Criticality Analysis Results of Bangladesh Road Transport Network

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1. Overview of metrics

There are several metrics used for analyzing the criticality of the road transport network as shown in Figure 1. Different metrics are employed since each metric has its own real-world implication and real-world representation. Eventually, each metric will give different insights for decision makers.

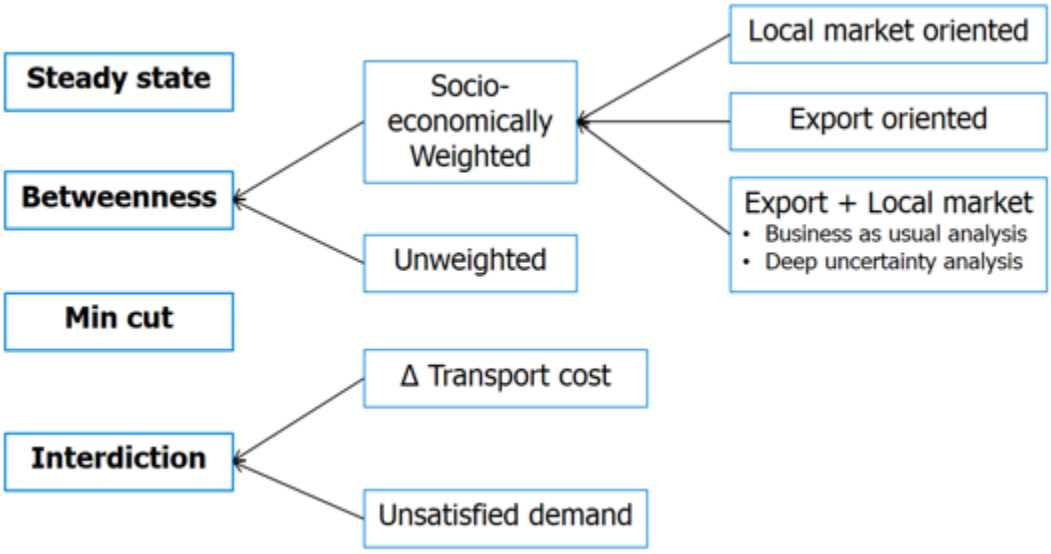

Figure 1 Criticality Metrics Overview

a. Steady state criticality
   Steady state criticality measures the empirical traffic flow of the road network. Specifically, AADT (Annual Average Daily Traffic) of small, medium and large trucks data taken from Bangladesh's Roads and Highway Department database is used for indicating the busyness of the roads.

b. Betweenness criticality (Socio-economically weighted)
   Betweenness criticality adopts betweenness centrality measure in graph theory body of knowledge. Given transport flows between all OD (origin-destination) pairs in Bangladesh, betweenness criticality measures the percentage of the total flows which goes through a particular road segment. The flows between all OD pairs are socioeconomically weighted in three ways: flows for local consumption within Bangladesh, flows for export through land ports and sea ports, and combination between the two. Betweenness criticality gives insight on the magnitude of trucks that have to find detour route if a particular road segment is disrupted.

c. Betweenness criticality (Unweighted)
The third metric is similar to the second one. However, in this metric the centrality is not weighted (i.e. all OD pairs have precisely same flows). The main purpose for this metric is to give 'equal opportunity' to all districts, thus the results do not give higher importance to districts with higher population or higher economic activities.

d. Minimum edge cut criticality
Minimum edge cut criticality is adopted from graph theory body of knowledge as well. A minimum edge cut for each OD pair is the minimum combination of edges (in this case road segments) which if removed from the network will completely disconnect the OD pair. Therefore, this metric provides information about critical edges which if removed may disconnect a lot of OD pairs.

e. Interdiction criticality
The last metric tries to understand the impact of the disruption to the overall total transport cost which is calculated in ton-kilometer. Interdiction technique removes each edge independently one by one, then recalculate the total transport cost everytime each edge is removed. The edge which if removed increases the total transport cost the most, since a lot of trucks have to make long detour, becomes the most critical road segment. Another sub-metric that can be calculated is the magnitude of the unsatisfied demand if a particular edge is removed, which is derived from the magnitude of flows between OD pairs that become disconnected after an edge is disrupted.

