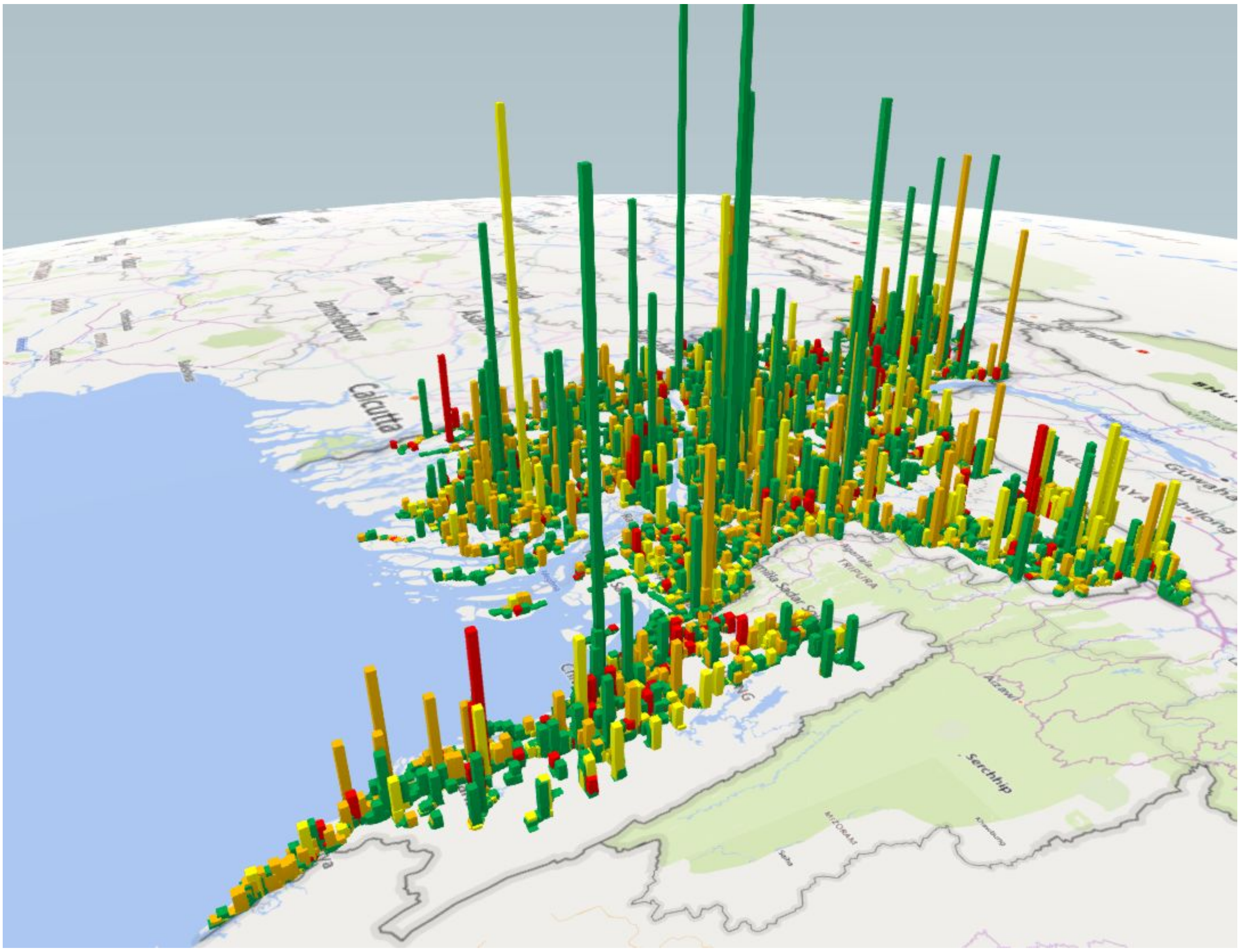
# Assignment 3: Data Visualization




**Group 16**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# Index

# 1. Introduction

This report documents the process for the visualization of the Bangladesh road network by Group 16 for EPA1351. The goal of this report is to communicate the critical and vulnerable roads to the World Bank in order to ease the decision-making process.

Firstly, vulnerability and criticality will be defined and operationalized based on a literature study. These terms can have very different meanings depending on the context they are applied to. Therefore, it is important that they are defined and operationalized in the context of this research to present the World Bank with the most relevant visualization of the road network of Bangladesh.

