel demand parameters

Emissions factors
Allocate emissions spatially

Stats analysis
Neighborhood typology

Residential and business locational choice models

Translate demand models and county's economic structure into model parameters

Trips
- Mode choice
- Link-level traffic volumes and average speeds

Locations of employment centers and residences

Assess scenarios using integrated land use-transportation model

Design/redesign future scenarios

Populate model's databases with baseline land use, employment, households, and transportation supply

Calibrate land and travel demand parameters

Vehicular emission factors model
- Highway vehicle technology

Allocate emissions spatially

Compare scenarios
Translate demand models and county’s economic structure into model parameters

Populate model’s databases with baseline land use, employment, households, and transportation supply

Calibrate land and travel demand parameters

Assess scenarios using integrated land use-transportation model

Design/redesign future scenarios

Allocate emissions spatially

Compare scenarios

Vehicular emission factors model

Highway vehicle technology

Locations of employment centers and residences

Link-level traffic volumes and average speeds

Trips

Mode choice

Neighborhood typology

Travel mode choice models

Residential and business locational choice models

Input-output model of Mecklenburg County
Residential and business locational choice models

Neighborhood typology

Translate demand models and county’s economic structure into model parameters

Populate model’s databases with baseline land use, employment, households, and transportation supply

Calibrate land and travel demand parameters

Input-output model of Mecklenburg County

Trips
  Mode choice
  Link-level traffic volumes and average speeds

Locations of employment centers and residences

Assess scenarios using integrated land use-transportation model

Design/redesign future scenarios

Allocate emissions spatially

Compare scenarios

Vehicular emission factors model
  Highway vehicle technology
Presentation outline

- Motivation
- Study area
- Model development
- Design of futures
- Analysis of emissions
- Conclusions
Scenarios

Baseline

Business as Usual (trend)

Compact growth

2000 2050
Scenarios’ common features

- **Transportation**
  - Road and bus network (alignment)
  - Road capacity increased as needed
  - Vehicle operating costs and fares are constant

- **Economy structural changes**
  - Third-party socioeconomic projections
    - Population/employment to triple
  - Major declines in low-wage jobs in construction, manufacturing, and retail trade
  - Major increase in services, public administration
Scenarios’ differences

**Business as Usual**
- 2 light rail lines and commuter rail + lesser increase in LRT service
- Local bus service increases by 2.2 times
- 12 zones become walkable and transit friendly
- Development allowed in all zones at current levels

**Compact Growth**
- 3 LRT lines, BRT, and commuter rail + service increases
- Local & express bus service increases by 4.5 times
- Development liberally allowed in TOD and “transition” zones – walk and transit friendly areas
- Development severely restricted in “wedge” zones
Plan and zoning

Source: Metrolina COG
Results -- Households
Low income households

Compact growth

Legend
% of Low Income Households
- 0 - 10%
- 10 - 22%
- 22 - 37%
- 37 - 63%
- 63 - 100%

Business as Usual

Legend
% of Low Income Households
- 0 - 10%
- 10 - 22%
- 22 - 37%
- 37 - 63%
- 63 - 99.5%
Presentation outline

- Motivation
- Study area
- Model development
- Design of futures
- Analysis of emissions
- Conclusions
Tailpipe emissions, 2050

Compared to baseline (2000)

- Emissions decrease between 59% and 89%
  - Tougher federal emissions standards
- Except for CO$_2$, which increases between 76% and 96%
  - Population growth
  - VMT growth
## Tailpipe emissions, 2050

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Land Pattern</th>
<th>Compact growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbons</td>
<td>Benchmark</td>
<td>-7.8%</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>Benchmark</td>
<td>-6.3%</td>
</tr>
<tr>
<td>NOx</td>
<td>Benchmark</td>
<td>-5.5%</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>Benchmark</td>
<td>-7.1%</td>
</tr>
</tbody>
</table>
Testing hypotheses

- Overall population exposure
- Analysis of disproportionate exposure for low income groups
  - Visual description
  - Hotspot detection with LISA + K-S tests of low income households in hotspots vs. elsewhere
Overall exposure

- Compact growth pulls population to zones where activity concentrates
- Despite overall decreases in emissions, population exposure (at neighborhood level) increases under compactness
  - 36.2% for HC
  - 40.4% for CO
  - 41.8% for NOx
Location of emissions

Compact Growth (NO$_x$)

