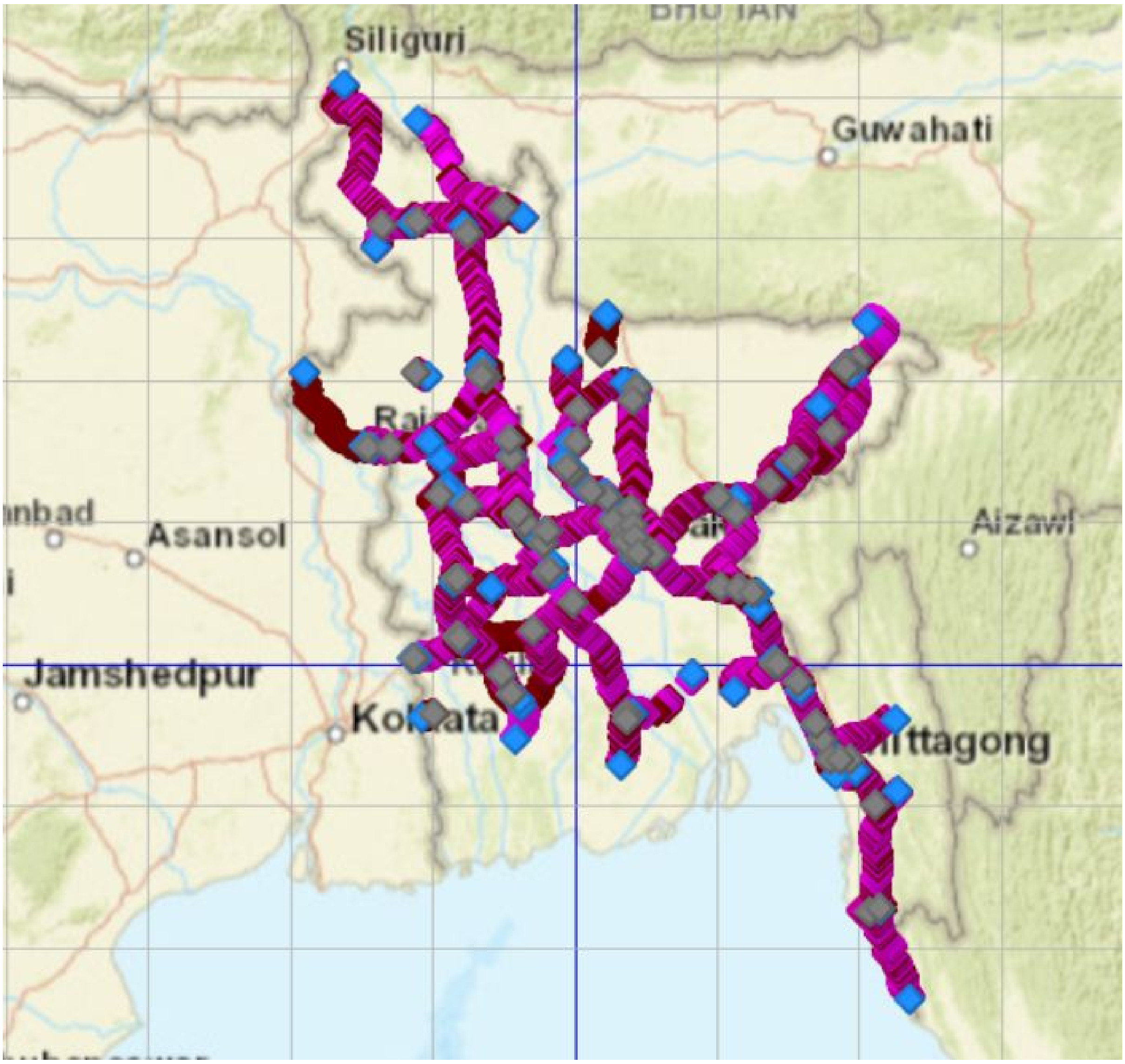
# Building a Component for Data-Driven Simulation




Group 16

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**Overview supporting files and instructions:**
Python data and scripts:

- "Data Model Generation.ipynb"
    - _roads3.csv
    - BMMS_overview.xlsx
- "Calculate KPI's.ipynb"
    - output.csv (results from Simio experiments)

The Python scripts processed the files needed for model generation or processed the model output of the Simio model. For further information see the UML class diagram in the report.