Secondly, the N1 road, as it is a major road between the port and the capital, will be visualized for traffic density per mode of transport. The different mode of transports are important to understand the road usage. The road usage is shared between trucks, buses, cars, and other vehicles. The different usages can give insight into the importance and value of the road segments.

Thirdly, insight into the top 10 most vulnerable as well as critical roads will be given for cargo transport. The most important roads (segments) will then be evaluated.

Lastly, the defined vulnerability of the road network will be visualized, for both the important N1 road, but also for the whole road network.

A combination of Python and Excel was used to represent and visualize the data. Explanation of the Excel file is mentioned in 4. Visualisation, while the script explanations are in the Jupyter Notebook files. The following files were used in the creation of the results in this report (they are also added to the delivered zip file):

- bridgesWith3DMap.xlsx
- Visualization.ipynb
    - N1.traffic.htm
    - _roads3.csv
- All Roads Criticality.ipynb
    - [all roads].htm

# 2. Criteria definitions

The cornerstone of this analysis are clear definitions of the criteria vulnerability and criticality. Based on these definitions the road network of Bangladesh will be analyzed and presented.

## 2.1 Vulnerability

The case relates vulnerability to the probability that a road becomes impassable after a natural disaster. D'Este and Taylor (2003) argue that reliability of a road (segment) concerns the probability of failure, whereas vulnerability concerns the effects of failure occurring. Berdica (2002) sees vulnerability in a broader form as she believes that reliability can be defined in non-probabilistic terms as well. In this definition, vulnerability isn't just about the consequences of failure. Vulnerability is instead an indicator of the availability of a road, given a certain risk, in a certain time frame. This is expanded upon by Jenelius (2009), who identifies cut links as the biggest vulnerability of existing road networks. As such the vulnerability of a road is also dependent on the number of alternative routes available. It also addresses how more frequently used roads can be considered more vulnerable as a failure would be more significant. Mattson and Jenelius (2015) identify that even though a lot of progress has been made in the field of transport network vulnerability, no clear definition has come out yet. This is in part due to how vulnerability relates to other concepts in the field such as risk, fragility, survivability, reliability, and robustness.

Since vulnerability in this report focuses on nation wide disaster relief the definition by Jenelius and Mattson (2015) is used: "Transport system vulnerability is here seen as society's risk of transport system disruptions and degradations.".

Following this definition, and given the available data, vulnerability is operationalized by the number of bridges, the condition of the bridges and their length. These are seen as indicators of their failure probability. The more "vulnerable" bridges are present in a certain road segment, the more vulnerable this segment is.

## 2.2 Criticality

In the case, criticality is first related to the economic performance of a road. However, it can be argued that vulnerability already covers this potential definition of criticality. In their literature review Faturechi and Miller-Hooks (2015) identified seven different measures of performance for in transportation literature that they reviewed. Vulnerability was one of these measures, yet criticality was not. This suggests that criticality should be approached from a different angle than vulnerability. Instead of a measure of performance, criticality is an indicator of where improvements can be made to the network to minimize vulnerability in case of disruptions. Unlike with vulnerability, the literature seems quite in agreement with how to define criticality. It is generally defined as the performance of the system after removal or damage to a component (Ukkusuri & Yushimito (2009); Yang et. al (2018)). A component specific definition would be linked to the replaceability of a component should it fail (Lu, Peng & Zhang, 2015).

The measuring of criticality has seen differing views. Criticality has often been done using a volume/capacity method, however this is a measure of congestion not criticality (Lu, Peng & Zhang 2015). Alternatives would be to focus on changes in travel time (Ukkusuri & Yushimito, 2009) or a location based accessibility index (Lu, Peng & Zhang, 2015).

Considering the available data, and how the case presented criticality, the rest of this report will consider criticality using the volume/capacity method in relation to the value of the traffic on a given segment. We repeat the definition by Ukkusuri & Yushimito (2009): “A generic measure of criticality in a network can be defined by the change in the performance of the network after the removal or damage of one its components.”. As such, components with more high value traffic are seen as more critical. As it is yet unclear what the exact relative economic value is of the different kinds of traffic, the analysis will leave space for easily changing this relative value, while choosing one plausible set.

# 3. Data preparation

In the Python file “Visualization.ipynb” the preparation techniques can be found for the Python visualization. First the LRP points that are part of a road are loaded in, which are then combined with the road segment each of these LRP’s are on, which is also loaded in. Currently, this has only been done for the N1 road, but it can be adjusted to include all of the roads in the future, as the code has room for scaling. If this is done, all roads can be visualized as a real road on the globe such as Figure 1 in chapter 4.1.

