

# Effects of Regional Growth on the Environment: A Case Study in the National Capital Region of Delhi, India

Creating Sustainable Urban Environments:  
Future Forms for City Living

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# Outline

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- Context of region and city
- Models – optimization, simulation and land use

## 2. Delhi city level results (focus on bus/ transit)

- Bus trips located spatially
- Shortfall located spatially

## 3. NCR results

- Land use change
- Trips generated

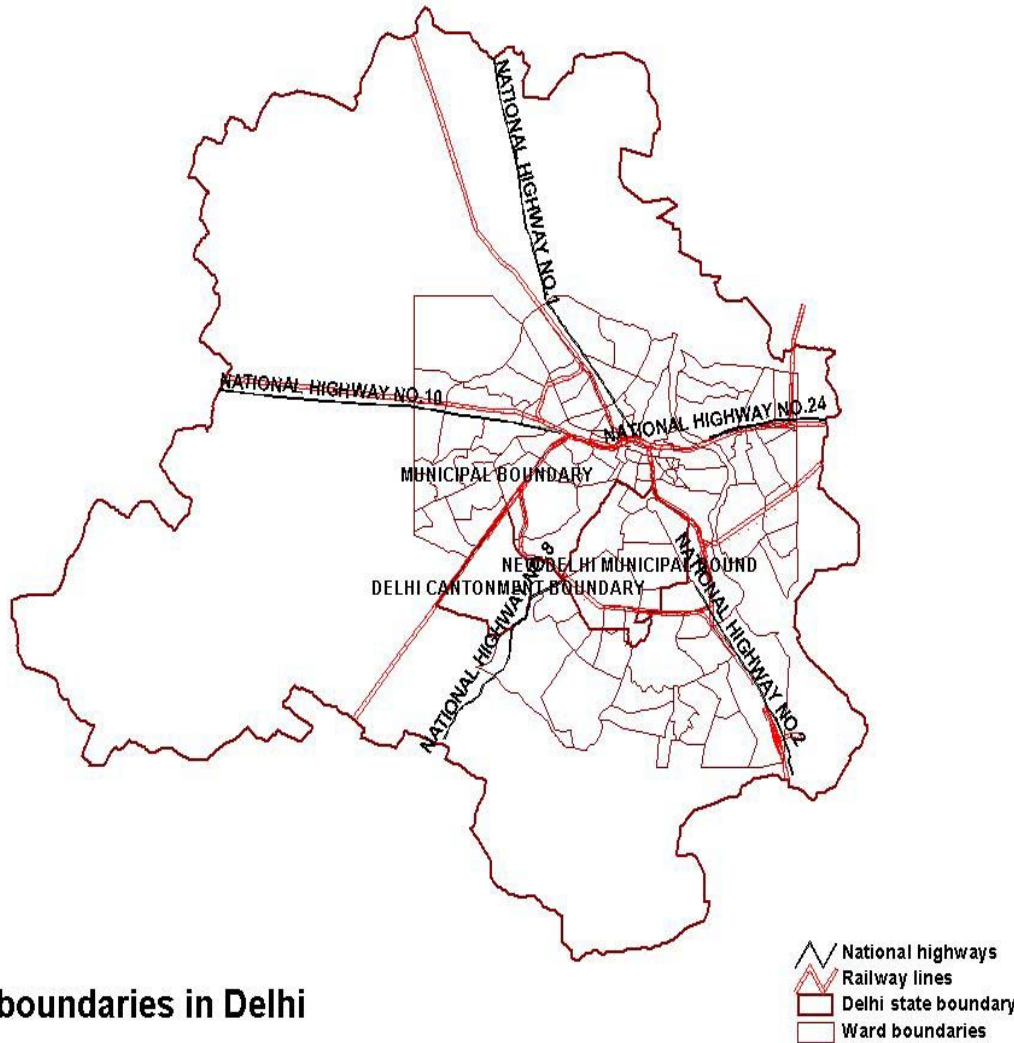
## 4. Implications for planning

## 5. Future research directions

# Introduction

- UNESCAP/ADB names Delhi as the most polluted city in the world in terms of suspended particulate matter (2002)
- Particle levels in Delhi consistently remain 3 to 5 times the national standards. Maximum levels have even reached 8 times the standards during the winter of 1998 (CPCB data)
- Delhi has the highest road length in India: 1284km/100km<sup>2</sup> area (26,379km of total length in 1998/99). Delhi's roads with better traffic management, can accommodate 2-3 times the existing number of vehicles. (IIT, 1997)
- The region has also urbanized rapidly (and as the largest city in northern India) will continue to do so
- Census 2001 reports a 50% decadal growth rate and one of the highest population densities (about 9000 persons per square km) in the country