Simio data and scripts:

- "Base Simio Model - Chittagong to Dhaka.spfx"
    - Only1_RoadsBridges.xlsx
    - OnlyN1_Sources_Sinks.xlsx
- "Expanded Simio Model - All N-Roads.spfx"
    - All_N_Roads_Sinks.xlsx
    - All_N_Roads_Sources.xlsx
    - All_N_Roads.xlsx

The "Base Simio Model - Chittagong to Dhaka" only looks at this specific part of the N1 road for this assignment. The files needed for AutoCreation in Simio are also listed. The 'OnlyN1_Sources_Sinks' file was created manually as this was the more convenient option. The "Expanded Simio Model" is not operational, however all N-roads have been loaded in. This is helpful for future work on this project.

Extra files:

- AllRoads_BridgesRoads.xlsx
- AllRoads_Sinks.xlsx
- AllRoads_Sources.xlsx
- Bridges.xlsx
- Expected critical bridges.xlsx

Additionally, files for all roads in Bangladesh could be provided, if you would need to load them in but this has not been verificated. An extra method to do the bonus assignment was using Excel operations, these files have also been added for comparison.

# 1. Component-Based Modelling

This is a concise report detailing the model generation process to look at the critical infrastructure in Bangladesh made by Group 16 for EPA1351. **Accompanied with this report comes a Jupyter Notebook script, a Simio model, a data file used as input for the Simio model and a validation file.**

## 1.1 Bangladesh case

The country of Bangladesh is a river delta that needs to be prepared to face three types of disasters: earthquakes, river flooding, and cyclones. In order to prepare for these disasters the logistics of human aids is an important aspect. Therefore, the World Bank needs to make an assessment of the critical infrastructure in Bangladesh. The critically important road N1 between the Port of the country, Chittagong, and the capital, Daka, will be investigated first. The research question can then be formulated as such: **"What are the effects of bridge maintenance or unavailability on traffic throughput on the N1 road from Chittagong to Dhaka in Bangladesh?"**

## 1.2 Methodology: AutoCreate Function in Simio

To answer the research question, a multi-model transport network will be made in Simio generated from Excel data. This is a form of component-based modelling using data-driven modelling and solutions. The built-in AutoCreate function is preferred over the add-in Simio extension due to the official support from Simio and its efficiency in computational power.

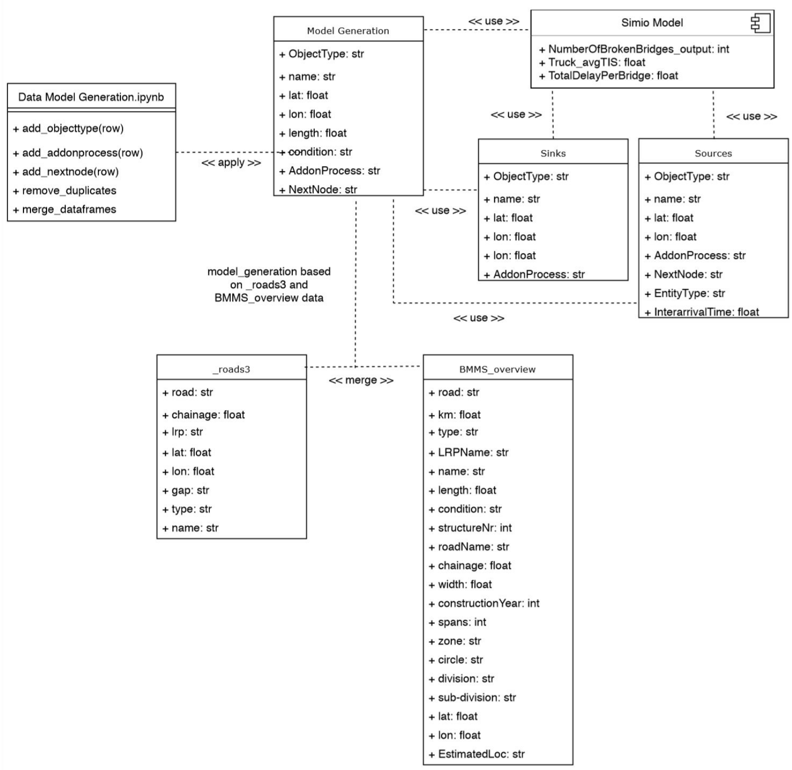


Figure 1 gives a general overview of the data files, scripts, and model used for the project. The files used for data preparation are '_roads3' and 'BMMS_overview'. The Python script 'Data Model Generation' merges, cleans, and adds data for the model input file 'Model Generation'.

*Figure 1. UML Class Diagram*

# 2. Data preparation

In order to create an accurate representation of the roads and bridges in Bangladesh, the data set resulted from assignment 1 (we used Alexander's file) has to be processed further. In this section the steps taken to create a dataset usable for the Simio model will be discussed. All of the preparation has been executed in the "Data Model Generation" script.

