Use of GIS in road sector analysis

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Transport Forum and Learning Week 2007
Transport Measurement Matters – Indicators of Performance and Impact
Geographic information

- Using an explicitly spatial perspective in the analysis of transport data
- Why bother? Benefits of GIS
- Example application – Mozambique
- Comparison with other approaches (surveys)
- Implications
Geographic information systems

- GIS: set of tools and techniques to manipulate geographically referenced data ("digital maps")
- Data capture
- Data integration
- Data visualization
- Data analysis
Data integration:
GIS provides a platform for many types of information

- Tabular data
- Maps
- Pictures & multimedia
- Air photos & satellite images
Data integration

Geographic location provides the frame of reference: “space as an indexing system”
Data capture

- Traditionally from paper maps (digitizing, scanning)
- Increasingly from up-to-date remote sensing images or collected using global positioning systems
- [www.road-management.info](http://www.road-management.info)
- Direct link from spatial data to extensive attribute information
- Very little excuse for countries not to georeference their road management systems
Example application for Mozambique: Computing simple rural access indicators (with Kavita Sethi, AFTTR)

• Data inputs
  – geographically referenced road network indicating type of road
  – rural village locations with basic demographic indicators

• Analytical approach
  – compute for each village the distance to the nearest road of any type in the network
  – repeat process for different types of roads
  – aggregate rural population figures by distance bands around roads and compute summary measures
Road network in Mozambique
## Types of road in the GIS database of the road network in Mozambique

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of segments</th>
<th>Length in GIS database (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>316</td>
<td>5,869</td>
</tr>
<tr>
<td>Secondary</td>
<td>191</td>
<td>4,792</td>
</tr>
<tr>
<td>Tertiary</td>
<td>490</td>
<td>12,161</td>
</tr>
<tr>
<td>Vicinal</td>
<td>260</td>
<td>6,530</td>
</tr>
<tr>
<td>Other</td>
<td>184</td>
<td>4,979</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,441</strong></td>
<td><strong>34,331</strong></td>
</tr>
</tbody>
</table>

*These figures are summarized from the GIS database and may not exactly match government statistics!*
Overall population density (and protected areas)
Distribution of rural villages

Note: no data for one district in Zambezia
For each village we determine the distance from various types of roads
An estimated 20% of the rural population lives within 5 km of a primary road. About 70% live within 5 km of any road.
## Cumulative percent of rural population by distance from various types of roads

<table>
<thead>
<tr>
<th>Distance in km</th>
<th>Primary road</th>
<th>Secondary or better</th>
<th>Tertiary or better</th>
<th>Vicinal or better</th>
<th>Any road</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>8.2</td>
<td>12.3</td>
<td>21.6</td>
<td>26.2</td>
<td>28.7</td>
</tr>
<tr>
<td>1 - 2</td>
<td>11.6</td>
<td>17.8</td>
<td>31.8</td>
<td>38.3</td>
<td>41.5</td>
</tr>
<tr>
<td>2 - 3</td>
<td>14.6</td>
<td>22.0</td>
<td>39.5</td>
<td>47.1</td>
<td>50.7</td>
</tr>
<tr>
<td>3 - 4</td>
<td>17.6</td>
<td>26.4</td>
<td>46.9</td>
<td>55.4</td>
<td>59.4</td>
</tr>
<tr>
<td>4 - 5</td>
<td>20.0</td>
<td>29.9</td>
<td>53.1</td>
<td>62.7</td>
<td>67.0</td>
</tr>
<tr>
<td>5 - 6</td>
<td>22.5</td>
<td>33.5</td>
<td>58.2</td>
<td>68.4</td>
<td>72.8</td>
</tr>
<tr>
<td>6 - 7</td>
<td>25.2</td>
<td>37.1</td>
<td>63.6</td>
<td>73.3</td>
<td>77.5</td>
</tr>
<tr>
<td>7 - 8</td>
<td>27.9</td>
<td>40.7</td>
<td>68.4</td>
<td>77.5</td>
<td>81.6</td>
</tr>
<tr>
<td>8 - 9</td>
<td>30.4</td>
<td>44.0</td>
<td>72.5</td>
<td>81.1</td>
<td>84.7</td>
</tr>
<tr>
<td>9 - 10</td>
<td>31.9</td>
<td>46.2</td>
<td>75.6</td>
<td>83.8</td>
<td>87.1</td>
</tr>
</tbody>
</table>
Cumulative percent of rural population by distance from *any* type of roads by province