# Context — Delhi State and City



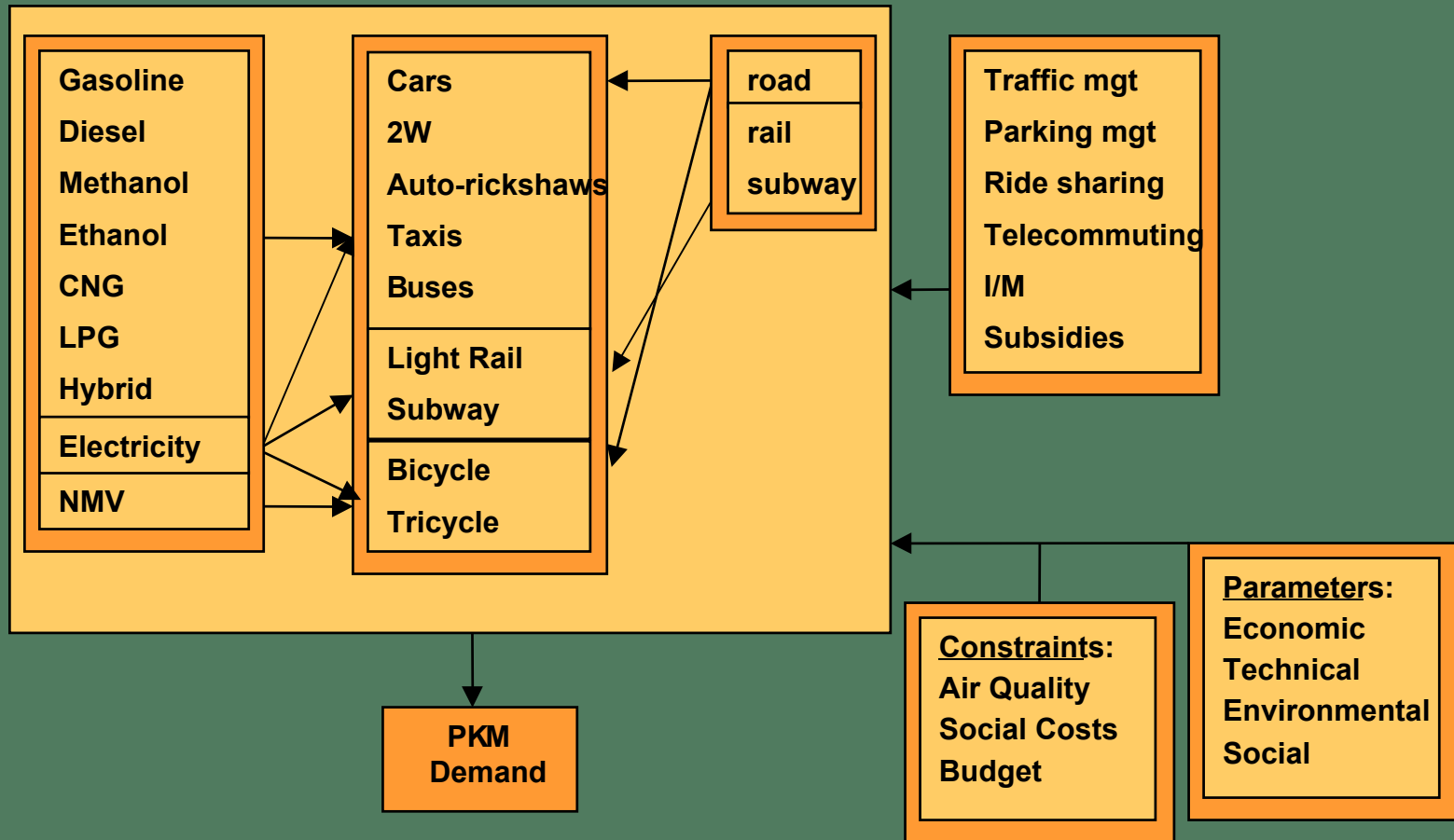
Ward boundaries in Delhi

- Became state in 1992
- 2001 Population
  - state: 13,782,976
  - city: 9,817,439
- Key bodies for all municipal services:
  - MCD (Municipal Corporation of Delhi)
  - NDMC (New Delhi Municipal Committee)
  - Delhi Cantonment Board
- National Capital Region (NCR) consists of 11 districts including Delhi

# Introduction - models

- Simulation model (VAPIS spreadsheet model for forecasts of business-as-usual scenario)
- Optimization model (for forecasts of least environmental and social cost scenarios)
- Land use change models (for forecasts of future land use)
  - At ward level for Delhi (discrete choice model)
  - At National Capital Region level (Cellular Automaton/ Markov model)