In order to prepare the data for visualization of the vulnerability, the quality of the bridges has been added to serve as the prime measurement factor. This value will decide the color of the bridges in the excel world map (see visualization).

To prepare the data for visualization of the criticality the variable ‘’TOTcritic” was added (see Visualization.ipynb). This variable is the weighted sum of all of the different types of traffic that cross the road segment and shows the actual criticality of a road. In the Python file the weights that the different kinds of traffic have in calculating the total criticality can be changed. This makes it possible to experiment with varying importance of traffic types.

While calculating the total criticality for all of the roads, it turned out that for some roads the data for the intensity of the traffic was not available. Instead of integers for a number of heavy trucks, the value "NS” or “* NS” was given, leading to problems when summing up the different types of vehicles. In order to solve this, all “NS” and “* NS” values were changed to zero, meaning these segments will not be seen as critical for decision making.

# 4. Visualization

Visualization is performed in two very distinct ways. The first way uses a plugin inside Excel called 3D map, which was used to visualize the vulnerability of the roads in Bangladesh. For data that does not require much preparation, such as the bridge data file, this is a quick and easy visualization method. It is also very convenient as no programming skills are required to visualize the data and only requires basic understanding of excel. The second method uses the Python library, with which the criticality of the roads has been visualized. Python is very applicable due to its capabilities to combine and change data frames. While Python has many capabilities, it is very time-intensive to get a very polished product for those not fluent in Python and its libraries.

## 4.1 Vulnerability

As was stated in chapter 2, the measurement of vulnerability is based on the number of bridges that a particular road has, the quality of these bridges and also the length of the bridges. In Figure 1 the bridges of the N1 road are visualized in different colours as well as different sizes. The colours correspond to the condition whereas the height corresponds to the length of the bridges. This way tense reddish areas can be spotted to find the most vulnerable parts of a road. Right now, this can only be done in a qualitative way, which is not very interesting. In the future, the road segments should be made clear, in order to point out the most vulnerable segments. Still, as can be seen in Figure 2, a dense area of long bridges can be seen around Dhaka. If these bridges do break down, this could influence the road system significantly.