<table>
<thead>
<tr>
<th>Province</th>
<th>&lt;1</th>
<th>1 - 2</th>
<th>2 - 3</th>
<th>3 - 4</th>
<th>4 - 5</th>
<th>5 - 6</th>
<th>6 - 7</th>
<th>7 - 8</th>
<th>8 - 9</th>
<th>9 - 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niassa</td>
<td>45.1</td>
<td>54.5</td>
<td>60.3</td>
<td>65.7</td>
<td>70.8</td>
<td>75.1</td>
<td>78.7</td>
<td>81.4</td>
<td>83.8</td>
<td>86.0</td>
</tr>
<tr>
<td>Cabo Delgado</td>
<td>41.9</td>
<td>50.0</td>
<td>59.0</td>
<td>65.2</td>
<td>69.7</td>
<td>74.1</td>
<td>78.5</td>
<td>82.6</td>
<td>87.1</td>
<td>89.5</td>
</tr>
<tr>
<td>Nampula</td>
<td>20.3</td>
<td>33.5</td>
<td>45.1</td>
<td>55.2</td>
<td>63.8</td>
<td>72.0</td>
<td>77.2</td>
<td>82.7</td>
<td>86.0</td>
<td>89.1</td>
</tr>
<tr>
<td>Zambezia</td>
<td>22.6</td>
<td>35.6</td>
<td>44.3</td>
<td>53.6</td>
<td>61.8</td>
<td>67.3</td>
<td>72.2</td>
<td>77.2</td>
<td>81.0</td>
<td>83.7</td>
</tr>
<tr>
<td>Tete</td>
<td>32.4</td>
<td>42.4</td>
<td>51.3</td>
<td>61.0</td>
<td>67.8</td>
<td>72.4</td>
<td>77.9</td>
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<td>85.1</td>
<td>87.2</td>
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<td>Manica</td>
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<td>46.3</td>
<td>52.1</td>
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</tr>
<tr>
<td>Sofala</td>
<td>26.7</td>
<td>40.2</td>
<td>46.6</td>
<td>55.8</td>
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<td>74.1</td>
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</tr>
<tr>
<td>Inhambane</td>
<td>30.5</td>
<td>46.8</td>
<td>56.8</td>
<td>65.1</td>
<td>74.9</td>
<td>81.8</td>
<td>86.3</td>
<td>90.4</td>
<td>92.0</td>
<td>92.8</td>
</tr>
<tr>
<td>Gaza</td>
<td>30.3</td>
<td>45.3</td>
<td>54.0</td>
<td>64.5</td>
<td>72.5</td>
<td>81.8</td>
<td>87.0</td>
<td>88.7</td>
<td>91.1</td>
<td>93.9</td>
</tr>
<tr>
<td>Maputo</td>
<td>39.5</td>
<td>55.6</td>
<td>71.0</td>
<td>78.3</td>
<td>84.3</td>
<td>91.2</td>
<td>93.5</td>
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<td>96.3</td>
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</tr>
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Some of the most densely settled provinces have the lowest share of population within 2km from any road in our network!
Some of the most densely settled provinces have the lowest shares of population within 2 km from any road in the network!

blue villages – within 2 km of a road
red villages – further than 2 km
Estimating the length of the ("hidden") rural road network in Mozambique

- Many villages in Mozambique are more than 2km from an existing road that is part of the official national and regional road network.

- However, these villagers must get to markets and towns somehow.

- That means there must be a network of feeder roads and trails that connect remote villages to the official network that is not captured in official national level road information data sets.