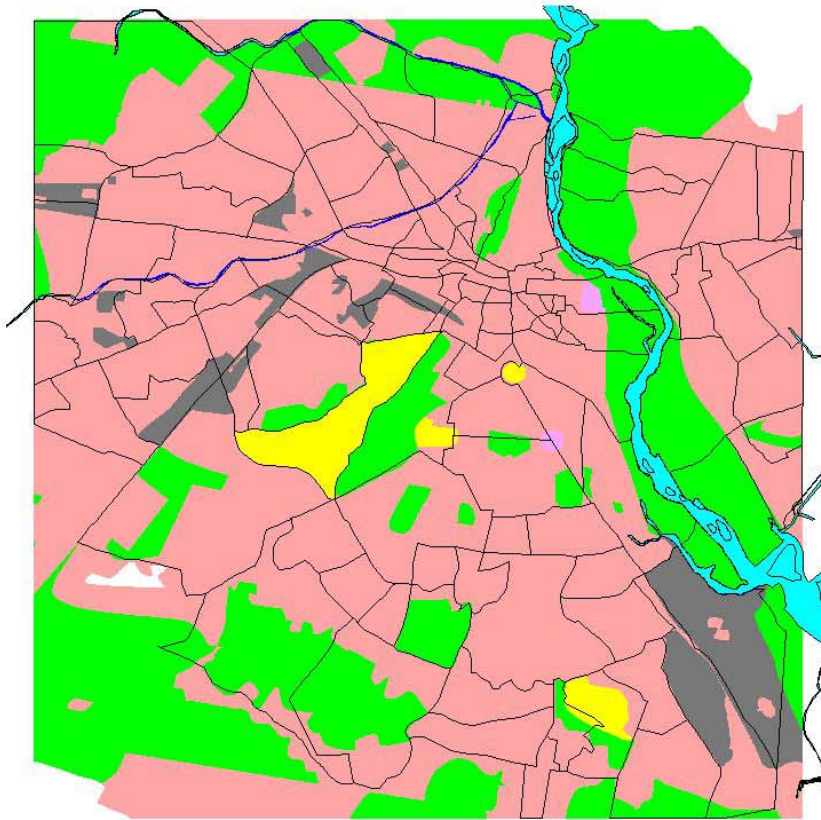
# Optimization model structure



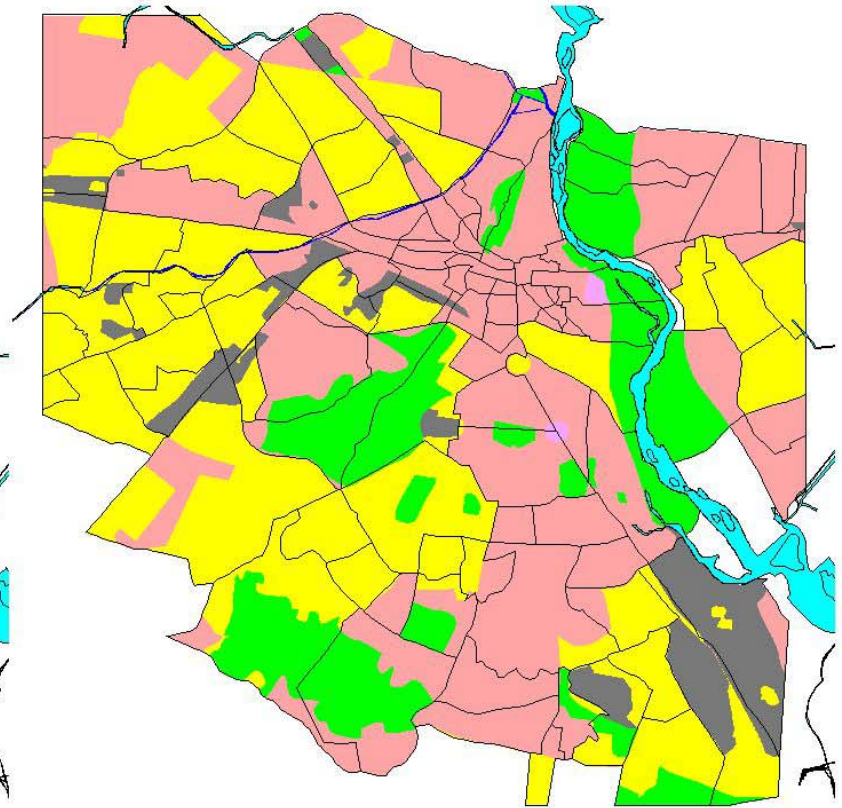
# Delhi trip forecast methodology

- Optimization and spreadsheet models used to forecast number of passenger trips made by various modes in 2020 for three different scenarios
- Land use intensification model used to forecast ward-level land uses in the future (2010) for the 110 wards for which land use data was available
- Land use, employment and population forecasts are used to predict share of work and other trips generated and attracted from each ward (using regressions estimated by the Chennai Transportation Study, 1991)
  - Trips generated = Function (Number of vehicles, Number of workers, Population)
  - Trips attracted = Function (Number of workplaces, Commercial area in hectares, Population)

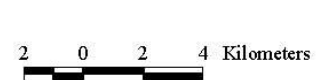
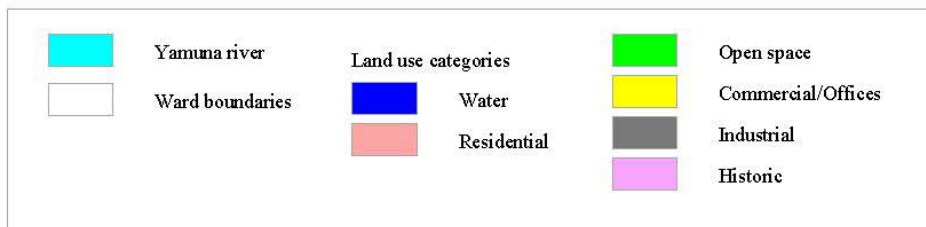
# Delhi land use forecast



Land use in 1999



Land use in 2010  
(as predicted by the land use change model)



# Delhi vehicle forecasts

	2020	Scenario 1	Scenario 2	Scenario 3
<b>total motor vehicles</b>		<b>2,619,781</b>	<b>6,066,004</b>	<b>13,556,004</b>
<b>cars</b>		<b>1,267,537</b>	<b>1,267,537</b>	<b>5,831,141</b>
<b>two wheelers</b>		<b>1,000,000</b>	<b>4,229,432</b>	<b>7,044,943</b>
<b>autorickshaws</b>		<b>25,000</b>	<b>278,000</b>	<b>121,510</b>
<b>taxis</b>		<b>11,600</b>	<b>11,600</b>	<b>98,284</b>
<b>buses</b>		<b>71,210</b>	<b>35,000</b>	<b>53,569</b>
<b>trucks</b>		<b>244,435</b>	<b>244,435</b>	<b>406,557</b>
<b>subway</b>		-	-	
<b>light rail</b>		-	667	
<b>bicycle</b>		<b>2,200,000</b>	<b>13,000,000</b>	
<b>tricycle</b>		<b>60,000</b>	<b>210,000</b>	
<b>value of time</b>	<i>million \$</i>	<b>2,392</b>	<b>8,742</b>	<b>16,537</b>
<b>health costs</b>	<i>million \$</i>	<b>1,257</b>	<b>1,546</b>	<b>2,919</b>
<b>fuel costs</b>	<i>million \$</i>	<b>2,317</b>	<b>2,723</b>	<b>7,453</b>
<b>GWC</b>	<i>million \$</i>	<b>42</b>	<b>59</b>	<b>176</b>
<b>DALYs</b>		<b>288,095</b>	<b>354,582</b>	<b>670,180</b>
<b>PMD</b>		<b>2,846</b>	<b>3,501</b>	<b>6,614</b>
<b>LYL</b>		<b>105,300</b>	<b>129,526</b>	<b>244,728</b>
<b>MTC</b>		<b>2.12</b>	<b>2.93</b>	<b>8.80</b>
<b>PM10 conc</b>	<i>micrograms/m<sup>3</sup></i>	<b>13.40</b>	<b>16.50</b>	<b>31.20</b>
<b>SO2 conc</b>	<i>micrograms/m<sup>3</sup></i>	<b>0.18</b>	<b>0.17</b>	<b>0.18</b>
<b>TSP emissions</b>	<i>tons/yr</i>	<b>2,085</b>	<b>2,717</b>	<b>9,563</b>
<b>SO2 emissions</b>	<i>tons/yr</i>	<b>267</b>	<b>151</b>	<b>256</b>
<b>PKM</b>	<i>bpkm</i>	<b>251</b>	<b>251</b>	<b>359</b>
<b>Passengers</b>	<i>billion pass/da</i>	<b>10.13</b>	<b>24.51</b>	<b>24.51</b>
<b>Total Costs</b>	<i>billion \$</i>	<b>9.82</b>	<b>11.61</b>	<b>66.17</b>

**Scenario 1:** Minimizing total costs without social costs with only the first three control options for vehicle technologies, fuels, and rail infrastructure with SET 1 PKM demand