2. Criticality results

2.1 Steady state criticality

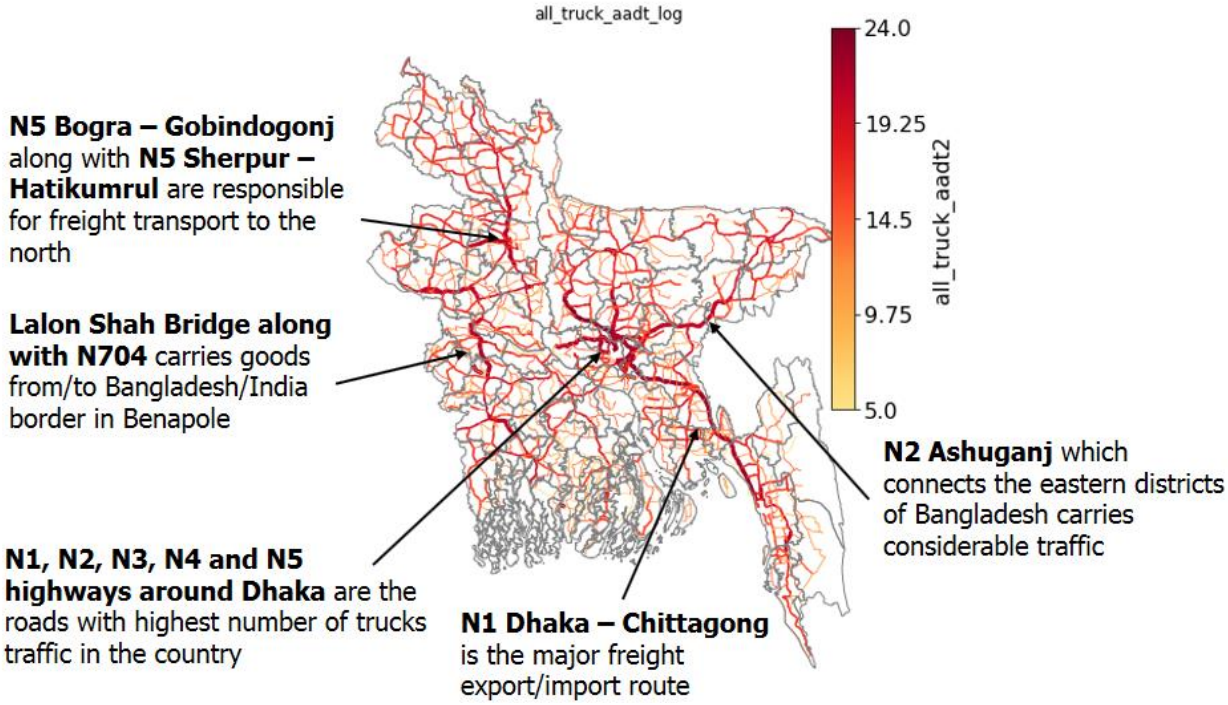

Figure 2 Logarithmically Scaled Trucks AADT

The results of the steady state criticality analysis, as well as the most critical roads are highlighted in Figure 2. As expected, we see that roads around Dhaka and N1 which connects Dhaka and Chittagong come out as the most critical road segments. A more complete list of this criticality metrix can be found in Appendix A.

2.2 Betweenness criticality (Socio-economically weighted)

Three different metrics are derived from the socio-economically weighted betweenness centrality: local market flow based, export market flow based, and combination between the two. Figure 3 to Figure 5 show the overall results of these three metrics. As expected, we can see high criticality on roads around Dhaka due to Dhaka's high population. N1 road that connects Dhaka to Chittagong is also a vital element from this perspective, since this road is the main connector between Chittagong port to all other districts. Furthermore, Bangabandhu bridge on N405 and Lalon shah bridge on N704 are two bridges which carry highest traffic in Bangladesh. A full list of top fiftenn road segments based on these metrics can be found in Appendix B.

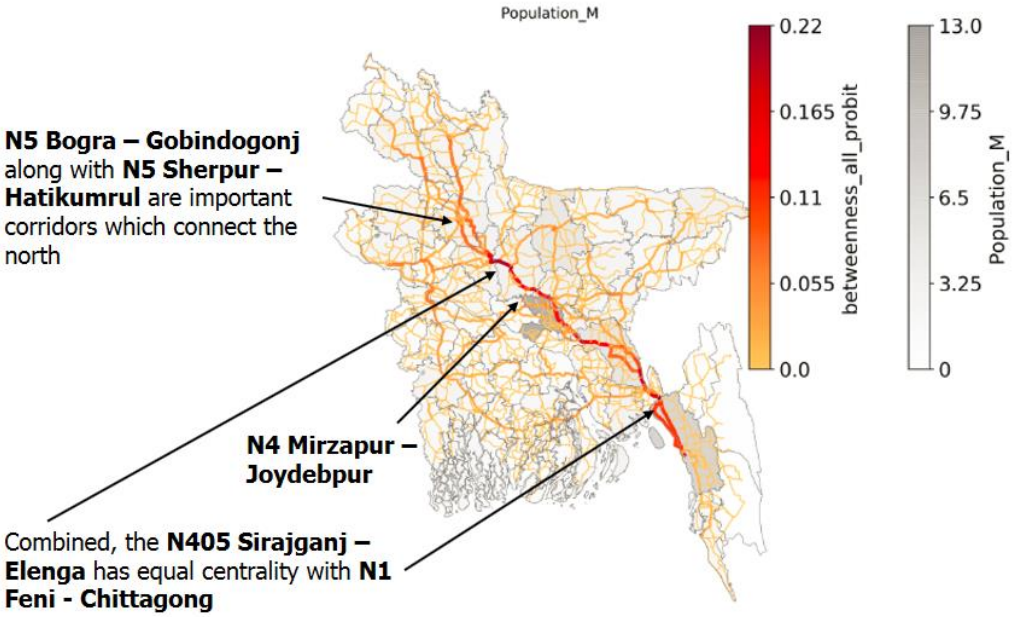

Figure 3 Socioeconomically Weighted Betweenness Centrality (Local + Export)

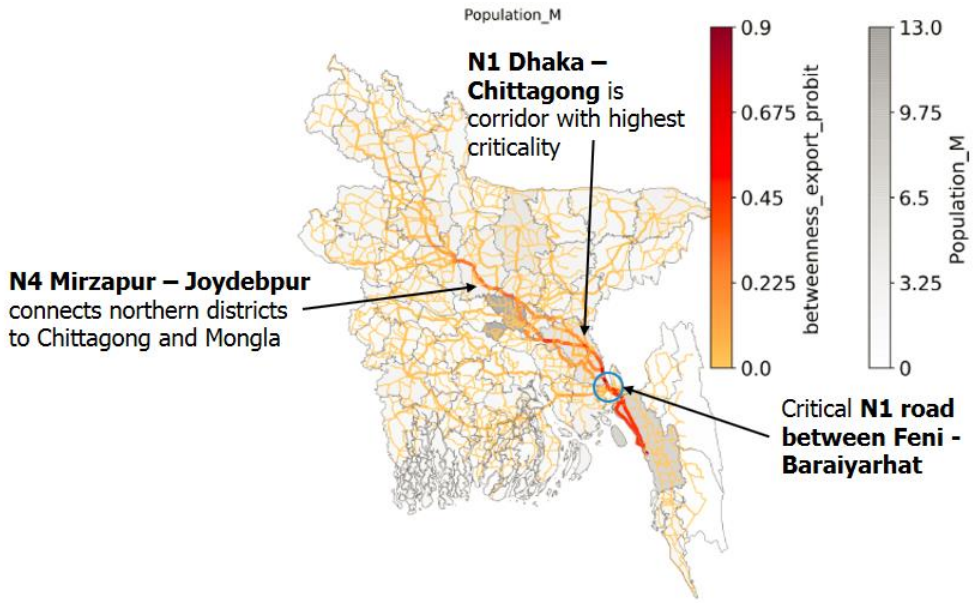

Figure 4 Socioeconomically Weighted Betweenness Centrality (Export)

