PRIORITIZATION OF ROAD INTERVENTION IN NAMPULA AND ZAMBEZIA, MOZAMBIQUE

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March 2017
Objective: Improve rural accessibility and agriculture production...
... Despite recurrent floods
Where should we invest and which type of intervention is best?
Based on a LAC Regional Study*, we built a tool to:

1) Prioritize districts where investments will have the highest impact
   a. Criticality: proximity to ag potential, lack of redundancy, poverty
   b. Risk: exposure and vulnerability to floods

2) Choose which investment are the most robust in each of the chosen districts
   a. Cost-benefit analysis accounting for benefits in terms of risk reduction and ag productivity
   b. Stress-test to find the investment which have high NPV under many future conditions

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• Rozenberg, Julie; Briceno-Garmendia, Cecilia M.; Bonzanigo, Laura; Moroz, Harry Edmund. 2017. Improving the resilience of Peru's road network to climate events. Washington, D.C.: World Bank Group
1) Prioritize districts where investments will have the highest impact
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Redundancy

Requires building a model of the road network
Identification of Nodes

- Agriculture Production Clusters
- Population Clusters
- Seaports
- Airports
- Crossing borders
Updated Road Network

Using RoadLabPRO app!
Giving Attributes to the Road Network

- HDM4 to assign user cost and travel speeds based on road condition (IRI)
- Simple TDM to allocate traffic between nodes

Traffic allocation based on simple model:

\[ T_y = \frac{A_y F_y K_y}{\sum_{i=1}^{n} A_x F_x K_{ix}} \times P_i \]
Identification of critical links based on redundancy
Identification of critical links based on redundancy

### Baseline OD matrix

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>...</th>
<th>Dn</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1</td>
<td>0</td>
<td>120</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>O2</td>
<td>120</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On</td>
<td>60</td>
<td>50</td>
<td></td>
<td>0</td>
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</table>

### Disrupted OD matrix

<table>
<thead>
<tr>
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<th>D2</th>
<th>...</th>
<th>Dn</th>
</tr>
</thead>
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<tr>
<td>O1</td>
<td>0</td>
<td>150</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>O2</td>
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<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On</td>
<td>70</td>
<td>50</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

### Disruption cost

Difference between ODs

Based on least cost routes

**Disruption cost =** Difference between ODs

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>...</th>
<th>Dn</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1</td>
<td>0</td>
<td>30</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>O2</td>
<td>30</td>
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<td>0</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On</td>
<td>10</td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Identification of critical links based on redundancy
1) Prioritize districts where investments will have the highest impact

- Redundancy
- Ag/fishery potential
- Current ag production
- Poverty

Criticality

Requires building a model of the road network

For the other criteria we overlay the network with other maps
Identification of critical links based on current ag production

Data from Agriculture Ministry 2015/16

Data from the National Statistics Institute - census 2010/11

Data from IFPRI SPAM model
Identification of critical links based on current ag production
Identification of critical links based on poverty maps
Identification of critical districts all criteria combined
1) Prioritize districts where investments will have the highest impact
We overlay the road network with current and future exposure to flood.

Flood maps based on:
- Past rainfall events
- Climate Change future projections (low, medium and high scenarios)
- 10 return periods: 5, 10, 25, 50, 75, 100, 200, 250, 500 and 1000
We estimated the flood vulnerability of each link

- Using existing Bridge Inventory Attributes
- Estimating condition of culverts
- Using simple damage functions (from local expertise)
- Using local cost and standard of rehabilitation and repair (from local expertise)
Risk is expressed as expected annual damage to the infrastructure

\[ EAD = \frac{1}{2} \sum_{i=1}^{n} \left( \frac{1}{T_i} - \frac{1}{T_{i+1}} \right) (D_i + D_{i+1}) \]

Where \( T_i \) is the \( i^{th} \) return period, and \( D_i \) is the damage to the infrastructure corresponding to \( T_i \).
1) Prioritize districts where investments will have the highest impact
We integrate criticality and risk

Prioridade
1. Maganja
2. Lugela
3. Morrumbala
4. Pebane
5. Chinde
6. Ile
7. Gurue
8. Nicoadala
We selected five districts as priority in each province.
2) Choose which investment are the most robust in each of the chosen districts

- This economic analysis will be included in the PAD.
  - It is used to choose which investment is best rather than justify a choice ex-post
  - It systematically accounts for uncertainties and looks for robustness
Traditional Planning
Asks “What Will The Future Bring?”

“Traditional Planning”

What will the future be?

What is the best near-term decision?

How sensitive is our decision to our prediction?

Works well when:

• Conditions are stable or easy to predict

• There is consensus among stakeholders
Decision Making Under Uncertainty Runs the Analysis Backwards

"Predict Then Act"

What will the future be?  →  What is the best near-term decision?  →  How sensitive is our decision to our predictions?