## 2.1 Bridge names

In the data file not all bridges have been given a name, some values are missing and for other bridges the name values are written as ".'', see figure 1. As Simio asks for every object to have a unique name, it is important to update the names. This has been done by attaching the road, lrp, and type to each other, creating unique names for all of the bridges.

## 2.2 Duplicated bridges and left & right bridges

Some of the bridges in Bangladesh have more than one row in the data. Because all bridges have a probability of breaking down, it is necessary to get rid of the duplicates, as they overestimate the breakdown of bridges and thus the delay. Some of these duplicate bridges can be deleted by looking at the newly created name explained in section 2.1, because the bridges have the same name, LRPName and road. Some bridges however, are identified as duplicate, but have different values in these columns as seen in Figure 2. Often these duplicates are (L) and (R) bridges, which we assume to be part of the same bridge, which means they can only break down together so they should be treated as one. Even the chainage can differ slightly. To delete these duplicate bridges, the lon and lat have been compared. If these values are the same for the two bridges, the latest bridge, so the one with the highest structure number, has been left in.

| road | km | type | LRPName | name | lat | lon | structureNr |
|---|---|---|---|---|---|---|---|
| N1 | 33.591 | PC Girder Bridge | LRP034a | MADHAYA BAUSHIA(L) | 23.543 | 90.67483 | 119889 |
| N1 | 33.591 | PC Girder Bridge | LRP034a | Madhya Baushia Bridge(L) | 23.543 | 90.67483 | 117861 |
| N1 | 33.591 | PC Girder Bridge | LRP034b | Madhya Baushia Bridge(R) | 23.543 | 90.67483 | 112531 |
| N1 | 33.591 | PC Girder Bridge | LRP034a | MADHAYA BAUSHIA BRIDGE(R) | 23.543 | 90.67483 | 117862 |
| N1 | 35.181 | Box Culvert | LRP035a | . | 23.533 | 90.68587 | 112532 |

*Figure 2. several data issue examples: duplicated bridges and missing names.*

## 2.3 Reducing computational power and adding attributes for the model

The roads and bridge file have been merged. The initial bridges in the roads file were removed to make use of the better bridge information from the bridge file and prevent duplicate bridges from occurring. Furthermore, this merged file has been reduced by removing the kmpost LRP's while keeping the rest. As the computational power would be too high with kmposts included without them providing any additional information. The final step was to add the attributes needed for Simio, including ObjectType, AddonProcess, and NextNode based on the information provided. These have also been ordered on chainage depending on the direction of the road (from Dhaka to Chittagong, means from high chainage to low).

| | ObjectType | name | lat | lon | length | condition | AddonProcess | NextNode |
|---|---|---|---|---|---|---|---|---|
| **38255** | EndLocs | N1_LRPE_Others | 20.862917 | 92.298083 | NaN | NaN | DummyProcess | N1_LRP466a_Culvert |
| **38256** | Road | N1_LRP466a_Culvert | 20.868860 | 92.298222 | NaN | NaN | GeneralTravel | N1_LRP456c_Bridge |
| **38257** | Bridge | N1_LRP456c_Bridge | 20.880985 | 92.297777 | 35.9 | C | InteractBridge | N1_LRP464b_Culvert |
| **38258** | Road | N1_LRP464b_Culvert | 20.882027 | 92.297777 | NaN | NaN | GeneralTravel | N1_LRP456b_Bridge |
| **38259** | Bridge | N1_LRP456b_Bridge | 20.883070 | 92.298163 | 1.5 | C | InteractBridge | N1_LRP456a_Bridge |

*Figure 3. Final dataframe*

# 3. Model

## 3.1 Model Introduction

A Simio model has been created using the prepared data on the roads and bridges (Base Simio Model - Chittigong to Dhaka). A short excerpt from the imported table is shown in Figure 4. The roads and bridges are instantiated as their own object type using the ObjectType column. The length and condition are added to their respective node as properties for easier access in the model. A source and sink are added in separate tables using a different excel sheet so that their unique attributes can be assigned without errors.