**Scenario 2:** Minimizing total costs without social costs with only the first three control options for vehicle technologies, fuels, and rail infrastructure with SET 1 PKM demand with limited number of buses (35,000)

**Scenario 3:** The spreadsheet simulation

**MTC:** million tons of carbon emissions.

**bpkm:** billion passenger km.

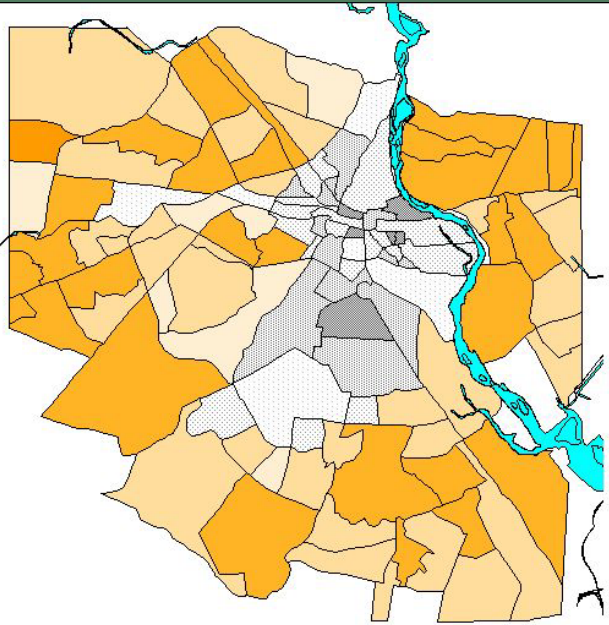
**PMD:** premature deaths due to air pollution resulting from vehicular emissions.

**GWC:** global warming costs.

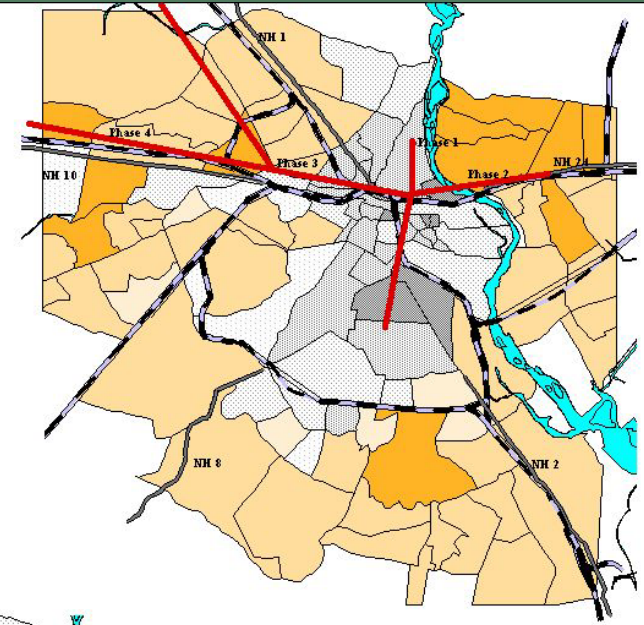
**LYL:** life years lost due to air pollution resulting from vehicular emissions.

**DALYs:** disability adjusted life years due to air pollution from vehicular emissions.

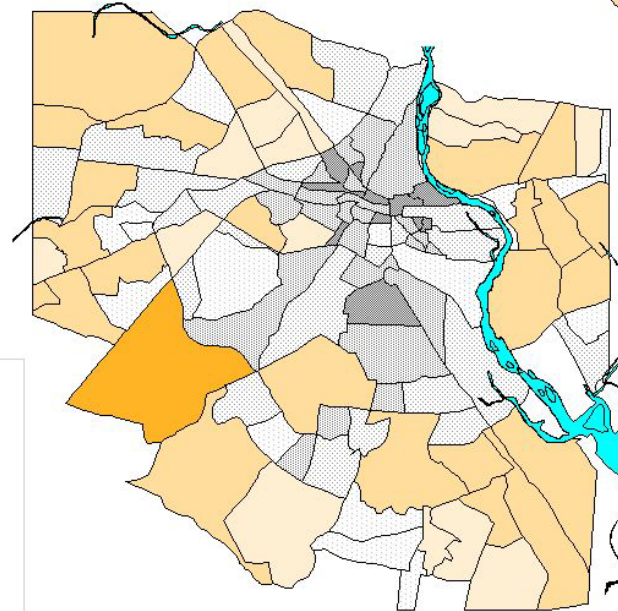
# Delhi bus trips generated



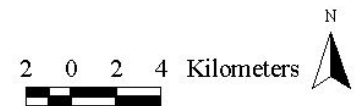
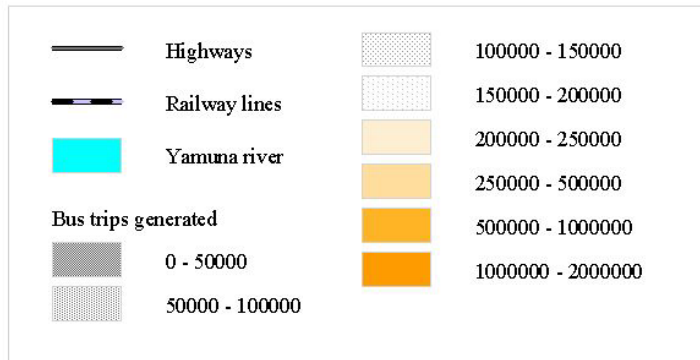
Scenario 1