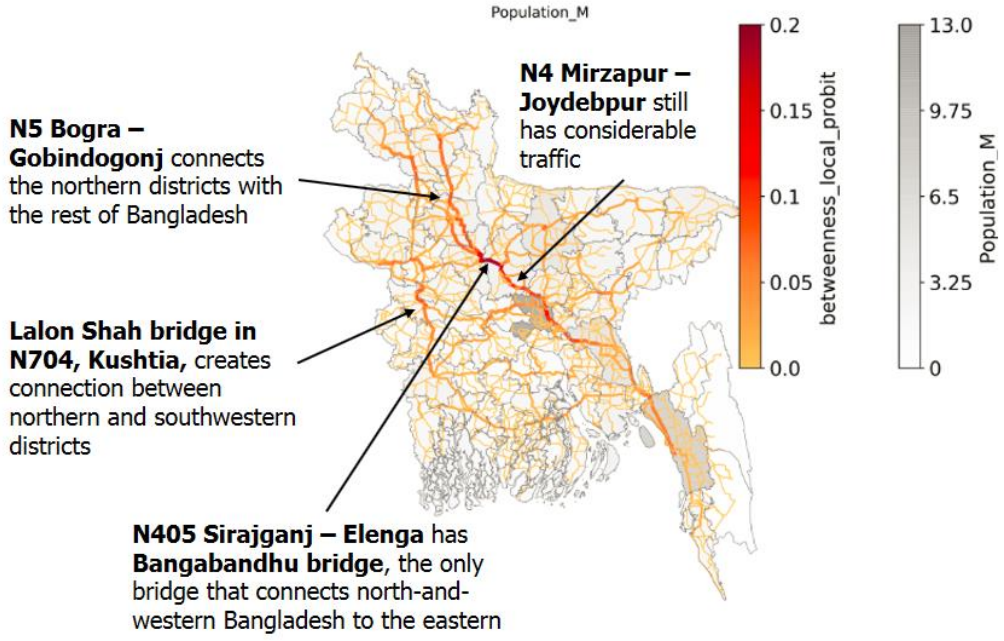

Figure 5 Socioeconomically Weighted Betweenness Centrality (Local)

2.3 Betweenness criticality (Unweighted)

Figure 6 displays unweighted betweenness criticality result where all districts are weighted equally regardless of their socioeconomic profile. We can observe that similar pattern like socio-economically weighted betweenness criticality of local-based market flows. This result emphasizes the importance of Bangabandhu and Lalon shah bridges as the main connectors between regions which are separated by Padma and Brahmaputra river. Furthermore, N1 and N4 roads around Dhaka still become important roads in the central part of Bangladesh. This shows that these roads are the shortest path route which connects

various districts which are located far apart. The top fifteen road segments with highest unweighted betweenness criticality can be found in Appendix C.

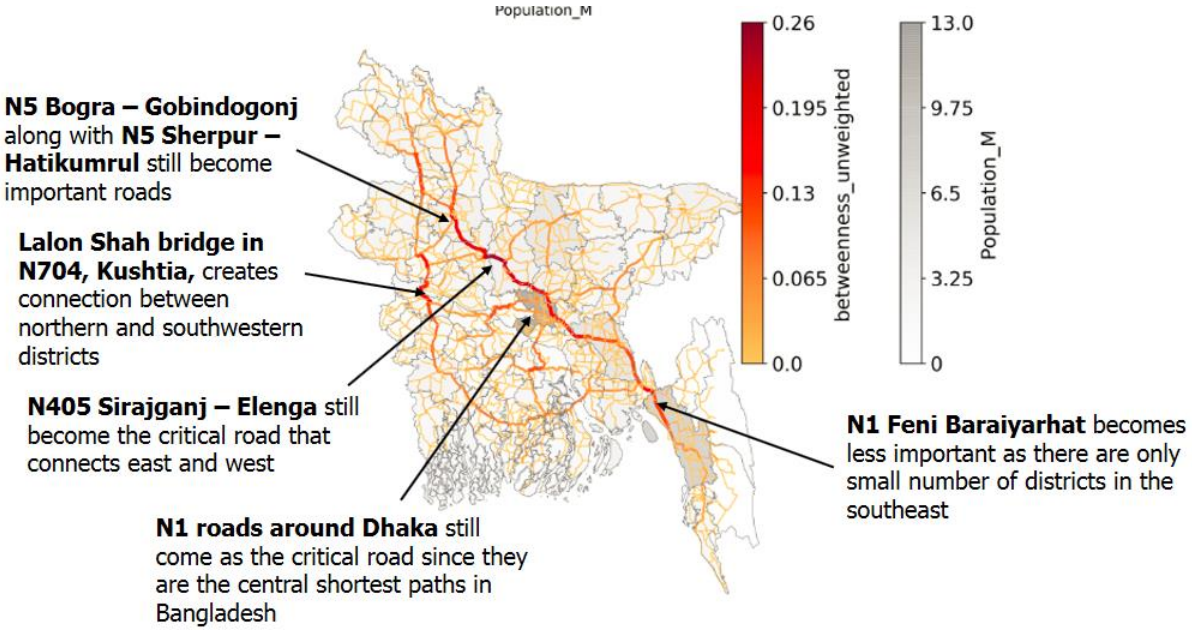

Figure 6 Unweighted Betweenness Centrality

2.4 Minimum edge cut criticality

By using minimum edge cut criticality measure, as can be seen in Figure 7, we can identify small road segments which if disrupted simultaneously may cause high degree of disconnection. These small segments are ubiquitous in southern districts, showing that the southern districts are substantially vulnerable if the roads there are disrupted. A small chunk of N102 road in Brahmanbaria is also identified as critical since this segment is the main element that connects districts in the far east. List of top fifteen road segments with highest minimum edge cut criticality can be found in Appendix D.