NOx emissions

%Low Income Households

Legend

<table>
<thead>
<tr>
<th>% of Low Income Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10%</td>
</tr>
<tr>
<td>10 - 22%</td>
</tr>
<tr>
<td>22 - 37%</td>
</tr>
<tr>
<td>37 - 63%</td>
</tr>
<tr>
<td>63 - 100%</td>
</tr>
</tbody>
</table>
LISA
\((\text{NO}_x)\)

Percentage of Low Income Residents and LISA of NOx
for the CG Scenario

Legend
LISA of NOx
- High - High
- Low - Low
% of Low Income Residents
- 0 - 10%
- 10 - 22%
- 22 - 37%
- 37 - 63%
- 63 - 100%

Percentage of Low Income Residents and LISA of NOx
for the BAU Scenario

Legend
LISA of NOx
- High - High
- Low - Low
% of Low Income Residents
- 0 - 16%
- 10 - 22%
- 22 - 37%
- 37 - 63%
- 63 - 99.5%

Carolina Transportation Program
Hotspot distribution
Compact Growth (NO\textsubscript{x})

Ratio of Low Income Residents to All Income Residents

Kolmogorov-Smirnov test \( p < 0.05 \)
Hotspot distribution, NO$_x$

Business as Usual vs. Compact Growth

- Compact Growth (median=0.24)
- Business as Usual (median=0.14)

Ratio of Low-Income Residents to All-Income Residents

Fraction (%)

0 0.1 0.2 0.3 0.4 0.5

0 0.2 0.4 0.6 0.8 1

Carolina Transportation Program
Conclusions

- Modest reductions in emissions due to compact growth (~ 5-7%)
  - Relative to baseline, HC, CO and NO\textsubscript{x} emissions decrease but CO\textsubscript{2} increases
- Despite decreases, population exposure is higher by 36-42%
- Some evidence of disproportional exposure of low income households
Acknowledgements

- EPA STAR Grant R831835
- Lincoln Institute for Land Policy
- ITRE + UNC matching funds
  § Joe Huey, Mei Ingram, & Bing Mei
- Data
  Twyla McDermott, Anna Gallup, & others with City of Charlotte & Mecklenburg County
- TRANUS, Tomás de la Barra
## Project staff & researchers

<table>
<thead>
<tr>
<th>Land use &amp; scenarios</th>
<th>Transportation validation</th>
<th>Vehicular emissions</th>
<th>Air quality (to come)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian Morton, Ph.D.</td>
<td>Asad Khattak</td>
<td>Chris Frey, Ph.D.</td>
<td>Sarav Arunachalam</td>
</tr>
<tr>
<td>Eun Joo Cho</td>
<td>Morton and Rodriguez</td>
<td>Nagui Roupail, Ph.D.</td>
<td>Adel Hanna</td>
</tr>
<tr>
<td>Tracy Hadden-Loh</td>
<td>Xin Wang</td>
<td>Haibo Zhai, Ph.D.</td>
<td></td>
</tr>
<tr>
<td>Shaopeng Zhong</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian Morton, Ph.D.</td>
</tr>
<tr>
<td>Daniel Rodriguez</td>
</tr>
<tr>
<td>Asad Khattak, Ph.D.</td>
</tr>
<tr>
<td>Elizabeth Shay, Ph.D.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neighborhoods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yan Song, Ph.D.</td>
</tr>
<tr>
<td>Bev Wilson</td>
</tr>
</tbody>
</table>
Questions
Neighborhoods

- Set of census block groups with similar built environments
- Based on
  - Land use (sectors, parks, tree canopy)
  - Employment
  - Housing and population
  - Street network
  - Access to bus stops and various land uses
Neighborhoods in baseline scenario

- Data factor-analyzed
  - walkability
  - accessibility
  - agglomeration
  - property value
  - industry

- Cluster analysis of factors

Wilson, B. and Y. Song, 2009, *Journal of Urbanism*
Type 1 (Red)

- One, unique CBD block group
- Mostly office
- High local/regional accessibility
- High improvements to total parcel value ratio (commercial uses)
Type 3 (Yellow Blue)

- Some mixing of land uses
- High local/regional accessibility
- Roughly the second ring
Type 6 (Dark Blue)

- Single family residential is dominant
- High levels of green space
- Limited local/regional accessibility
- Bridge between rural and suburban
Residential location choice

Proportion of employees who work in zone 1 and live in zone 10 (for example) is directly influenced by:

- Cost to commute to zone 1
- Cost of residential land in zone 10
- Zone 10’s attractiveness – qualitative attributes (choice model)