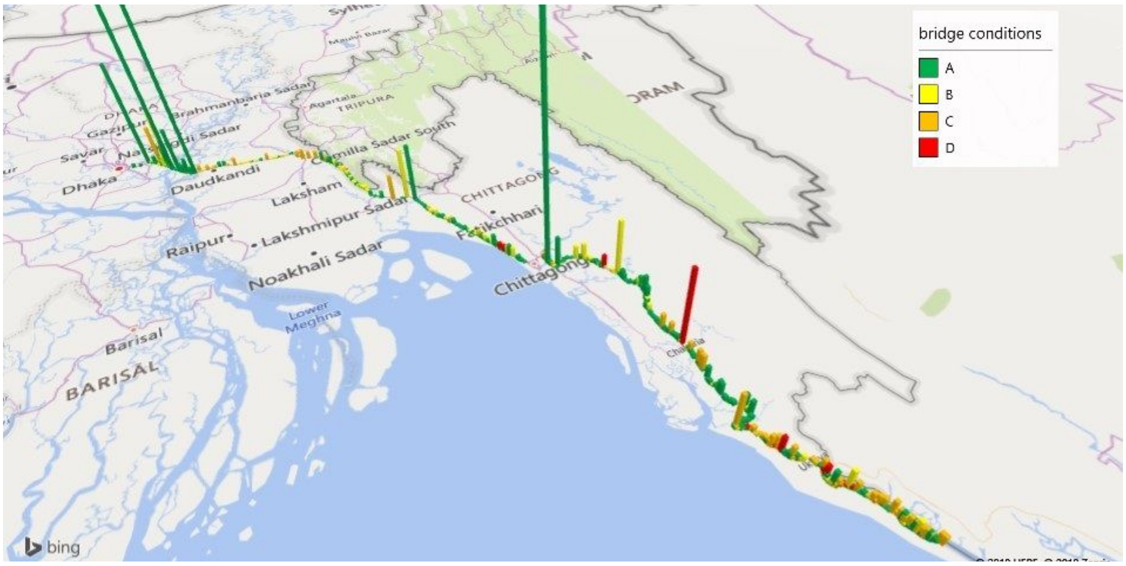


*Figure 1. bridge vulnerability N1 road*

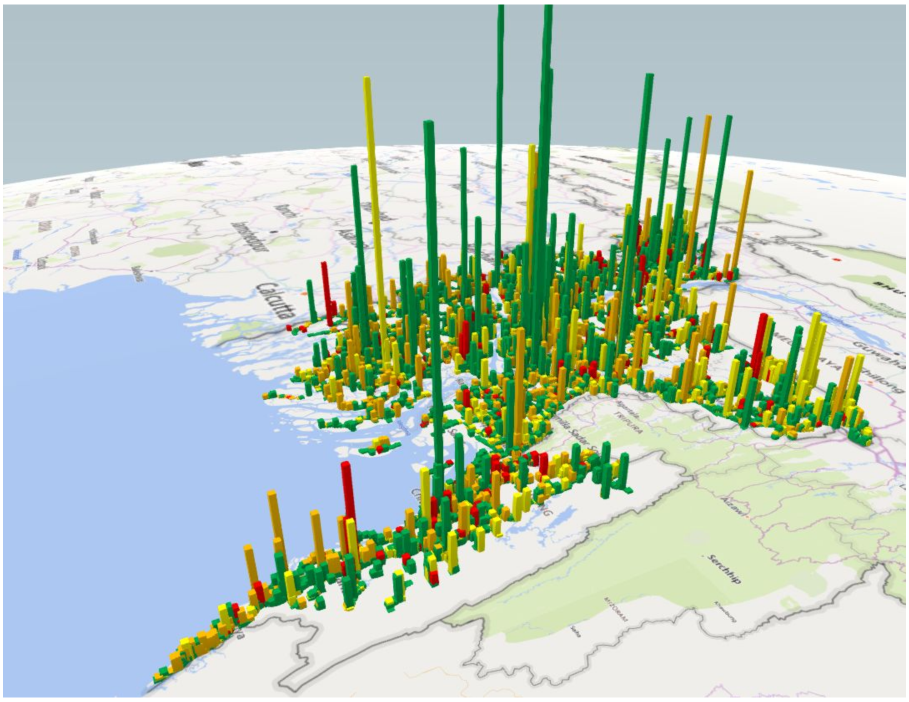


*Figure 2. bridge information for all of Dhaka*

The interactive visualization can be found in the excel file “bridgesWith3DMap.xlsx”. To see the visualization go to ‘insert’, ‘3D Map’ and open ‘Vulnerability Bridges’. Each of the bridges shows its name, type, length, and condition when hovering over them (see Figure 3). Roads can also be selected for visualization with the filter options in the Layer Pane.

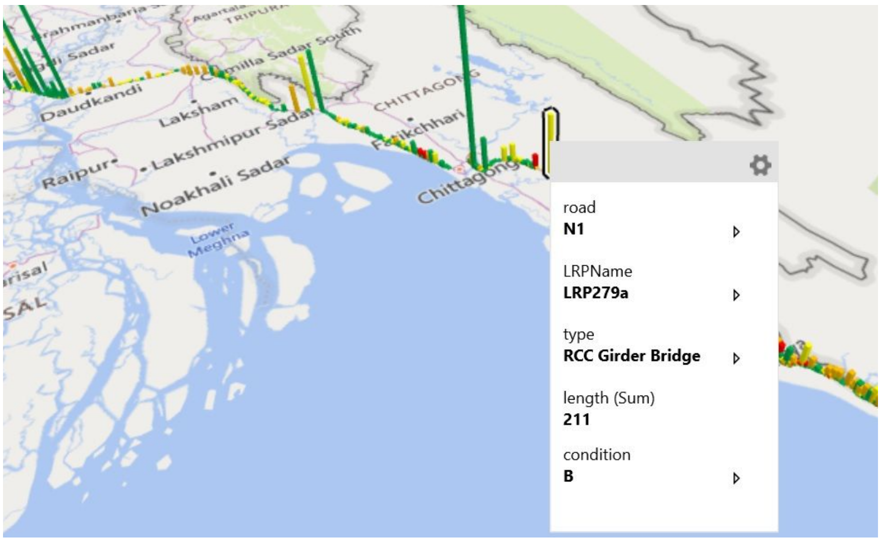


*Figure 3. bridge information*

## 4.2 Criticality

The definition of critality has led to the operationalization of critical infrastructure as those components that carry the most valuable traffic. However, “most valuable” is per definition based on the perceptions of the reader, which means that no definitive importance can be assigned to the types of traffic. A total value has been based on the traffic per mode and multiplied by its weight. The weights used to calculate the total criticality are adjustable in the Python file (Visualization.ipynb).