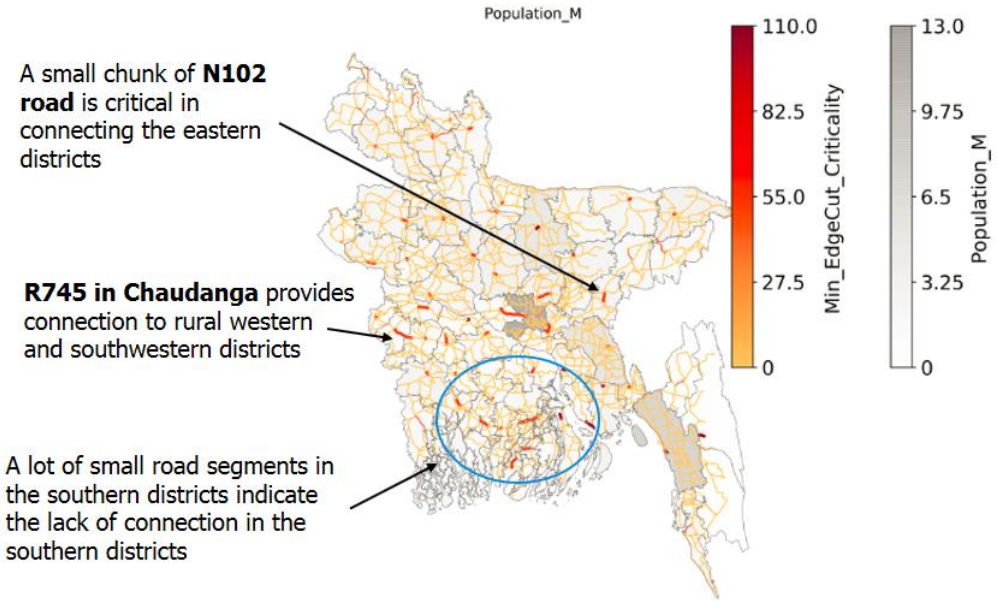

Figure 7 Minimum Edge Cut Criticality

2.5 Interdiction criticality

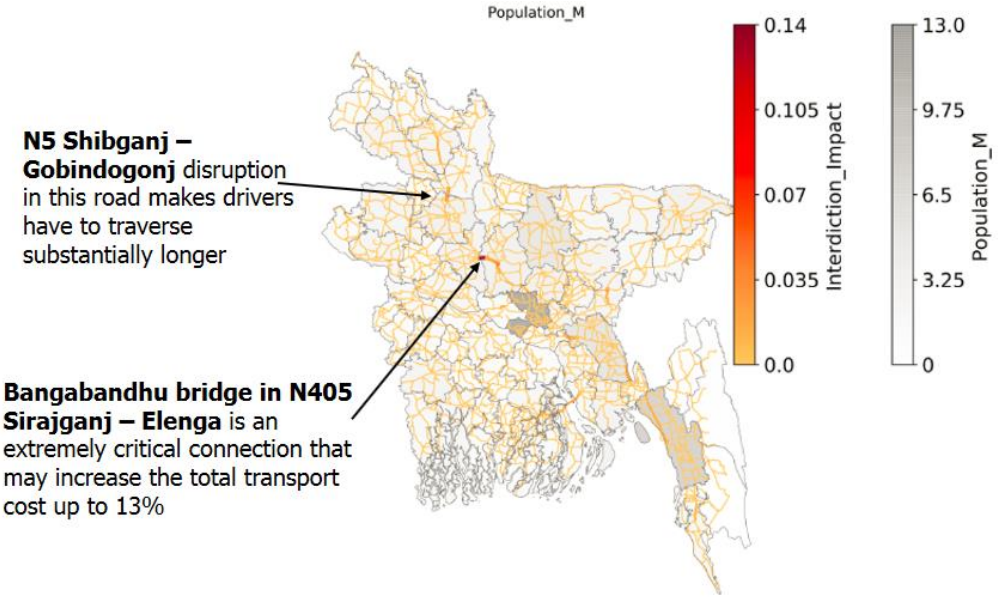

Figure 8 Increase in Total Cost from Interdiction Technique

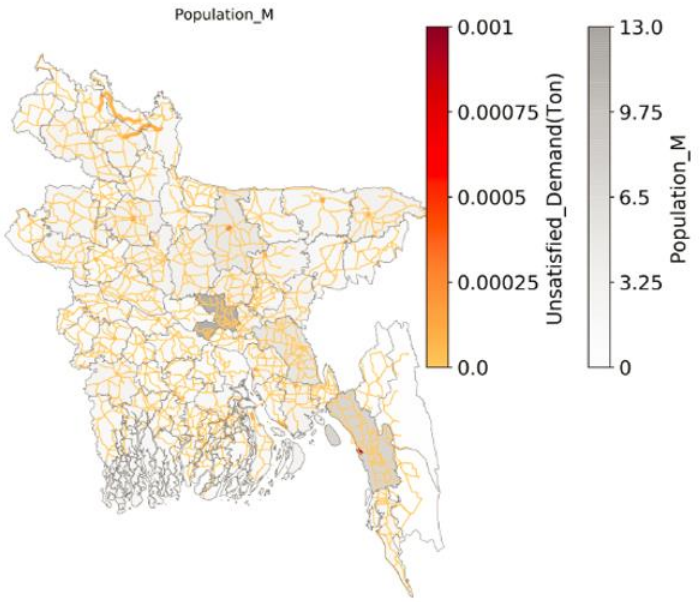

Figure 9 Unsatisfied Demand from Interdiction Technique

Interdiction technique systematically remove each road segment one by one independently, then calculate the increase of the system's total cost and the magnitude of the unsatisfied demand due to the removal. From Figure 8, it is observed that Bangabandhu bridge on N405 is the single source of failure in the system. Disruption on this bridge may increase the total transport cost up to 13%. Beside this bridge, none of the road segment will create substantial increase in total transport cost if disrupted individually. The unsatisfied demand result shown in Figure 9 shows insignificant amount of unsatisfied demand if any single road segment is disrupted. This shows the robustness to single disruption of Bangladesh's road transport network as no significant disconnection between any district will happen if only one road segment is removed from the network. A more complete list of road segments with highest increase in total cost from interdiction technique can be found in Appendix E.