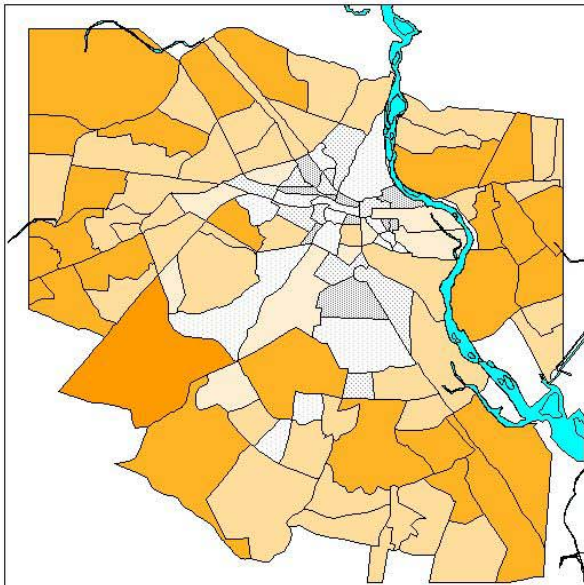
Scenario 3



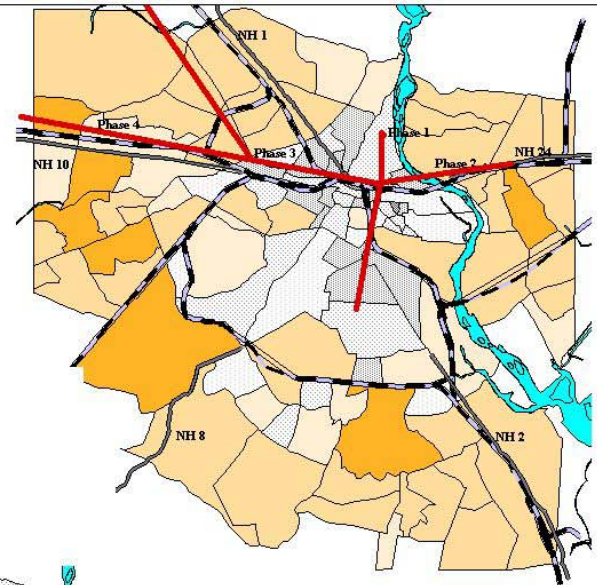
Scenario 2



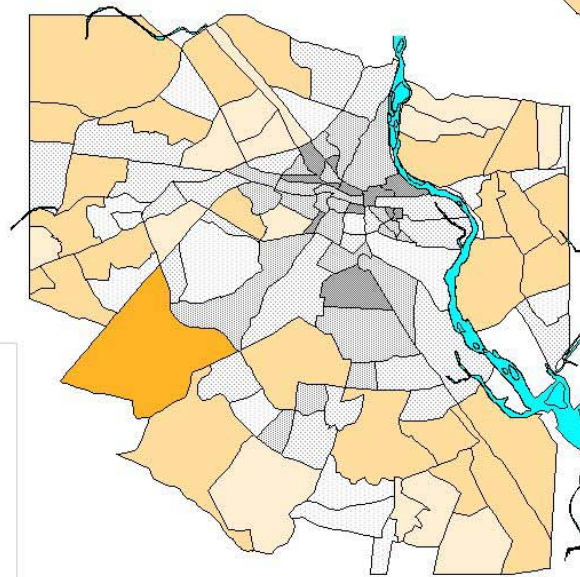
# Delhi bus trips attracted



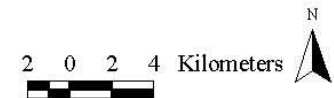
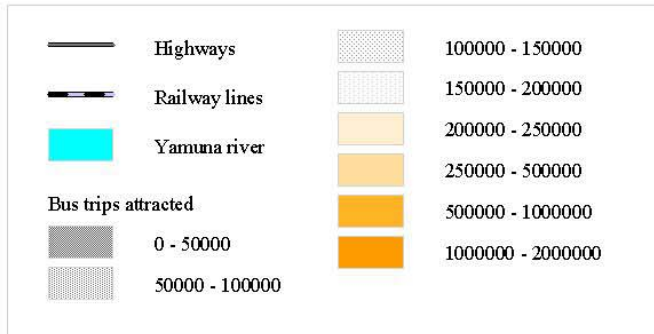
Scenario 1



Scenario 3



Scenario 2



# Defining “shortfall”

The share of transit trips that will be generated (attracted) by ward are:

- Share of trips generated = Function (Per cent high income households, Distance to CBD, Residential density)
- Share of trips attracted = Function (Employment)

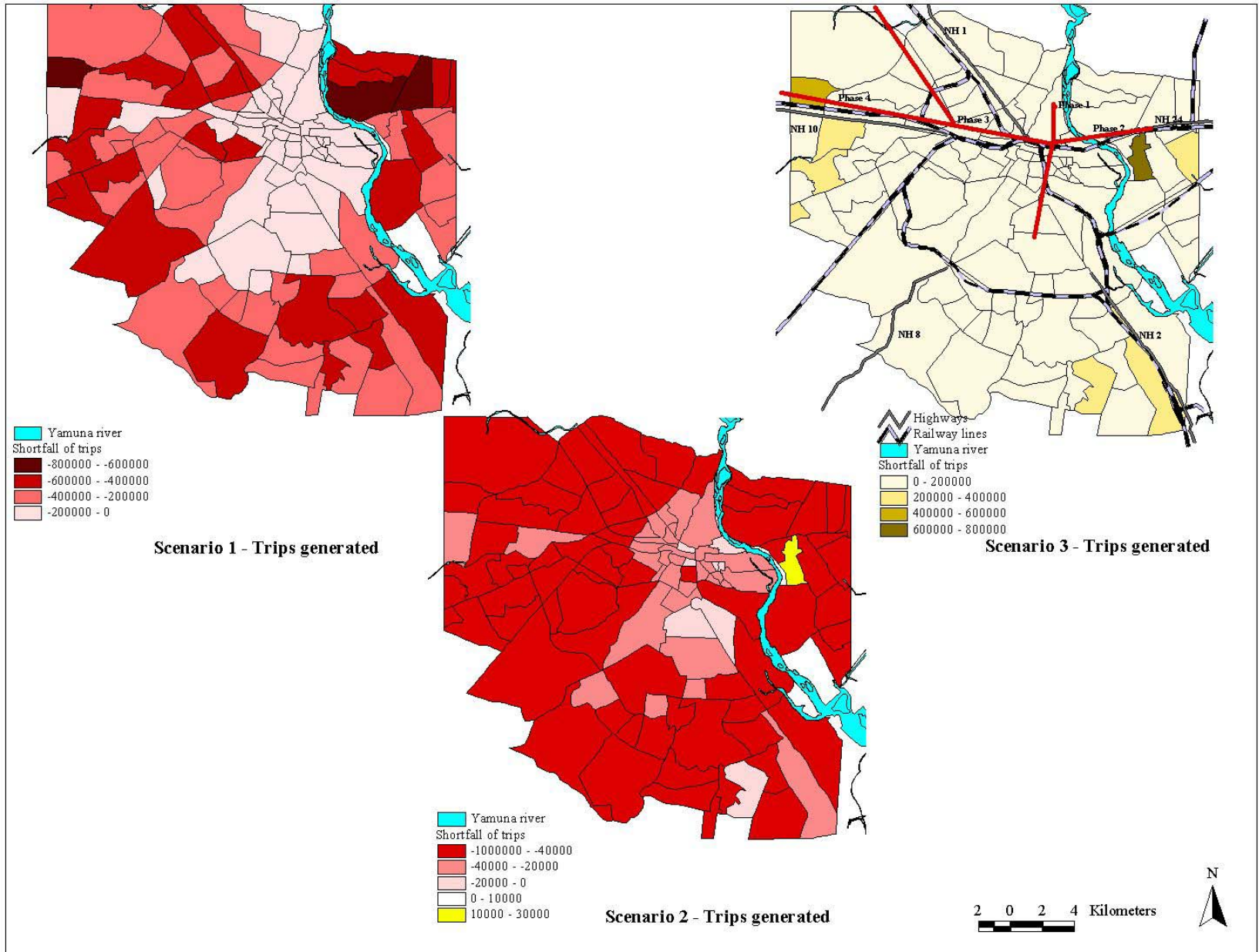
The transit trips that need to be generated (attracted) by ward are:

- [Share \* Total trips generated(or attracted)]

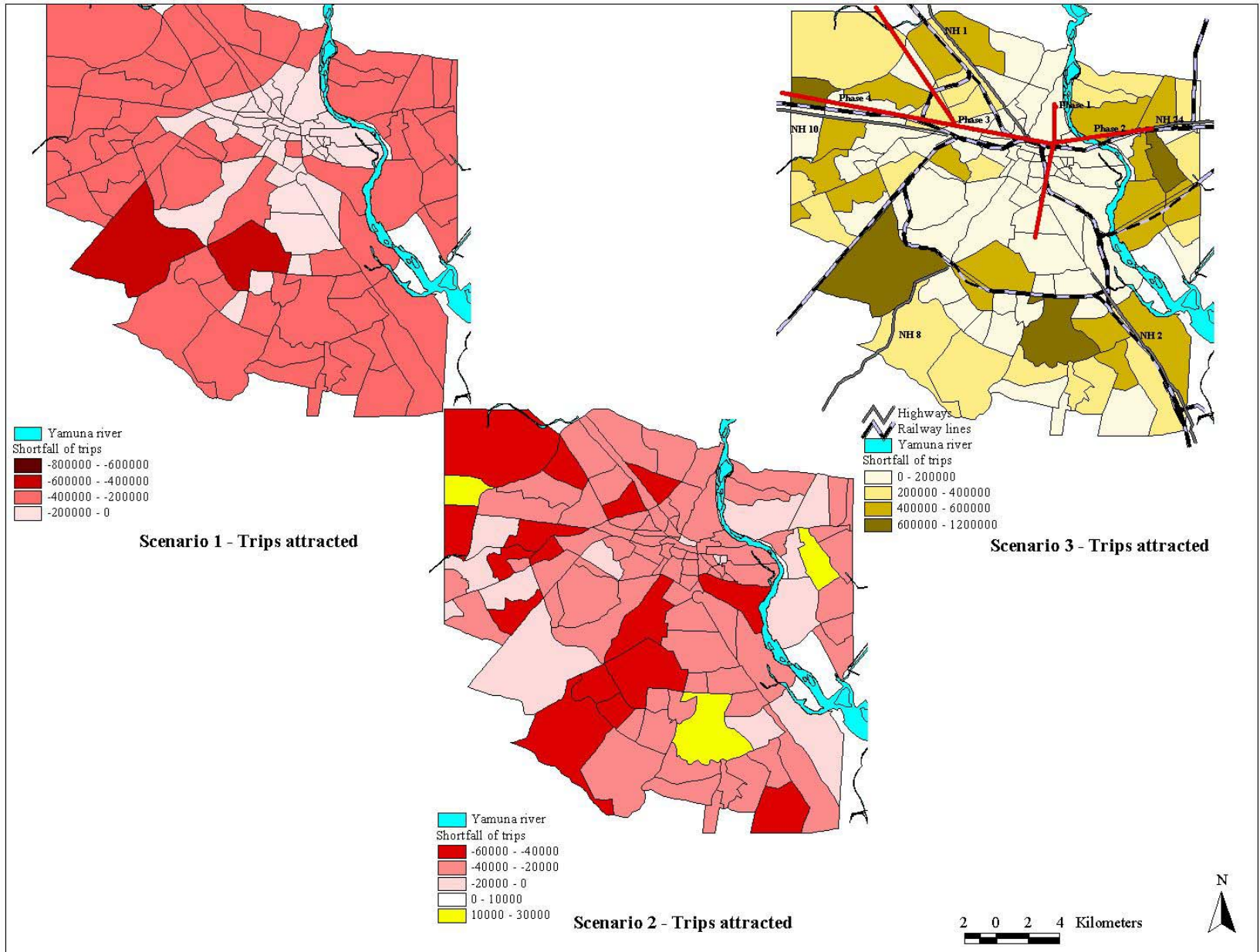
The shortfall of transit (bus) trips by ward:

- [Passenger trips that will be demanded (based on Sarna) – Passenger trips needed (based on Kokaz et al)]