The Python file (Visualization.ipynb) is interactive, allowing the user to choose between different modes of transport. For example, if a user cares more about small trucks, the criticality can be based more on small trucks than on large trucks, or even only on small trucks. The coding allows for such changes.

Figure 4 visualizes the criticality of the different road segments of the important N1 road, based on the weighted total number of vehicles that cross the road segment. Figure 5 shows the same N1 road, but this time inside of the country of Bangladesh. Together the two graphs give an overview of the most critical geographic places that the N1 passes. In the Python file, the image from Figure 4 is interactive, allowing the user to retrieve the desired information through zooming and scrolling. As can be seen in Figure 4 and 5, mostly the north part of the N1 can be seen as critical, given the current weights for all the different types of vehicles. Figure 6 shows an additional feature, as labels are added to each road segment. These labels can be hovered over to see the criticality score for that particular segment. Table 1 shows the initial traffic type weights, which can be changed in the Python file. The values of criticality are relative, meaning the absolute value in the legend does not add any value right now.

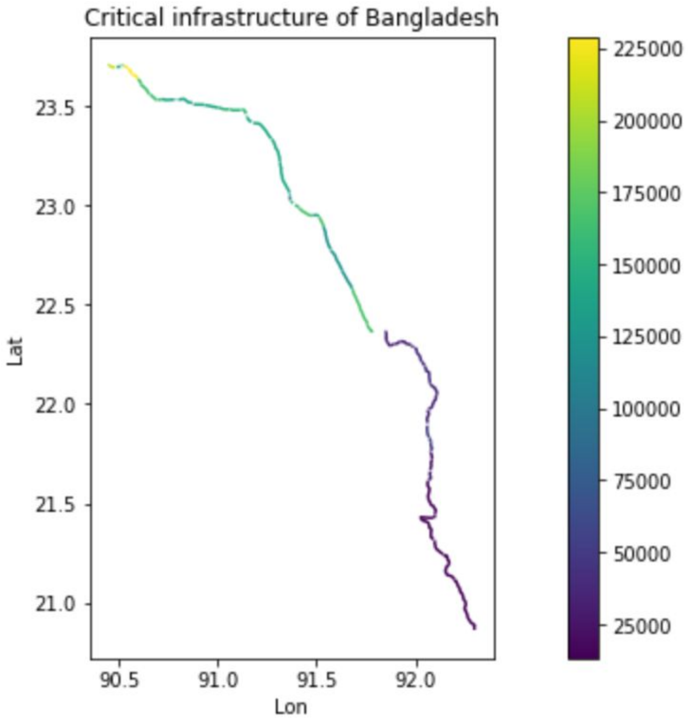


Figure 4. criticality road segments N1


Figure 5. criticality N1 in map Bangladesh

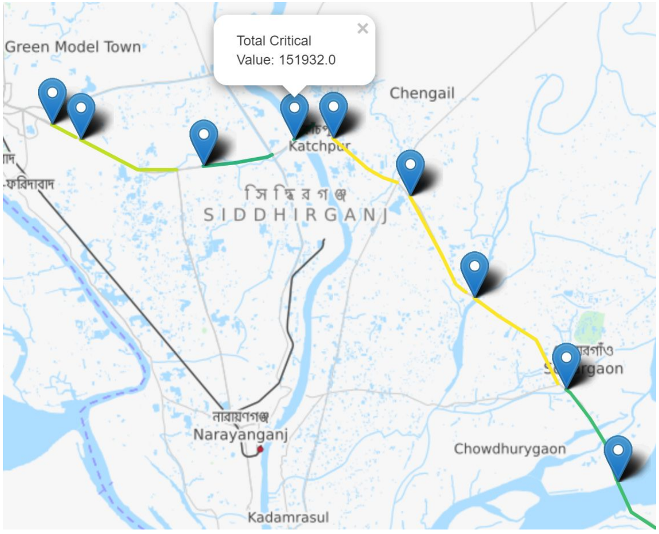


*Figure 6. labels with the critical score for a road segment*

To get a clear overview of the criticality of all the roads in Bangladesh, the Python file (All Roads Criticality.ipynb) creates a sorted list of critical road segments. Figure 7 shows the ten most critical road segments in a bar chart. This bar chart has been chosen over a scatter plot, as the length of the bars clearly indicates the difference between two road segments. The used criticality measure is a relative score, which makes the difference between two bars more insightful. A surprising result in the top ten critical segments is the dominating presence of the N3 and N4 roads, and the absence of the N1 road. This could be the result of the chosen weights for the different types of traffic. However an additional run (Figure 8 and Table 1) with different weights showed that the exact same road segments were considered to be most critical. Though this can't be seen as a full sensitivity analysis, it makes a start in strengthening the findings. Regardless, it suggests that not the N1, but the N3 and the N4 are critical roads in Bangladesh.