3 Discussions and conclusion

We have analyzed the criticality of Bangladesh's road network from different perspectives by employing seven metrics in total. The analysis shows that the way at which criticality is defined and operationalized highlights different road segments as critical. Focusing only a single metric will lead to incomplete insight of overall functioning of the transport network. Therefore, it is important for decision makers to decide their goal before deciding final prioritization from the criticality results.

In general, if resources are limited, Bangladesh government have two main options: securing aggregate economic growth or improving accessibility of remote districts in the far-east, north and southwest. If the first one is preferred, results from socio-economically weighted betweenness criticality and interdiction criticality may be used. In this case, N1 road segment between Feni – Baraiyarhat and Bangabandhu bridge in N405 are of particular interest, since they handle extensive amount of freight transport from and to Chittagong port in the south. Otherwise, unweighted betweenness criticality and minimum edge cut criticality can be utilized for the second option. Accordingly, N102 road in Brahmanbaria, and N704 road in Kushtia become the most critical ones.

Another deliberation that we observed from this exercise is that Bangladesh is very Dhaka-centric in terms of population and garment industry, and very Chittagong-centric in terms of export and import. Consequently, an enormous amount of goods, especially food products, from all over the countries is transported to Dhaka for feeding people and maintaining and sustaining garment production. An even larger portion of goods are transported to Chittagong for export. This makes roads which provide connections to these districts even more critical. We see that in the medium term, the expansion of Mongla port is a promising intervention in order to disperse export and import goods transport flow.

Appendix A: Steady state criticality top 15 road segment

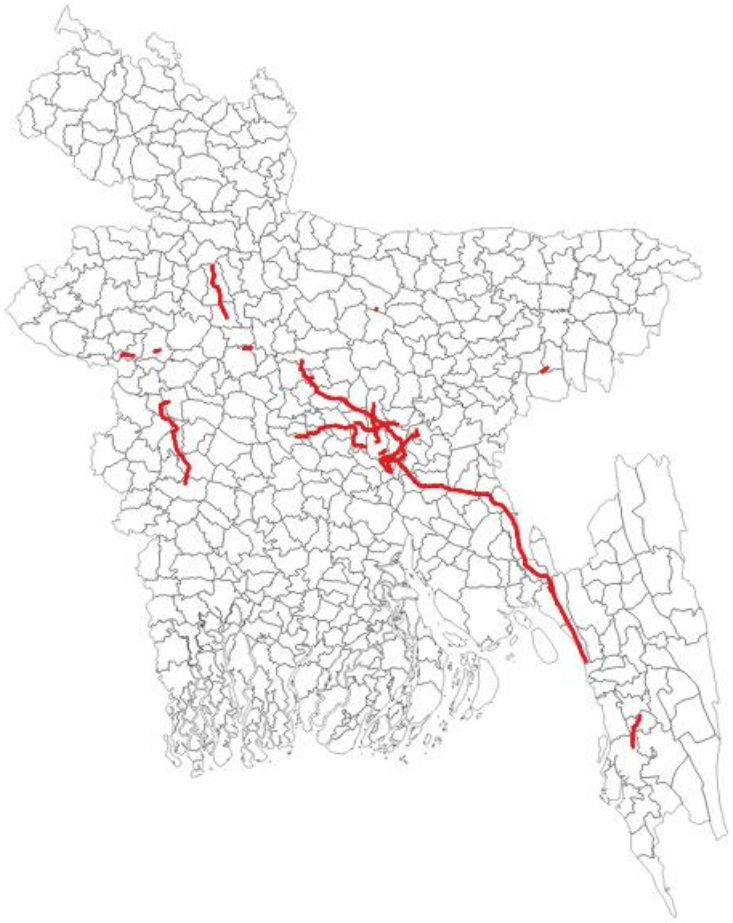

Figure 10 Road Segment with Trucks AADT >3400

Table 1 Top 15 Road Segments with Highest Steady State Criticality

Rank	Road	Trucks AADT	Location
1	N4	10804	Dhaka
2	N1	8617	Dhaka
3	N1	7982	Gazaria - Daudkandi
4	N2	6815	Narayanganj
5	N405	5833	Bangabandhu bridge
6	N5	5364	Savar, Dhaka
7	N105	5216	Sonargaonj, Narayanganj district
8	N2	5090	Ashuganj
9	N5	4853	Sherpur - Bogra
10	R810	4345	Narayanganj

11	R110	4237	Narayanganj
12	N704	4045	Lalon Shah bridge, Kushtia - Mirpur
13	R301	3812	Narsingdi - Gazipur
14	N3	3764	Gazipur, Dhaka
15	N6	3401	Natore - Puthia

