Assignment 3: Networks

Meghna Bridge. From *Obayashi Corporation*

EPA133A Advanced Simulation: Lab Assignment 2
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1. Introduction

This assignment builds on the previous one by introducing an intersection component into the model and the implementation of a network model using NetworkX for determining the routes of vehicles. The aim for this assignment is to try to understand which bridges have the most traffic and how their breakdown affects the driving time, in order to be in a position where recommendations regarding investment in infrastructure can be made. In this analysis, 5 different scenarios were analysed, which can be seen in Table 1.

Scenario	Cat A %	Cat B %	Cat C %	Cat D %
0	0	0	0	0
1	0	0	0	5
2	0	0	5	10
3	0	5	10	20
4	5	10	20	40

Table 1: Scenarios

2. Data Preparation and Mesa Modifications

In order to analyse the bridge failure rates and delay times when using different routes, the data needed to be prepared to be fit for purpose, and implement a NetworkX structure.

a. Data Preparation

In order to create the data, four steps were taken. Firstly, the bridge dataset was cleaned in the method clean_bridges(). This removes any possible duplicate bridges. Secondly, the intersections were found in the method add_intersections(). This was done by looking at the road data and searching in other roads for data points closeby through lat and lon, then using a cut-off point for it to be seen as an intersection. The closest two points were chosen as the intersection. This has certain limitations. Mainly that there could be water between the roads or the roads could run in parallel. Furthermore, roads can intersect multiple times. The roads dataset was chosen due to having more entries, therefore having a higher chance of finding correct intersections. Thirdly, the links and source-sinks were added through the method called add_road_lengths(). Most importantly, for the analysis it was chosen to only keep the roads that hold bridges, roads that only have intersections were left out, as the focus of this research is finding out what effect bridge reparations have. Lastly, the ID's were added to every datapoint.

b. Model Modifications

To collect sufficient data for analysis and answer the research question, a few modifications are made to the given Model. The most notable modifications are explained below.

Mesa built-in random module: To account for the Stochastic nature of the simulation, the built-in Mesa random module is used consistently throughout the Model to simulate randomness.

Travel distance as an attribute of the Vehicle class: In this experiment, vehicles travel on different roads with different lengths. The difference in length of different roads affect the vehicle travel time in addition to the delay time caused by bridge breakdown. So, the travel distance of a vehicle must also be considered in the analysis. To keep track of the vehicle travel distance, the attribute travel_distance is added to the Vehicle Class. This attribute is updated in the Vehicle.drive, Vehicle.drive_to_next and Vehicle.arrive_at_next methods accordingly as a vehicle traverses its path.

Road network graph as a Model attribute: Networkx Graph is used to represent the road network. The network graph is implemented as follows: Each element - SourceSink, Link, Bridge, Intersection - is a vertex in the graph; as a vehicle travels from vertex A to vertex B, the length of vertex A is the length of the edge connecting A to B. There are two main reasons for this implementation:

1. Each road element is recorded as an entry in the road data with their corresponding length. There is no data on the distance between two elements, which is semantically realistic because as each element ends, it is immediately connected to the next element.
2. The Vehicle.drive, Vehicle.drive_to_next, Vehicle.arrive_at_next functions work in conjunction to make the vehicle travel the entirety of an element before moving on the next.

Route selection strategy as a Model attribute: In the simulation, the Model supports two types of route selection strategies, namely random and straight route. Given that different routes have different lengths, the route selection strategy also impacts the travel distance of a vehicle, which in turn impacts the travel time of a vehicle. Providing the significant impact of the route selection strategy, this element must be controlled at the model level as an attribute. Therefore, a new model attribute BangladeshModel.route_strategy is added to the model to control whether a Vehicle class will travel a random or straight route in a simulation.