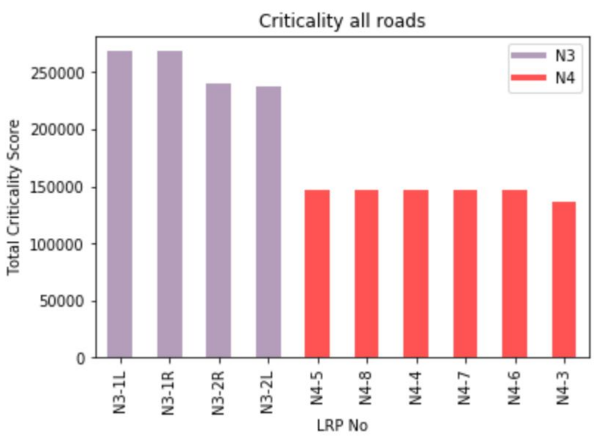


*Figure 7. most critical segments*

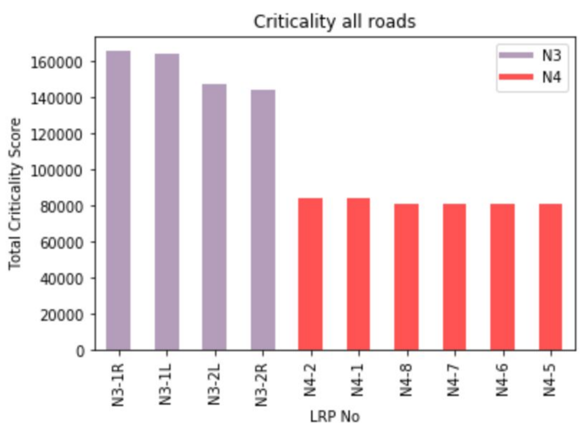


*Figure 8. most critical segments, different weights*

*Table 1. weights used to calculate criticality (left is scenario 1, right is scenario 2)*

| Mode of traffic | Weight | Mode of traffic | Weight | Mode of traffic | Weight | Mode of traffic | Weight |
|---|---|---|---|---|---|---|---|
| Heavy Trucks | 10 | Car | 3 | Heavy Trucks | 5 | Car | 2 |
| Medium Trucks | 8 | Auto Rickshaw | 1 | Medium Trucks | 5 | Auto Rickshaw | 1 |
| Small Trucks | 6 | Motor | 1 | Small Trucks | 5 | Motor | 1 |
| Large Bus | 7 | Bicycle | 1 | Large Bus | 2 | Bicycle | 1 |
| Medium Bus | 5 | Cycle Rickshaw | 1 | Medium Bus | 2 | Cycle Rickshaw | 1 |
| Micro Bus | 3 | Cart | 1 | Micro Bus | 2 | Cart | 1 |
| Utility | 2 | | | Utility | 1 | | |

# 5. Conclusion, limitations, and recommendations

Visualizing both the vulnerability and the criticality of all the roads in Bangladesh is insightful for deciding on where investments in the road network can provide the most benefit. The findings of this report have found many critical segments on both the N3 and the N4 roads, which should be examined more thoroughly to validate these findings. The used measurement for vulnerability is qualitative in nature, yet it does relate the size of a bridge to its condition, which is a measurement of how likely it is to break down. The visualization showed that there are many long but reliable(A-condition) bridges around Dhaka. If these long bridges do break down they could greatly hamper the accessibility of the road network. As such this area is a potential vulnerability in the system.

When using the current approach further validation is important. A first step was made by running an alternative scenario for the truck weights. However, a more thorough sensitivity analysis would provide better insight in the used measurement and its reliability.