Appendix B: Socioeconomically weighted betweenness criticality

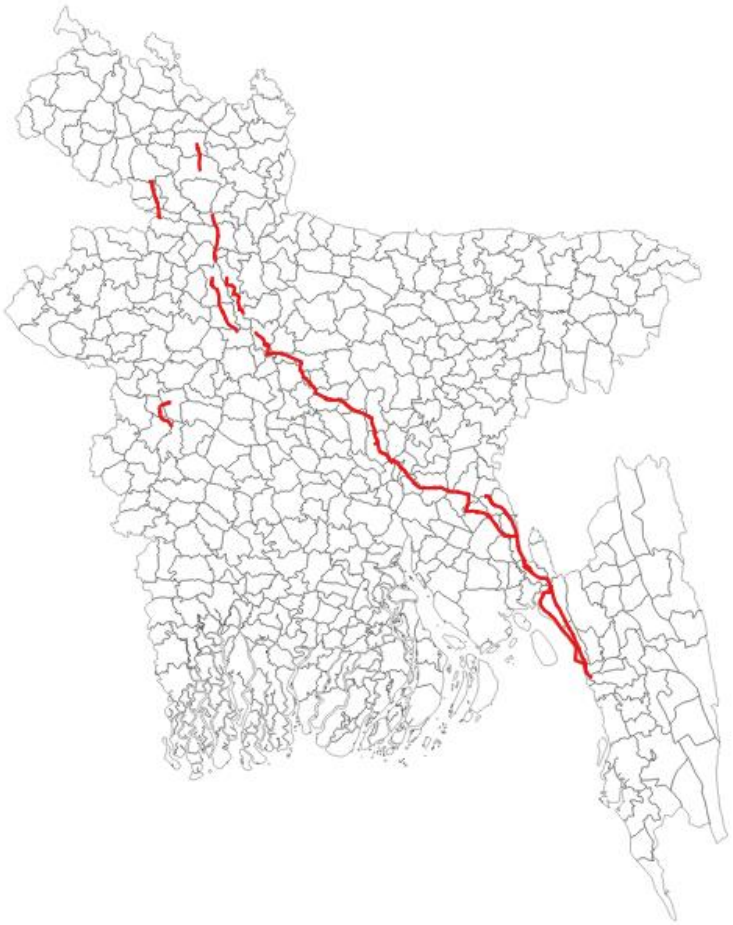

Figure 11 Road Segments with Betweenness Centrality (Local + export flows) > 0.065

Table 2 Top 15 Road Segments with Highest Betweenness Criticality (Local + Export flows)

Rank	Road	Betweenness Criticality (All)	Location
1	N1	0.215	Feni - Baraiyarhat
2	N405	0.213	Bangabandhu bridge
3	N1	0.154	Munshiganj - Comilla
4	N4	0.152	Mirzapur

5	N3	0.143	Tejgaon, Dhaka
6	N1	0.135	Chandina - Daudkandi, Comilla
7	R112	0.124	Tejgaon, Dhaka
8	N4	0.12	Gazipur - Kalikair
9	N1	0.106	Chittagong
10	N5	0.087	Shibganj, Bogra district
11	N517	0.085	Rangpur
12	N5	0.082	Sherpur
13	N5	0.077	Pirganj - Rangpur
14	Z5503	0.068	Hakimpur
15	N704	0.067	Lalon shah bridge, Kushtia

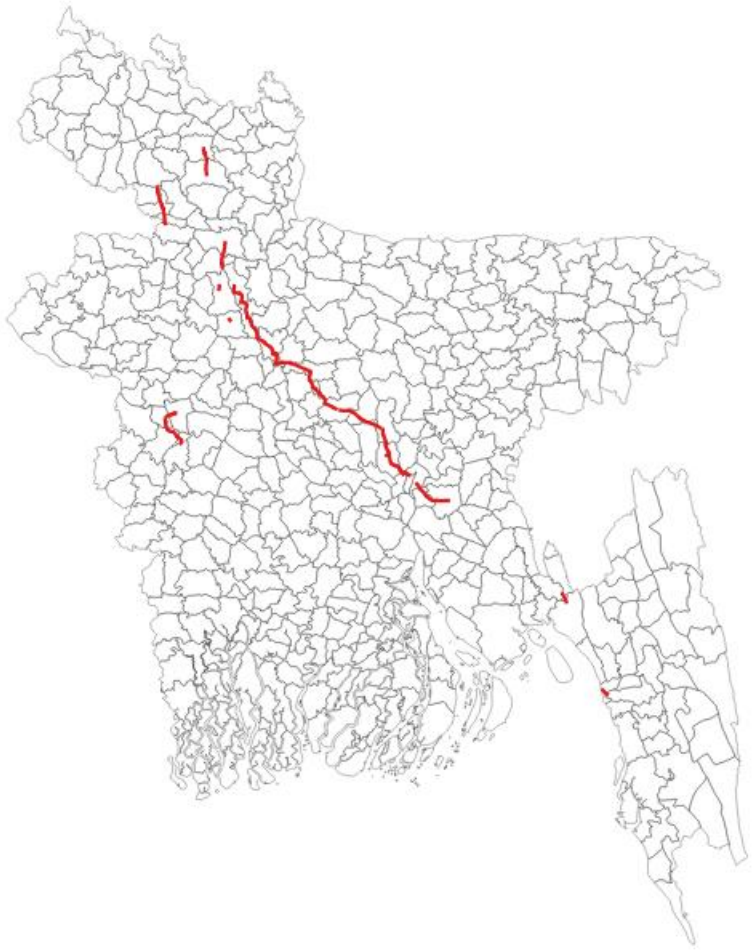

Figure 12 Road Segments with Betweenness Centrality (Local flows) > 0.069

Table 3 Top 15 Road Segments with Highest Betweenness Criticality (Local flows)

Rank	Road	Betweenness Criticality (Local)	Location
1	N405	0.196	Bangabandhu bridge
2	R450	0.146	Sirajganj
3	N3	0.123	Tejgaon, Dhaka district
4	N4	0.116	Tangail
5	N4	0.115	Kaliakair, Gazipur district
6	R112	0.096	Tejgaon, Dhaka district
7	N4	0.089	Mirzapur
8	N517	0.089	Rangpur
9	N1	0.084	Feni - Baraiyarhat
10	N1	0.084	Daudkandi - Gazaria
11	N5	0.077	Shibganj - Gobindaganj
12	N704	0.077	Lalon shah bridge, Kushtia
13	Z5072	0.074	Dhunat, Bogra
14	Z5503	0.072	Hakimpur, Dinajpur
15	R585	0.069	Birampur - Phulbari