Length as the criteria for route selection algorithm: In addition to length, there are different criteria when selecting a route between two SourceSink instances such as toll fee, route condition, social and economical significance of a route, etc. However, the sole criterion used in determining a Vehicle instance's route is the route length. The main reason for this decision is to ensure simplicity and reduce model implementation time. Once it is certain that the Model runs, more complexity can be implemented via the introduction of more realistic criteria in the route selection strategy in the future versions of the Model.

3. Bonus Question

As explained in section 2a: Data Preparation, the original method to find the intersections came with numerous limitations. Intersections were ‘guessed’ based on whether other roads were close by. However, the shapefiles from Assignment 1 offered another method to find the intersections. The .shx file that was used contained all the geographical information of every road section. Using this file, the exact location of intersections could be determined more precisely.
The notebook created around the shapefile showed that 69 roads cross either the N1 or the N2, as shown in Figure 1. It is unclear how many of these roads are longer than 25 km. Therefore, it was not possible to judge how many intersections were missed or created extra during the Data preparation phase.

When comparing the locations of the intersections from the Data Preparation with the locations found in the shapefile analysis, it was clear that many of the created intersections were either not registered in the shapefile or falsely created. One of the intersections, with the Z1098, was located over 300 km away from all intersections, thus, this intersection is unlikely to exist in the real world. The intersection with the R360 on the other hand, was estimated very precisely, the location only differed 30 metres from the location according to the shapefile. Out of all thirty intersections found during the data preparation, only four were located within 0.25 degrees (approximately 27 km) of any of the intersections from the shapefile analysis. These numbers imply that either the locations found in the data preparation were mostly wrong, or that the shapefile analysis has not found all the intersections. Overall, it is clear that one of the two analyses contains mistakes, therefore, it is impossible to conclude this comparison.

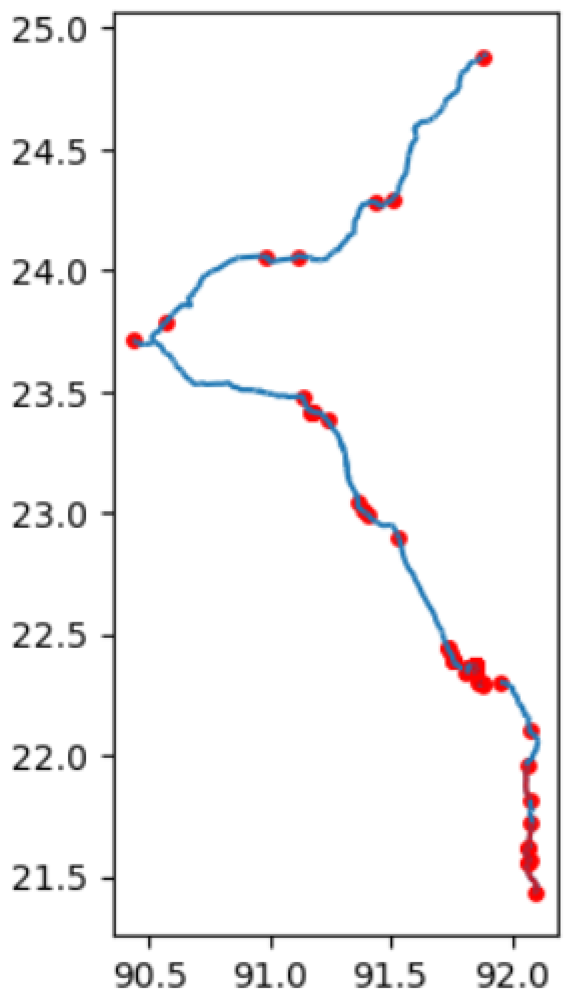

Figure 1: Intersections found on the shapefile

4. Observations and Conclusions

As expected, the travel time increases significantly from scenario 0 to scenario 4, the increase is especially significant from scenario 3 to scenario 4. Table 2 represents the average travel time for each of the 5 scenarios.