The definitions and measuring of criticality and also vulnerability were largely based on the available data. Based on literature other approaches may be of interest. Instead of seeing criticality as a direct measure of economic loss it is also valuable to measure criticality as the increase in travel time due to damaged components. This is especially relevant when considering a relief effort after a natural disaster, as is the case here.

In literature, vulnerability is often seen as a measure encompassing many other commonly used variables. Vulnerability as a field of study is also ever evolving. Repeating the analysis of this report with different definitions and operationalizations of vulnerability could provide valuable information. Visualizing the vulnerability based on the quality and length of existing bridges can show vulnerable parts of roads. However, this qualitative conclusion is not a strong base for deciding on investments. When more research is done into the exact effect on vulnerability of both the length and the quality of the bridges, stronger conclusions can be made. A second improvement to quantify the vulnerability, would be to add the probability of disasters in all areas, which gives meaning to the effect of a vulnerable bridge. When areas have a small chance of flooding for example, the quality and vulnerability of a bridge has less effect, because even bad quality bridges will hold in normal circumstances.

A valuable follow-up study to improve the way criticality is measured would be to relate the criticality of damaged components to how it affects the accessibility of different areas. This could be used to further specify the criticality. The criticality of a component would go down if it largely services a low-demand area. The analysis in this report made a start to this, but it would require more data on the full flow of traffic.

Improving visualization is important to communicate clearly to the World Bank where the vulnerable and critical roads are in Bangladesh. Where as the current visualizations are a nice basis, more can be done. Firstly, there would be real-time data and movement of vehicles visualized. This is important as historic data might not be the best estimation of the current infrastructure, seeing there might have been significant upgrades to roads not taken into account. Secondly, more interactive elements such as that the user can delete a road segment and immediately get the results on important criteria. It would also be interesting to add interactive data input, such as increasing the flood risk in a certain area because of an upcoming typhoon. Thirdly, combining data visualizations onto one platform would increase the user experience. Fourthly, with enough time and resources it is important to make the visualizations generalizable for other traffic projects. The making of visual elements at the moment is hampered by the extensive time used on programming, however this can be reduced with generalized visual components such as 3D Map in Excel.

## References


Berdica, K. (2002). An introduction to road vulnerability: what has been done, is done and should be done. Transport Policy, 9(2), 117–127. https://doi.org/10.1016/s0967-070x(02)00011-2

D'Este, G.M., Taylor, M.A.P. (2003) Network vulnerability: an approach to reliability analysis at the level of national strategic transport networks. The Network Reliability of Transport. Proceedings of the 1st International Symposium on Transportation Network Reliability (INSTR), pp. 23-44.

Faturechi, R., & Miller-Hooks, E. (2015). Measuring the Performance of Transportation Infrastructure Systems in Disasters: A Comprehensive Review. Journal of Infrastructure Systems, 21(1). https://doi.org/10.1061/(asce)is.1943-555x.0000212

Jenelius, E. (2009). Network structure and travel patterns: explaining the geographical disparities of road network vulnerability. Journal of Transport Geography, 17(3), 234–244. https://doi.org/10.1016/j.jtrangeo.2008.06.002

Jenelius, E., & Mattsson, L. (2015). Road network vulnerability analysis: Conceptualization, implementation and application. Computers, Environment and Urban Systems, 49, 136–147. https://doi.org/10.1016/j.compenvurbsys.2014.02.003

Lu, Q., Peng, Z., & Zhang, J. (2015). Identification and Prioritization of Critical Transportation Infrastructure: Case Study of Coastal Flooding. Journal of Transportation Engineering, 141(3). https://doi.org/10.1061/(asce)te.1943-5436.0000743

Mattsson, L., & Jenelius, E. (2015). Vulnerability and resilience of transport systems – A discussion of recent research. Transportation Research Part A: Policy and Practice, 81, 16–34. https://doi.org/10.1016/j.tra.2015.06.002

Ukkusuri, S. V., & Yushimito, W. F. (2009). A methodology to assess the criticality of highway transportation networks. Journal of Transportation Security, 2(2), 29–46. https://doi.org/10.1007/s12198-009-0025-4

Yang, S., Hu, F., Thompson, R. G., Wang, W., Li, Y., Li, S., & Ni, W. (2018). Criticality ranking for components of a transportation network at risk from tropical cyclones. International Journal of Disaster Risk Reduction, 28, 43–55. https://doi.org/10.1016/j.ijdrr.2018.02.017