Decision Making Under Uncertainty (DMU)

What are the available strategies?  →  Identify vulnerabilities of these strategies  →  Develop strategy adaptations to reduce vulnerabilities
Pre-identification of combinations of investments

During a workshop local stakeholders chose, for each district, several combinations of:

- Upgrade to surface treatment
- Upgrade to gravel road
- Partial reconstruction of earth roads
- Clean and repair bridges
- Replace culverts
Cost-benefit analysis under uncertainty

Benefits (over 20yrs):  
• Reduction of flood damage to infrastructure (EAD)  
• Reduction of flood disruption cost for users (EAUL)  
• Maintenance Savings  
• Reduction of road user cost  

Costs (over 20yrs):  
• Initial capital cost  
• Maintenance expenditure  

Uncertainties:  
• Climate projections: current, low, medium and high  
• Flood duration, -50% to 50%  
• Traffic growth, 0 to 6%  
• Traffic growth to agriculture increase elasticity, 0.5 to 1.5  
• Discount rate, 3 to 12%  
• Repair time, -50% to 50%  
• Capital Cost, -50% to 50%  
• Bridge Repair, -50% to 50%
# Murrumbala – Investment Options

<table>
<thead>
<tr>
<th>RoadID</th>
<th>Paving</th>
<th>Gravel</th>
<th>Partial Rehab</th>
<th>Bridge</th>
<th>Culverts</th>
<th>Initial Capital Cost</th>
<th>Life-Cycle Cost (Median)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N322</td>
<td></td>
<td></td>
<td>others</td>
<td></td>
<td></td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>R652</td>
<td></td>
<td></td>
<td>others</td>
<td></td>
<td></td>
<td>15</td>
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<td>others</td>
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<td>all</td>
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<td>R650 and R652</td>
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<td>others</td>
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<tr>
<td>others</td>
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<td></td>
<td>R650 and R652</td>
<td></td>
<td></td>
<td>18</td>
<td>29</td>
</tr>
</tbody>
</table>
Murrumbala – Benefits breakdown

Inv. 1: Paving of 45km + partial rehabilitation of 551km

Inv. 2: Paving of 66km + partial rehabilitation of 530km

Inv. 3: Upgrade all culverts, clean and repair all bridges + partial rehab of 596km

Inv. 4: Graveling of 213km + partial rehab of 383km

Inv. 5: Graveling of 383km + partial rehab of 213km
Investment 3 (bridges and culverts) is the best option in 98% of scenarios and has a BCR >1 in 95%.

It has the highest saved trips/dollar ratio.

Minimax regret option.
Murrumbala – Stress-test results

• Investment 3 (bridges and culverts) has a BCR >1 in 95%.
  – Stress-test: in 5% of the scenarios Inv. 3 can have a BCR<1. Those are scenarios with high discount rate (>11%), low cost of (reactive) bridge repair (40% lower than current estimates) and high bridge construction cost (>45% of current estimates). It is highly unlikely to see those conditions met together so the we are confident the BCR of Inv. 3 will always be >1.

• Second best option is Inv. 2 (paving R652). It has a BCR >1 in 40% of scenarios. Second-best saved trips ratio. Lowest regret after Inv. 3.
  – Stress-test: it will have BCR<1 for medium and high climate change.
Summary of best investments if we give the same budget to each district

<table>
<thead>
<tr>
<th>Province</th>
<th>District</th>
<th>Investment Description</th>
<th>Robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zambezia</td>
<td>Murrumbala</td>
<td>Clean and repair all bridges and upgrade all culverts</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Maganja</td>
<td>Clean and repair bridges in N324</td>
<td>Medium (good only if climate change is high)</td>
</tr>
<tr>
<td></td>
<td>Pebane</td>
<td>Clean and repair bridges in N324 + upgrade all culverts</td>
<td>High for Inv 4, medium for inv 3</td>
</tr>
<tr>
<td>Nampula</td>
<td>Membra</td>
<td>Clean and repair all bridges and upgrade all culverts</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Namapa/Erati</td>
<td>Clean and repair all bridges and upgrade all culverts</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Monapo</td>
<td>Paving R700 &amp; R1153 + Clean and repair all bridges and upgrade all culverts</td>
<td>Very high for Inv 4, medium for Inv 3 (good only if traffic growth is high)</td>
</tr>
</tbody>
</table>
Summary of best investments if we prioritize over the province
Summary of best investments if we prioritize over the province

Isolated Trips sorted by MINMAX - Zambezia

Million Trips

Million USD

Inv 1B Murrumbala
Inv 3 Murrumbala
Inv 2 Maganja
Inv 1 Maganja
Inv 4 Murrumbala
Inv 5 Murrumbala
Inv 4 Pembe
Inv 5 Pembe
Inv 2 Pembe
Inv 3 Pembe
Inv 4 Maganja
Inv 5 Maganja
Conclusion and Next steps

• This tool helped
  – Prioritize districts where transport investments should yield the highest benefits
  – Choose the most robust combinations of investments between several pre-defined ones

• As a next step we want to guide decision makers at the national level without having to pre-define investment portfolios
  – We will build an optimization model at the country level
  – Use DMDU to optimize under uncertainty or stress-test the “optimal” solutions