- We estimate a lower bound for the total length of this feeder road network using a simple GIS based algorithm.

- Results for a portion of Mozambique are shown in the next slide.
Blue dots = villages
Black lines = existing network
Red lines = imputed access links
Estimating the length of the (“hidden”) rural road network in Mozambique

- Lower bound for the rural feeder road network of 28,000 km (compared to 34,000 km of national and regional roads)

- Lower bound because it connects villages by straight lines and because it ignores non-essential connections, e.g., between villages that connect to different parts of the network in our solution

- Estimates are “minimum concrete” solution, not necessarily the welfare-maximizing. I.e., there may be trade-offs where a less optimal solution provides large time or cost savings to certain villages
Estimating the length of the ("hidden") rural road network in Mozambique

- A somewhat smaller estimate of total feeder road length would be obtained if all villages only need to be within 2 km of a regional or national road (future analysis)

- Ideally, these synthetic estimates could be compared to spatial information on actual feeder road networks

- One could do a GPS survey in a few areas of the country or obtain high resolution satellite data in which feeder roads should be visible
Possible extensions to Mozambique analysis

• Differentiate by road quality
  – primary roads may be paved, gravel, earth, or “unknown”

• Consider different population characteristics
  – is there a link between basic demographic factors and distance from roads
    (e.g., significant shortage/surplus of working age men/women could point to rural labor shortages in the most marginal areas)?
Possible extensions (cont.)

• Look at possible effects of access / remoteness
  – is distance to roads related to poverty?
  – do we see different cropping patterns / economic activities as a function of distance to roads (econ./agric. census or surveys)
  – … (many other possible questions)
Possible extensions (cont.)

• Identify major gaps in the road network
  – high population concentrations with no close access to all weather roads

• Estimate alternative access measures
  – estimated travel time to nearest market, school, clinic using reasonable assumptions about travel speeds on different road and surface types
  – simulate effects of road upgrading (as opposed to new roads)
  – It’s not access to roads that matters, but access to points of interest (services, markets, etc.)!
Estimated poverty headcount rates by Posts

Data source: Ken Simler (IFPRI) & Virgulino Nhate (MPF, Maputo)
Based on 1997 Census and 1996-97 Mozambique National Household Survey of Living Conditions
Distribution of the estimated number of poor

Each dot represents 1000 poor persons (dots are placed randomly within each Posto unit)

Data source: Ken Simler (IFPRI) & Virgulino Nhate (MPF, Maputo)
Based on 1997 Census and 1996-97 Mozambique National Household Survey of Living Conditions
Cumulative percent of poor population by distance from various types of roads

Not too different from total rural population (may be aggregation problem since poverty data are available only at the admin post level)
Comparison: GIS approach

Pros

• Great flexibility in combining data sets to improve estimates or generate new indicators

• Eliminates some forms of respondent error

• Facilitates scenario analysis (e.g., effect of new road placement)

• Visualization can offer additional insights, new hypotheses

Cons

• Requires accurate and complete (!) data sets that are too often unavailable

• Some non-standard technical expertise required
## Comparison: Use of survey data

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Allows asking very specific questions</td>
<td>• Well documented problems with non-random respondent error (judging time, distance; knowledge of facilities)</td>
</tr>
<tr>
<td>• Links to rich behavioural, welfare and other household level information</td>
<td>• Difficult to integrate with other spatial data unless survey is georeferenced</td>
</tr>
<tr>
<td>• Analysis using standard techniques (DBMS, stats package)</td>
<td>• Limited spatial disaggregation</td>
</tr>
</tbody>
</table>
However:

• Surveys *versus* GIS is a false trade-off

• In reality we want to combine the rich detail of a (georeferenced) household survey with the completeness and contextual information of georeferenced roads, census and other information
Implications

• Georeferenced road management system as a central component in a national spatial data infrastructure (SDI)

• [www.gsdii.org](http://www.gsdii.org) (regional newsletters)

• Common framework data, standards, data sharing agreements, etc.

• Tremendous synergies from being able to integrate data across sectors
Thank you