Scenario	Average Travel Time (minutes)
0	174.46
1	174.77
2	179.89
3	191.50
4	305.60

Table 2: Average travel time per scenario

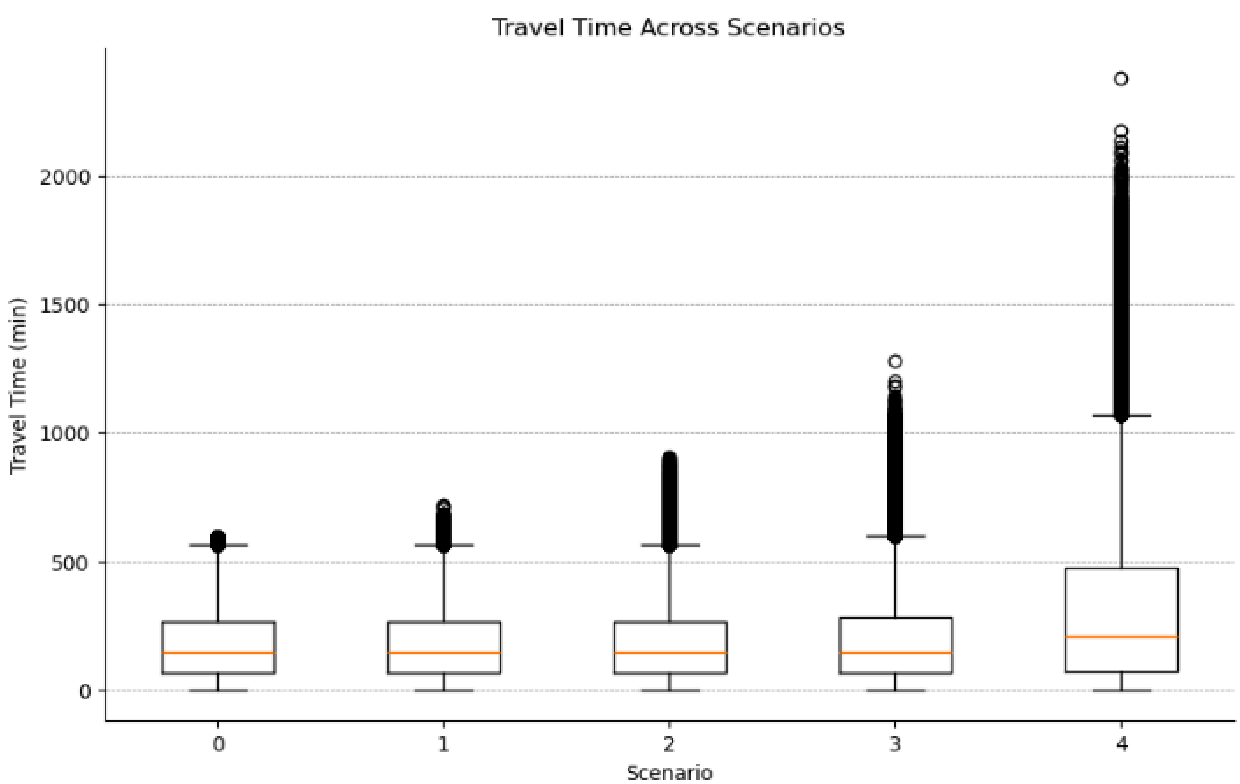

Figure 2: Boxplots for the travel times of all 5 scenarios

In Figure 2, scenarios 0,1, 2 and 3 have medians around the same range, but scenario 4 has a higher median, which corresponds with Table 2. The small black circles above the boxes represent outliers, they indicate data points that lie beyond 1.5 times the interquartile range from the quartiles. These extreme variations in scenario 4 could be caused due to various reasons, the obvious one being a lot of consecutive bridge breakdowns on one route. However, it should be noted that the driving time does not change by a lot till scenario 3, which illustrates that while the infrastructure is not sufficiently prepared to handle the worst case (scenario 4), it is quite robust in other situations that are not as extreme. Figure 3, presented below, offers a zoomed-up version of Figure 2, it highlights the difference in the median value better.
Also, as mentioned in the previous assignment, the stochastic effect of using different seeds is not very substantial on the model, which indicates that it is quite robust and behaves more or less in the same manner across different seed values.