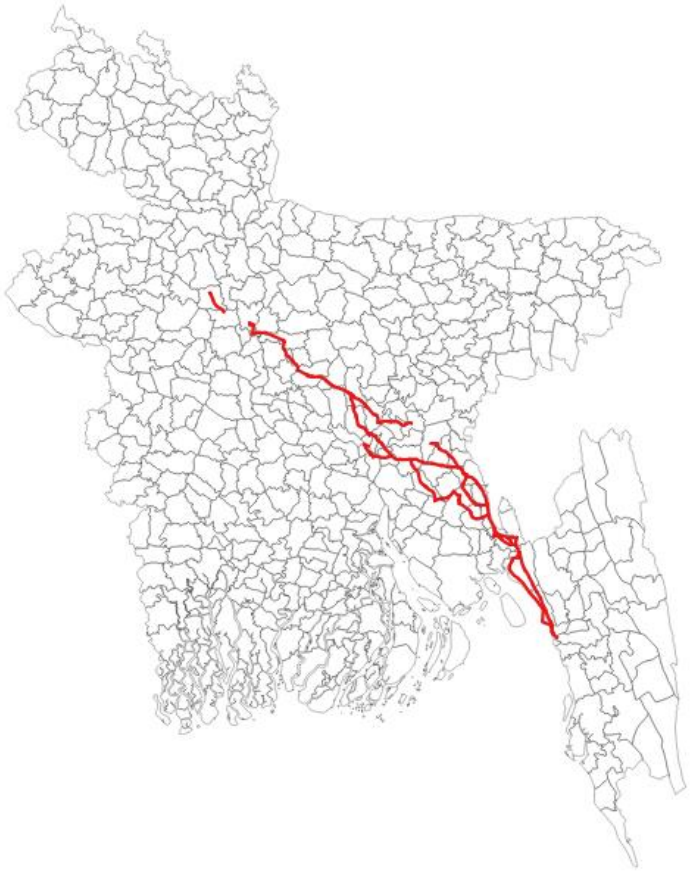

Figure 13 Road Segments with Betweenness Centrality (Export flows) > 0.12

Table 4 Top 15 Road Segments with Highest Betweenness Criticality (Export flows)

Rank	Road	Betweenness Criticality (Export)	Location
1	N1	0.885	Feni - Baraiyarhat
2	N1	0.664	Chauddagram, Comilla district
3	N1	0.456	Gazaria - Daudkandi
4	N1	0.443	Chittagong
5	R160	0.424	Chittagong
6	N4	0.317	Gazipur - Tangail
7	N1	0.298	Chandhina, Comilla district
8	N405	0.29	Bangabandhu bridge
9	R112	0.225	Tejgaon, Dhaka
10	N1	0.2	Narayanganj
11	N102	0.19	Debidwar, Comilla district
12	N3	0.185	Tejgaon - Gazipur
13	R140	0.157	Barura, Comilla district
14	Z1044	0.157	Kachua, Chandpur district
15	N5	0.13	Raiganj - Sherpur

Appendix C: Unweighted betweenness criticality

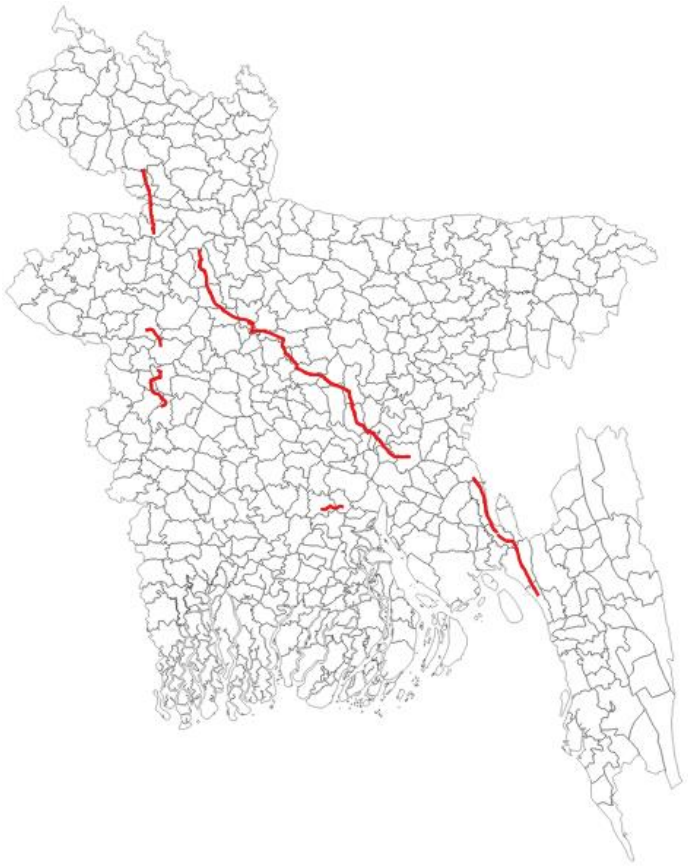

Figure 14 Road Segments with Unweighted Betweenness Centrality > 0.1

Table 5 Top 15 Road Segments with Highest Betweenness Criticality (Unweighted)

Rank	Road	Unweighted Betweenness Criticality	Location
1	N405	0.257	Bangabandhu bridge
2	N4	0.208	Tangail - Kalihati
3	N5	0.206	Raiganj - Bogra
4	N3	0.19	Tejgaon - Gazipur
5	N4	0.183	Mirzapur - Kaliakair
6	N1	0.168	Gazaria - Bandar
7	R112	0.155	Tejgaon - Gazipur
8	N704	0.147	Lalon shah bridge, Kushtia
9	N1	0.146	Feni - Baraiyarhat
10	N704	0.145	Kushtia - Bheramara
11	N6	0.143	Baraigram - Natore
12	N105	0.131	Narayanganj