Bridge List | Sources | Sinks

| | Object Type | Name | lat | lon | Length | Condition | Add On Process | Next Node |
|---|---|---|---|---|---|---|---|---|
| 1 | Road | N1_LRPE_Others | 20,8629167 | 92,298083 | 0 | | GeneralTravel | N1_LRP466a_Culvert |
| 2 | Road | N1_LRP466a_Culvert | 20,8688604 | 92,2982219 | 0 | | GeneralTravel | N1_LRP456c_Bridge |
| 3 | Bridge | N1_LRP456c_Bridge | 20,8809852229698 | 92,2977774 | 35,9 | C | InteractBridge | N1_LRP464b_Culvert |
| 4 | Road | N1_LRP464b_Culvert | 20,8820271 | 92,2977774 | 0 | | GeneralTravel | N1_LRP456b_Bridge |
| 5 | Bridge | N1_LRP456b_Bridge | 20,8830704487341 | 92,2981629575949 | 1,5 | C | InteractBridge | N1_LRP456a_Bridge |

*Figure 4. Bridgelist table in Simio*

The process *TravelFromSource* is used to to initiate travel from a source to the first node on a path. *GeneralTravel* is then used for the rest of the routing on road nodes. When a truck entity arrives at a bridge the *InteractBridge* process assigns a delay if the bridge is broken and then proceeds with regulating routing. In the bridge node the *UpdateBridgeCondition* process is used to decide whether any given bridge is considered broken in a replication or not. This process is run upon initialization.

The second model (Expanded Simio Model - All N-roads) loads in all the different N-roads. It also automatically creates sources and sinks for each different N-road at points that are assigned as their start and end location in the data. The model is not set up for running completely yet, but it forms a basis for exploration further than just the N1 road.

## 3.2 Model Verification

Basic verification was performed to make increase confidence in the workings of the model. The different steps will be discussed briefly. Entity routing was tested by moving nodes off the linear path to make sure that entities were going were they should and not just to the closest node. Tests were also performed to make sure that the delay was performed correctly on the entities as they tried to cross broken bridges. Trace tests were also performed to check the correctness of the various states and output statistics.

# 4. Results

## 4.1 Key Performance Indicators

The model tracks three different KPIs. The statistic *Truck_avgTIS* calculates the time in system of the vehicle and gives an indication of how the truck delays due to bridge breakdown varies across the eight different scenarios. It is calculated by subtracting the truck creation time from the truck destruction time. *TotalDelayPerBridge* stores the total delay all trucks accumulate on a given bridge when it is broken. It sums this delay per bridge when an entity enters a bridge and incurs a delay. *NumberOfBrokenBridges_output* gives an indication of how many bridges have broken down in a replication. This gives a better understanding of how the breakdown probabilities affect the actual rates of bridges broken down.

*Table 1. Results per scenario of the Truck_avgTIS and the NumberOfBrokenBridges_output KPI's*

| **Scenario** | **Truck_avgTIS [hour]<br>mean (standard deviation)** | **NumberOfBrokenBridges_output<br>mean** |
|---|---:|---:|
| **Scenario 1** | 5.10 (0.00) | 0 |
| **Scenario 2** | 5.22 (0.26) | 0.9 |
| **Scenario 3** | 5.72 (0.56) | 7.6 |
| **Scenario 4** | 6.05 (0.72) | 14.1 |
| **Scenario 5** | 7.38 (1.49) | 19.5 |
| **Scenario 6** | 9.94 (1.45) | 38.3 |
| **Scenario 7** | 12.31 (1.97) | 58.4 |
| **Scenario 8** | 19.93 (4.52) | 117.1 |

As can be seen in Table 1, Simio has generated an expected increase in broken down bridges as well as an increase in delay for higher scenarios where break down probabilities are higher. In the python script "Calculate KPI's" the results can also be seen in graphs that show a exponential like behaviour in the delay time when the breakdown chance increases. Mostly in the case where higher scenarios are expected, the caused delay is extraordinary large. As the journey would normally take approximately only 5 hours and 6 minutes, a duration of almost 20 hours (scenario 8) is a large increase. Also the number of bridges that break down increases immensely, meaning repairs need to take place at lots of different places. Table 2 shows the most critical bridges, with at the top the LRP023b bridge that causes an average delay of 0.2 hours per truck, taken into account that 1440 trucks drive through the system in a single run (12 * 24 * 5). It is probably profitable to invest in the top critical bridges, as they are placed on the N1 and investing in them saves the most time per bridge.