Characteristics of other zones
Supply of developable/redevelopable land
Resulting input-output

<table>
<thead>
<tr>
<th>Zone</th>
<th># High-Income Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>373</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone</th>
<th>Acres of Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>373</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone</th>
<th># Construction Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>373</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone</th>
<th>Construction Sector’s Purchase of Labor from High-Income Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>1</td>
</tr>
<tr>
<td>Demand</td>
<td>1</td>
</tr>
</tbody>
</table>

High-Income Households’ Purchases from Retail Sector

| Supply | 1 | 2 | --- | 373 |
| Demand | 1 | # | # |

And so on for every sector

And so on for additional sectors
Presentation outline

- Motivation
- Study area
- Model development
  - Land development/use model
  - Travel model
- Design of futures
- Results
- Conclusions
Baseline Scenario’s Transportation Network
Travel Demand Model Calibration and Validation

- Travel demand parameters were determined using a two-step process:
  - Mode choice models estimated with data from Metrolina travel demand survey
  - Calibration of modeled travel to observed traffic counts and mode shares, including Lynx ridership

- Validation results for 86 links:
  - Overall, 51% RMSE
  - 70% RMSE for I85
  - 25-34% RMSE for I77, I277, and I485
Travel demand model

Modes
- Walk; SOV; Carpool; Local bus and express bus; Light rail; commuter rail; and bus rapid transit

Trip categories
- Home-based work by income class
- Home-based other by income class
- Non-home based and home-based work external – specified in an exogenous zone-to-zone trip table
Economic flows generate transportation flows

Zone 256 supplies labor

Zone 258 demands labor
Structure of pax transport model

Pax flows

Disaggregate modal split

Probabilistic assignment

Sensitive to the neighborhood environment; 2001 travel survey
Presentation outline

- Motivation
- Study area
- Model development
  - Land development/use model
  - Travel model
  - Emissions model
- Design of futures
- Results
- Conclusions
Link-based emission factors

- Meteorology
- Facility type
  - Average cycle speed
  - Vehicle class & age
  - Vehicle fuel & technology
  - I/M program, standards
  - Year

Speed- and facility-specific link emission rates for a given technology

Speed correction factors for a given technology

Basic emission rates Technology correction factors

Travel demand modeling

Link-based vehicle volume, average speed, and travel time

On-road & rail-transit emission inventory

Source: Frey et al 2008
## Database

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Vehicle Fuel &amp; Technology</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Emission Rates</td>
<td>LDGV, LDDV, HDDT, HDDB</td>
<td>MOBILE6</td>
</tr>
<tr>
<td>Speed Correction Factors</td>
<td>LDGV, HDDT</td>
<td>NCSU PEMS</td>
</tr>
<tr>
<td></td>
<td>HDDB</td>
<td>EPA PEMS</td>
</tr>
<tr>
<td></td>
<td>LDDV</td>
<td>Portugal PEMS</td>
</tr>
<tr>
<td>Fuel Economy</td>
<td>LDGV</td>
<td>EPA</td>
</tr>
<tr>
<td></td>
<td>LDDV, HEV, CNG Cars</td>
<td>Fuel Economy Guide by EPA &amp; DOE</td>
</tr>
<tr>
<td>Technology Correction Factors</td>
<td>E85, HEV, CNG Cars</td>
<td>EPA Certification Tests</td>
</tr>
<tr>
<td></td>
<td>B20 trucks, CNG Buses</td>
<td>Literature*</td>
</tr>
</tbody>
</table>

* There were no data available for alternative heavy-duty vehicle technologies. Their TCFs are based on literature estimates for B20 versus diesel heavy-duty trucks, and NG versus diesel buses.
Link-based emission factors

\[ EF_{ct} = BER_{ct} + TECF + HCF + PCF + CCF_{ct} + TCF_{ct} + SCF_{ct} \]

- Link-based emission factor for a combination of vehicle class and technology (ct)
- Basic emission rate
- Temperature, humidity, and barometric pressure correction factors
- Cycle correction factor
- Technology correction factor
- Speed- and facility-specific correction factor
Tailpipe emission factors

Arterials, 2005

[Bar charts showing emissions factors for different vehicles across various speeds]
Sensitivity of Emissions Reductions to Total Market Penetration ($\eta$) of Alternative Vehicle Technologies for Present Alternative vs. Baseline Scenarios

Fraction of VMT for Alternative Fuels & Vehicles:

- E85
- HEV
- LDDV
- CNG
- EV & Fuel Cell

Source: Frey et al 2008