# Delhi bus trips generated (shortfalls)



# Delhi bus trips attracted (shortfalls)



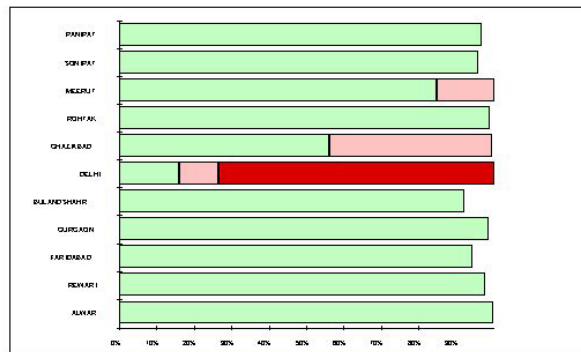
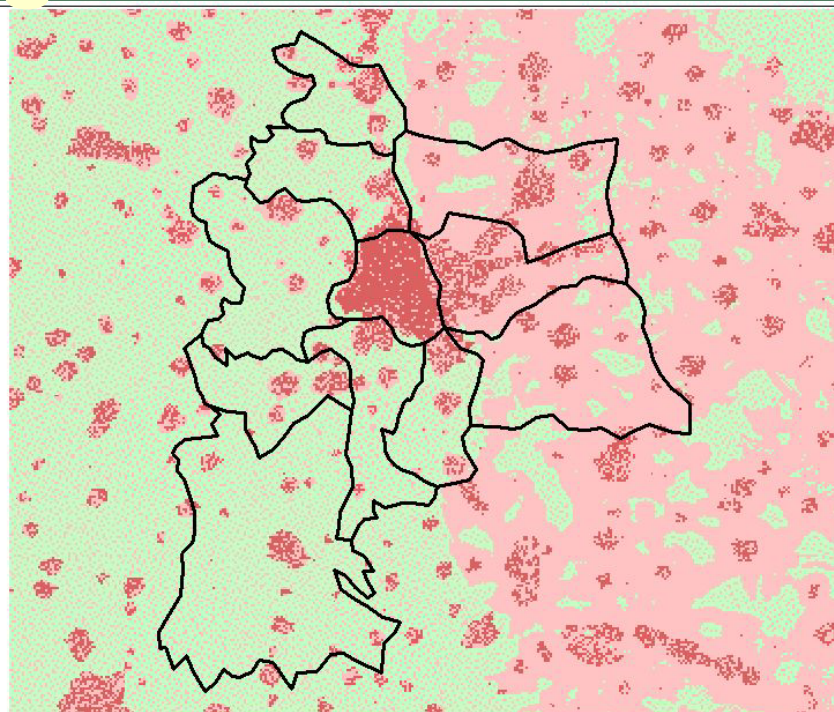
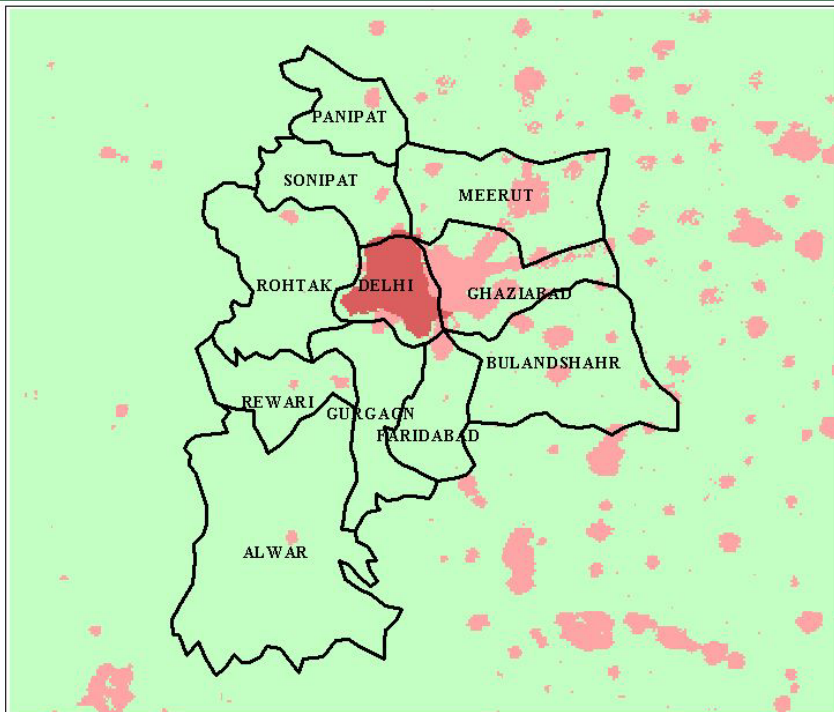
# Delhi results summary

- Land use will intensify in outer wards and along highways which will push trips generated and attracted to the periphery
- Even with conservative land use and trip generation forecasts it is evident that for the increased bus scenarios (1 and 2) there will be a shortfall in the outer wards (which spill over to the neighboring states which are suburbs of Delhi)
- In the business-as-usual scenario supply will exceed demand for bus trips
- In all cases, the subway currently being built will operate in areas that do not generate or attract most transit trips

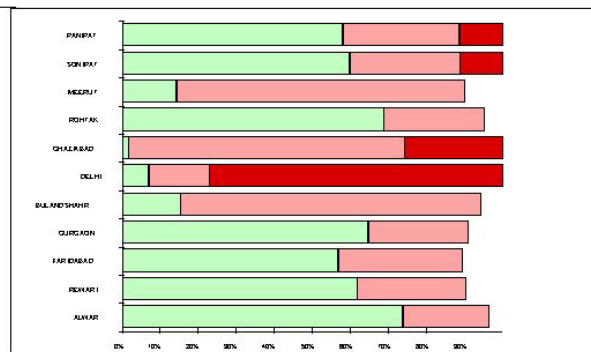
# NCR forecast methodology

- A cellular automaton/ Markov model was used with 1960 and 1995 data to generate data for 2030
- The model generates future land use intensity (rural, suburban and urban) based on suitability derived from proximity to highways, railroads, existing urban use and agricultural potential
- This forecast is combined with the OD study conducted by the National Capital Regional Planning Board forecasts of trip generation

# NCR land use change



1998



2030

NCR districts

Population density

Rural (<1000 per sq km)

Suburban (1000-5000 per sq km)

