Resilience in Urban Networks
Assessing Freetown’s transportation system under meteorological hazards

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Objective

Planning from the accessibility perspective from neighborhoods to Education and Health facilities taking into account the demand or limited capacity into these facilities.

Explore vulnerability of neighborhoods and services both Seasonal disruptions and Major hazards.
"Resilience" has various meanings

How systems resist, absorb, adapt, transform, and recover after stress or disasters.

We view “resilience” as the flipside of “vulnerability” to hazards.

Diminishing vulnerability increases resilience.
Part I

• Identify vulnerable and critical roads

• Simulate hazard scenarios and test road intervention sites
Estimating Risks

**Input:** Hydrological and Geological Risk Factors

**Output:** Hazard for river flooding, landslides, mudslides, sea level rise, and storm surge

**Geological Risk Factors**
- Mudslide
- Landslide

**Hydrological Risk Factors**
- Riverine Flooding
- Coastal Flooding
We developed a project with 3 key goals:

1. IDENTIFY KEY NODES
2. SIMULATE SCENARIOS
3. TEST IMPACT OF WORLD BANK PROJECTS

Resilience in the Freetown Road Network incl. how demand might change for projects if disaster happens and the network balance shifts.
Network Science Analysis

KEY CONCEPT: BETWEENNESS CENTRALITY
Quantifies the number of times a node lies on any shortest paths in the graph, including every possible pair of origin and destination points. Its calculation is given by:

BC serves as a strong measure of how important each node is for all origin-destination node pairs within the transportation network.
Through matrix, we select scenarios
Estimated Changes in the Road Network

**Centrality Gain**
- 0 - 0.05
- 0.05 - 0.10
- 0.10 - 0.15
- 0.15 - 0.20
- 0.20 - 0.25
- 0.25 - 0.30
- 0.30 - 0.35
- 0.35 - 0.40
- 0.40 - 0.45

**Centrality Loss**
- 0 - -0.05
- -0.05 - -0.10
- -0.10 - -0.15
- -0.15 - -0.20
- -0.20 - -0.25
- -0.25 - -0.30
- -0.30 - -0.35
- -0.35 - -0.40

- Roads
- Land/Sea Interface
For current interventions

- Intervention: Wallace J. Street Multi-Level Car Park
- Guard Street
- Junction Improvement: King Harman Road
- Junction Intervention: Congo Cross
- Junction Intervention: Kissy Ferry Terminal
- Intervention: Allen Town Transit Market
- Junction Intervention: Lumley Circle Car Park
- Intervention: Lumley Community Transit Market
Impacts of current developments

Changes in Betweenness

The importance of certain projects changes significantly during hazard scenarios

• Allen Town Transit Market
• Lumley
Part II

- Quantify Vulnerability as the Access to Key Facilities Service Area such as Schools and Health Centers

- Apply state of the art Climate Projection methods
Accessibility via Road Network - Schools
Flood Model Method from US Army Corps of Engineers’ free software: HEC-HMS, HEC-RAS, and their related plug-ins for use with ArcMap

Integrates satellite images with ancillary information from GIS to do a hydraulic simulation model
Part III

- Calculate trip demand informed by Call Detailed Records (CDRs)

- Focus vulnerability analysis on streets serving transit system
Call detailed records: Trip Production and Attraction

Within each of these regions, blue and red dots indicate the

net attraction: (trips received - trips generated)
or
net production: (trips generated - trips received)

Using CDR-based OD matrix in the morning peak
Road Classification adding CDR weights

We identify the road facilities which represent the top 10% highest values in all metrics (Critical, black), and the varying combinations of these metrics which also result.
Transit Routes

![Map of Transit Routes]

**Mode**
- Commercial Bus
- Taxi
- Poda Poda
- Ferry
Flooding Scenario on Transit Routes

Transit corridor on Western Area shown as most critical in terms on enhancing climate resilience of Freetown urban mobility.
Conclusions and Discussion

• This methods has:
  • Identify needs for climate resilience on urban mobility
  • Determine accessibility constraints to critical social services
  • Incorporate real transport demands with CDR
  • Define priority for transit corridor improvements from resilience angle

• Future: We will incorporate 2015 Census data to add an additional equity component – poverty
Thank you very much for your attention!

Questions or Comments?
Appendix
Demand and Accessibility Shifts
Vulnerability Metrics
Seasonal Risks
Population Centers

• Population sources are defined by centers of ~3000 people
Key Location Types

- Schools
- Hospitals
- Health Centers
- Pharmacies

Resilience in the Freetown Road Network
Accessibility measures per center (H, HC)

Resilience in the Freetown Road Network
Accessibility measures (P, Sch)
EXPANDING THE SCOPE: New data

New Data & New Opportunities

• Data Source 1:
  Multi-hazard event maps plus modeling techniques identify major weather hazards (major floods and Landslides)

• Data Source 2:
  Local university collaboration identifies minor weather hazards, temporary flooding and water accumulation on unpaved roads
S. Figure 1: Method: Neighborhood Generation, a) Neighborhood population size; b) Freetown CBD detail
S. Figure 2: Neighborhood Generation and Accessibility Calculation: Distribution of neighborhood distance to health facilities
S. Figure 3: Demand Distribution: a) Senior Secondary Schools (n = 208); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 4: Demand Distribution: a) Junior Secondary Schools (n = 353); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 5: Demand Distribution: a) Primary Schools (n = 746); b) Freetown Central Business District Detail; c) Distribution with fit

(a) Primary Schools (n = 746)
(b) Freetown Central Business District Detail
(c) Distribution with fit

- Top 10
- Empirical
- Exponential Fit: f(x) = 5.32e^{-6.32x}

1st Quartile: [0, 0.1] CP = 6.5%
2nd Quartile: [0.1, 0.2] CP = 15.4%
3rd Quartile: [0.2, 0.3] CP = 26.2%
4th Quartile: [0.3, 1.1] CP = 51.9%
S. Figure 6: Demand Distribution: a) Pre-Primary Schools (n = 532); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 7: Demand Distribution: a) Hospitals (n = 44); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 8: Demand Distribution: a) Health Centers (n = 164); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 9: Demand Distribution: a) Pharmacies (n = 50); b) Freetown Central Business District Detail; c) Distribution with fit
S. Figure 10: Demand, Size of service areas compared to population served: a) Education facilities; b) Health Facilities
S. Figure 11: Road Importance Process - Service Centrality for: a) health facilities, b) education facilities, and c) all facilities
S. Figure 12: Combining Service Centrality and Global Connectivity in the road network allows road segments to be categorized by anticipated usage: a) road categories in Western Area Urban and Western Area Rural; b) Freetown CBD detail; c) scatterplot of service centrality and edge betweenness centrality of network edges.
S. Figure 13: Seasonal Flooding Hazard Extent, a) Areas with slope of less than five degrees; b) Sinks, or areas with no outlet for drainage, c) Union of 11a) and 11b), representing the extent of expected seasonal flooding risk
S. Figure 14: Scenario 1 Results: a) Demand shifts for affected Health Centers; b) Health Center accessibility shifts for affected neighborhoods; c) Distribution of Health Centers accessibility shifts for affected neighborhoods
S. Figure 15: Scenario 1 Results: a) Demand shifts for affected Pharmacies; b) Pharmacy accessibility shifts for affected neighborhoods; c) Distribution of Pharmacies accessibility shifts for affected neighborhoods
S. Figure 16: Scenario 1 Results - Road Network (Major Flooding Hazard), a) Non-zero changes in service centrality and distribution; b) Non-zero changes in edge betweenness centrality and distribution