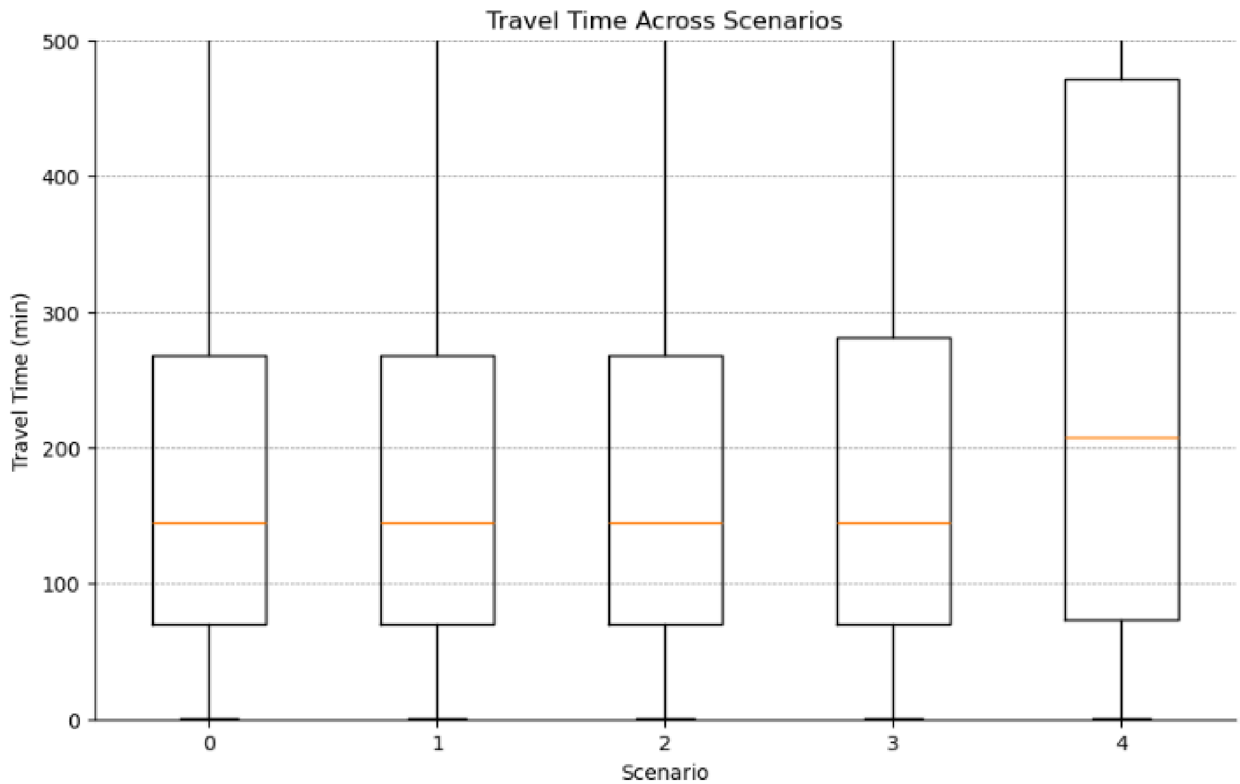

Figure 3: Zoomed-in version of Figure 2

Bridge ID	Road Name	Bridge Name	Latitude	Longitude	Delay Time (minutes)
11604	N2	SHER PUR	24.62886 81188679	91.67843 64069182	3920848.0
10497	N1	MATHAMUHU RI BRIDGE	21.77159 43354948	92.08210 99546075	1889713.0
10729	N1	SHAPUR STEEL BEAM AND RCC SLAB	21.29974 53619819	92.09747 72590991	955079.0
10359	N1	Sangu Bridge	22.15862 72806451	92.06820 63096774	803661.0
10199	N1	ISAMATI BOX CULVERT	22.71387 27382812	91.60823 52218749	777110.0