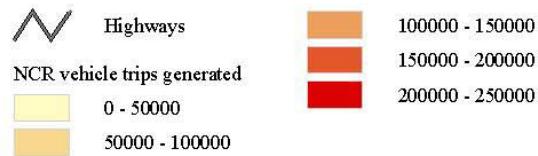
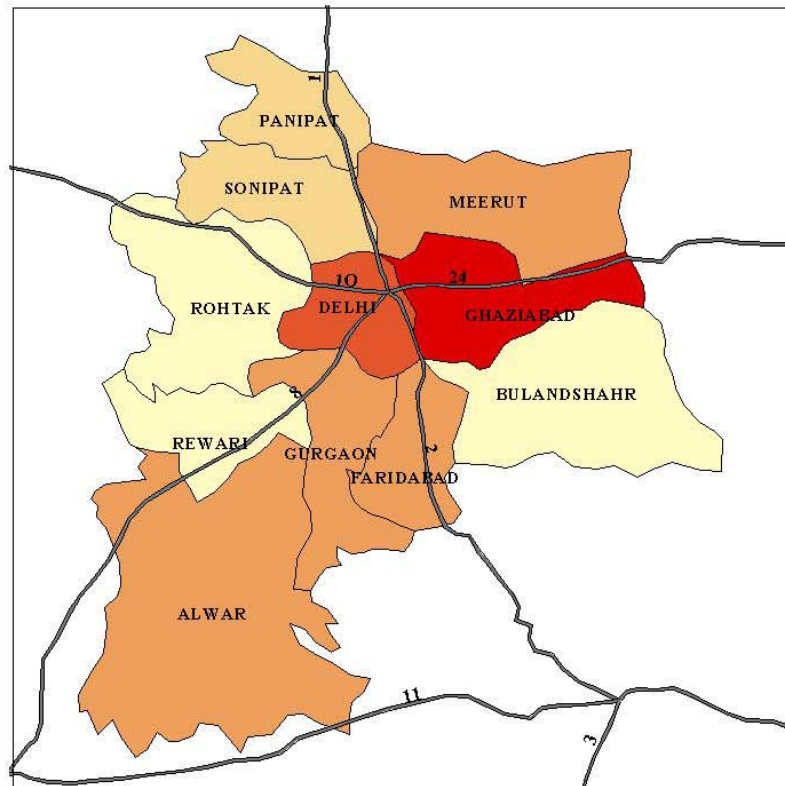
Urban (> 5000 per sq km)

Population density

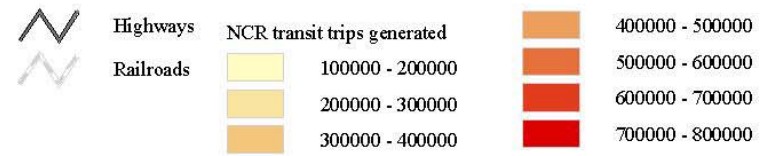
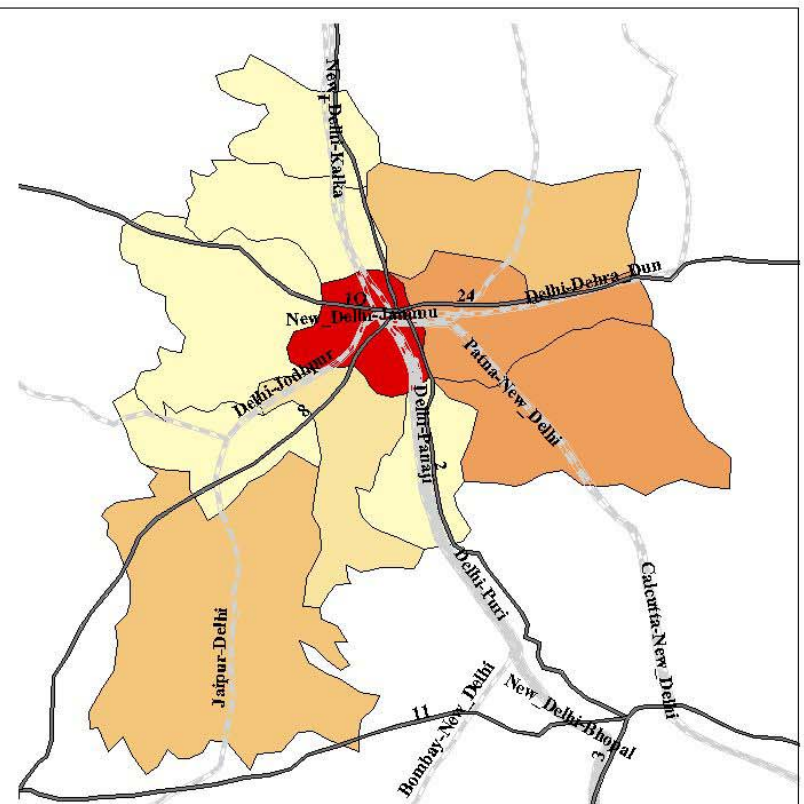
50 0 50 Kilometers



# NCR inter-district trips generated



Vehicle trips generated (excluding trucks)



Transit trips generated

50 0 50 Kilometers



# NCR results summary

- Land use change at current rates will create a mega city by 2030
- The implications for increases in intra-district travel are obvious
- Inter-district travel will also increase as the Delhi district intensifies to commercial/office type use and the neighboring districts begin to function as suburbs
- Inter-district truck movement will also be of concern

# Implications for planning

1. There are two levels at which transportation and land use planning must be coordinated – the local ward level and the regional level
2. Current transportation policy appears to be focused purely on increasing mobility using highly aggregated data
3. Accessibility to employment (and services) needs to be the focus of transportation policy and it needs to be disaggregated to at least the ward level if not the individual level
4. Data, disaggregated to the individual or ward level, remains a primary concern

# Future directions

## 1. Better data

- Motivating data collection by agencies involved in planning for the city and region
- Creating unifying mechanisms to share data between agencies

## 2. Better models

- Use of remote sensing data to create better land use change and land use intensification models
- Link land use and optimization models to create a seamless decision support model for policy makers
- Link models to air quality models to indicate spatial locations that will be of concern

## 3. Better research and policy linkages

- Create links between concerned planning agencies (NCRPB, DDA, TCPO, etc) and research institutions (CRRI, IIT, NIC, etc)

# Project webpage:

<http://www.deas.harvard.edu/TransportAsia/>