13	Z5503	0.131	Joypurhat
14	R585	0.114	Birampur, Dinajpur district
15	R860	0.107	Madaripur - Shariatpur

Appendix D: Minimum edge cut criticality

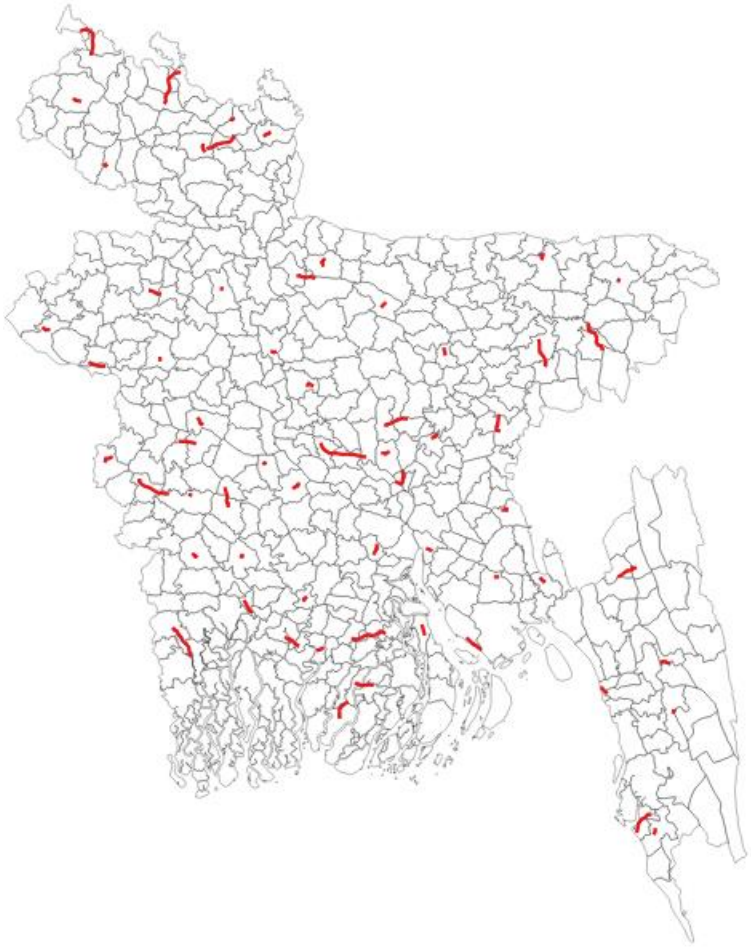

Figure 15 Road Segments with Minimum Edge Cut Criticality > 45

Table 6 Top 15 Road Segments with Highest Minimum Edge Cut Criticality

Rank	Road	Min Cut Criticality	Location
1	R164	110	Rajasthali, Chittagong division
1	R890	110	Bhola
1	R710	110	Rajbari
1	Z2809	110	Sylhet
2	Z2804	63	Sunamganj - Bishwamvarpur
2	Z5622	63	Kurigram
2	Z5901	63	Lalmonirhat, Rangpur division

3	Z7011	52	Magura - Sreepur
3	R745	52	Chuadanga
3	R504	52	Singair - Manikganj
3	R710	52	Kumarkhali - Kushtia
3	N6	52	Boalia, Rajshahi district
3	N517	52	Rangpur
3	N102	52	Brahmanbaria
4	R861	46	Shariatpur

Appendix E: Interdiction criticality

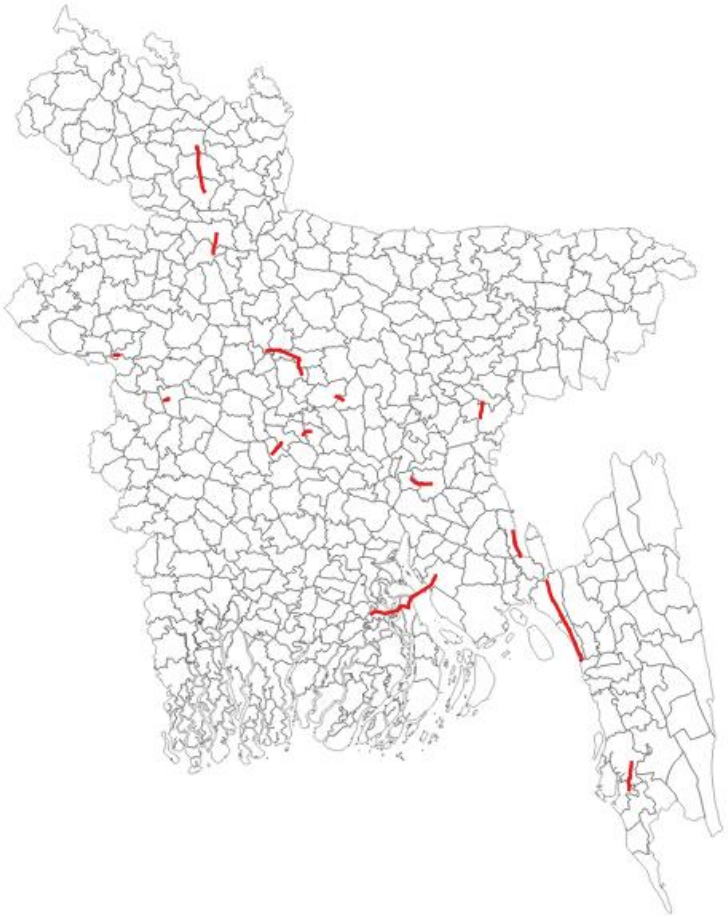

Figure 16 Road Segments with Total Increased Cost Due to Interdiction >1.1%

Table 7 Top 15 Road Segments with Highest Interdiction-based Criticality

Rank	Road	Increased Total Cost	Location
1	N405	0.1359	Bangabandhu bridge
2	N2	0.0303	Sarail, Brahmanbaria

3	N5	0.019	Shibganj - Gobindaganj
4	N1	0.0165	Feni - Baraiyarhat
5	N4	0.0155	Tangail - Kalihati
6	N1	0.0153	Comilla - Munshiganj
7	N809	0.0145	Bhola - Lakshmipur
8	N5	0.0144	Ghior - Manikganj
9	N7	0.0144	Goalandaghat, Rajbari district
10	N705	0.0143	Ishwardi, Pabna district
11	N517	0.0137	Rangpur
12	N1	0.013	Chittagong
13	N102	0.0116	Brahmanbaria
14	N5	0.0114	Pirganj - Mithapukur, Rangpur district
15	N6	0.0112	Puthia, Rajshahi district