Table 3: Top 5 Bridges with the highest breakdown time

Table 3 shows the five bridges that are causing the maximum delay according to the mesa model. Four out of these are located on N1, which is a major highway, this shows the vulnerability of this road. In this context, vulnerability has been defined from a utilitarian perspective, where it refers to the efficient usability of a road (Jafino, Kwakkel and Verbraeck, 2019). The higher the delay, the larger the disruption to traffic i.e., less vehicles can travel the road, therefore its usability decreases, which increases its vulnerability. We recommend improving the quality of especially these five bridges in order to decrease the vulnerability of Bangladesh's road network to natural disasters.

5. Policy Recommendation

After analysing the 5 scenarios and the delay and travel times of all bridges and trucks, we can conclude that while Bangladesh is not adequately prepared to deal with bridge breakdowns in the case of an extreme disaster (as in scenario 4), the infrastructure can handle not very extreme disruptions pretty well (the travel time does not change much across scenario 0 to 3). More insights can be gained by assessing exactly which bridges are breaking down in scenario 4, this investigation will lead to a better understanding of exactly where structural reinforcements need to be made.

Additionally, five bridges were indicated to cause the most delay in all scenarios. These bridges are highly recommended to improve. Depending on budget choices, it could be decided to improve more bridges which are in the top rankings of delay time. However, it must be kept in mind that these bridges have been deemed important dependent solely on their delay time (the time required to repair them), the notion of what is important can be changed depending on the aim of the analysis. For example, the maintenance of a bridge that connects a remote area to the highway can be deemed as more important than reinforcing the bridge with the highest delay time.

Further, the locations of the bridges found during the data preparation and of the bridges from the shapefile analysis are very different. It is therefore recommended to improve the data recording of the national infrastructure. From the shapefile analysis, it was impossible to find which roads were longer than 25 km, partly because every road was split into sections, which had their own specific names. Perhaps this difficulty can be overcome by improving the data collection process.

6. Limitations

The network analysis performed in this lab assignment by implementing a NetworkX model is limited as the NetworkX model is static even as the BangladeshModel Class experiences bridge breakdowns. This limited network analysis affects assessments of criticality and vulnerability as redundant bridges or alternative paths are not considered. The criticality of a specific route or infrastructure when defined in relation to the number of vehicle crossings or traffic flow would be less if multiple routes existed and were considered by vehicles in route planning. However, in this analysis, only a single shortest path is considered for each source to sink. The NetworkX shortest path function used in the implementation also only returns a single shortest path even if multiple shortest paths exist.

Further, this analysis has selected one interpretation of vulnerability for determining which bridges are ‘important’, which does not offer a holistic or true picture of what bridges are important or vulnerable (Jafino, Kwakkel and Verbraeck, 2019). For example, a bridge which connects the main highway, N1 in this case, to a semi-urban area and is the only connecting link between that region and the highway, is vulnerable in the sense that it facilitates the only possible access for a region. These nuances are not reflected in our analysis, as our chosen definition of vulnerability is quite utilitarian in nature. A study which includes different metrics of vulnerability, will offer a more egalitarian and therefore a more wholesome understanding of what bridges can be considered “important”.

The analysis could also benefit from a criticality analysis, which also has various metrics of criticality. In this context, however, as only roads longer than 25 km have been considered, minor roads and alternative paths using these roads are not accounted for. Any indicator of criticality which uses centrality metrics (betweenness, closeness and degree) would be valid only for this assumption of only representing roads longer than 25 km, for example- the highest degree centrality might change if more roads are included in the model.

7. References:

Assignment 2- Group 5

Jafino, B. A., Kwakkel, J., & Verbraeck, A. (2019). Transport network criticality metrics: a comparative analysis and a guideline for selection. *Transport Reviews*, *40*(2), 241-264.