*Table 2. The delay of the ten most critical bridges (sum over all trucks, mean over all scenarios and replications)*

| Object Name | Total delay per bridge [hours] | Delay per truck per bridge [hours] |
|---|---|---|
| N1_LRP023b_Bridge | 305.11 | 0.212 |
| N1_LRP017b_Bridge | 222.59 | 0.155 |
| N1_LRP098a_Bridge | 214.40 | 0.149 |
| N1_LRP220b_Bridge | 205.49 | 0.143 |
| N1_LRP223a_Bridge | 149.00 | 0.103 |
| N1_LRP072a_Bridge | 141.83 | 0.098 |
| N1_LRP092a_Bridge | 127.72 | 0.088 |
| N1_LRP228a_Bridge | 118.80 | 0.083 |
| N1_LRP104a_Bridge | 113.43 | 0.079 |
| N1_LRP037a_Bridge | 100.40 | 0.069 |

### 4.2 Most critical bridges (Bonus)

To improve the throughput on the N1 road from Chittagong to Dhaka investments can be made on the most critical bridges. In order to identify the five most critical bridges a mathematical expectation has been made with excel. In the excel file "Expected critical bridges" the prepared dataset of bridges has been compared to each other. Assuming the scenarios 2 through 7 have an equal probability of occuring, an expected risk has been determined for all of the bridges. The outcome as seen in figure 5 was compared to the results of the simio model as seen in figure 6. These figures show that the Simio model points out 4 of the same bridges being critical as the excel file. The fifth bridge in excel is on the 20nd place in the Simio model, which can be caused by probabilities and the few replications (10) Therefore, the five most critical bridges are identified as the five first bridges in figure 5, having the following LRPname values: LRP223a, LRP220b, LRP155a, LRP017b, LRP023b.

| LRPname | length | condition | Total risk |
|---|---|---|---|
| LRP223a | 24,32 | D | 5062,5 |
| LRP220b | 24,33 | D | 5062,5 |
| LRP155a | 98,87 | C | 4387,5 |
| LRP017b | 159,52 | C | 4387,5 |
| LRP023b | 224,82 | B | 3500 |
| LRP225a | 26,3 | C | 2437,5 |
| LRP208a | 22,25 | C | 2437,5 |
| LRP191c | 19,2 | C | 2437,5 |
| LRP176b | 12,4 | C | 2437,5 |
| LRP104a | 22,88 | C | 2437,5 |
| LRP098a | 27,35 | C | 2437,5 |
| LRP094a | 27,35 | C | 2437,5 |

*Figure 5. most critical bridges calculated in excel*

| Object Name | Value |
|---|---|
| N1_LRP023b_Bridge | 305.112798 |
| N1_LRP017b_Bridge | 222.591736 |
| N1_LRP098a_Bridge | 214.403567 |
| N1_LRP220b_Bridge | 205.485352 |
| N1_LRP223a_Bridge | 148.995772 |
| N1_LRP072a_Bridge | 141.832491 |
| N1_LRP092a_Bridge | 127.719791 |
| N1_LRP228a_Bridge | 118.795487 |
| N1_LRP104a_Bridge | 113.433161 |
| N1_LRP037a_Bridge | 100.403198 |
| N1_LRP124a_Bridge | 87.139869 |
| N1_LRP088a_Bridge | 83.800531 |
| N1_LRP056a_Bridge | 83.391553 |
| N1_LRP161a_Bridge | 77.711088 |
| N1_LRP149a_Bridge | 72.426347 |
| N1_LRP094a_Bridge | 70.856445 |
| N1_LRP191c_Bridge | 58.991430 |
| N1_LRP110a_Bridge | 56.502524 |
| N1_LRP040b_Bridge | 55.910039 |
| N1_LRP155a_Bridge | 52.336997 |

*Figure 6. most critical bridges as simulated by simio*

# 5. Conclusion and limitations

To answer the question ”What are the effects of bridge maintenance or unavailability on traffic throughput on the N1 road from Chittagong to Dhaka in Bangladesh?” component-based modelling using Simio has been used. The effects have been measured using the number of broken bridges, average truck times in system, and total delay time per bridge. The five most important bridges have also been identified and validated for the World Bank to invest. Under different scenarios the effect of unavailability can be seen, a higher probability of failure of bridges results in higher truck time in the system, which can up to 4 times the regular time in the system.

The focus in this report was on the N1 between Chittagong and Dhaka. Even though this is a crucial road, further investigations into other roads, including the section of the N1 south of Chittagong should be performed. A start of this is performed in the expanded Simio Model which incorporates all N roads. The data preparation has been done in a way that expanding the number of bridges can be done relatively easily.

It could also be of value to incorporate the repairing of bridges before the end of the run. If this is relevant in practise, it may reduce the relevance of certain smaller bridges.
A further consideration is using alternate routes when it is known that bridges aren’t available. In the current model all trucks will focus on a single road blindly, yet it may be more efficient to take an alternative route to their destination.

Even working with just the N1 road the model runs very slowly. To work on the whole road, network optimisations should be made. Improvements are likely found in how certain processes are defined, to make the runs faster. Currently it is difficult to make iterations or even quick tests as the model runs relatively slow.