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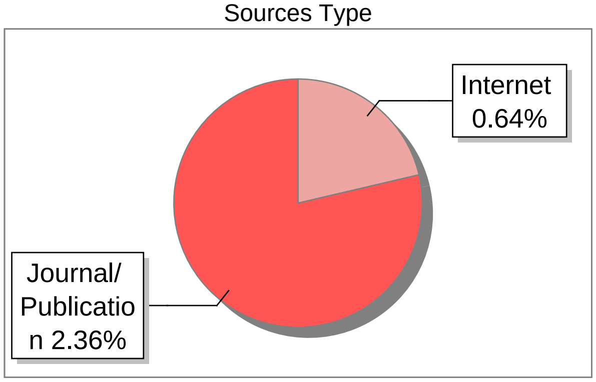

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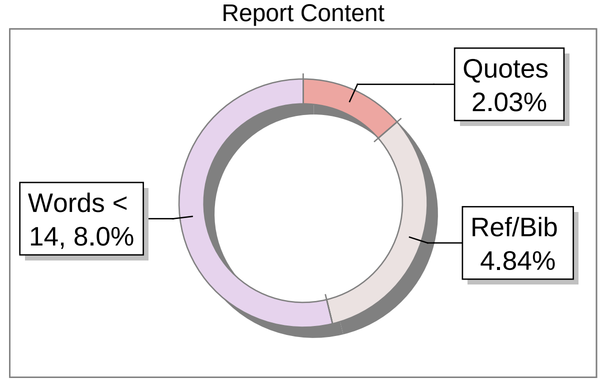

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ASSESSING THE RESILIENCE OF DELHI ROAD NETWORKS AGAINST ROAD CLOSURES

BY

ROSHAN KUMAR (Enrolment No. 20/11/EC/049)

under the guidance of

Dr. Krishnan Rajkumar, School of Engineering JNU, Delhi

in the partial fulfilment of the requirements
for the award of the degree of

Bachelor of Technology
(In Computer Science & Engineering)

School of Engineering

Jawaharlal Nehru University, New Delhi

May, 2024

JAWAHARLAL NEHRU UNIVERSITY SCHOOL OF ENGINEERING

DECLARATION

I declare that the project work entitled **“ASSESSING THE RESILIENCE OF DELHI ROAD NETWORKS AGAINST ROAD CLOSURES”** which is submitted by me in partial fulfilment of the requirements for the award of the **Bachelor of Technology** in **Computer Science Engineering** to the School of Engineering, Jawaharlal Nehru University, Delhi comprises only my original work, and due acknowledgement has been made in the text to all other materials used.

Roshan Kumar. 

JAWAHARLAL NEHRU UNIVERSITY
SCHOOL OF ENGINEERING

CERTIFICATE

This is to certify that the project work entitled **"ASSESSING THE RESILIENCE OF DELHI ROAD NETWORKS AGAINST ROAD CLOSURES"** being submitted by **Mr. Roshan Kumar** (Enrolment No. 20/11/EC/049) in fulfilment of the requirements for the award of the **Bachelor of Technology** in **Computer Science Engineering**, will be carried out by him under my supervision.

In my opinion, this work fulfils all the requirements of an Engineering Degree in respective streams as per the regulations of the School of Engineering, Jawaharlal Nehru University, Delhi. This thesis does not contain any work, which has been previously submitted for the award of any other degree.

13/05

Dr. Krishnan Rajkumar
(Supervisor)
Assistant Professor
School of Engineering
Jawaharlal Nehru University, Delhi

UNIVERSITY SCHOOL OF ENGINEERING

ACKNOWLEDGMENT

I express my sincere gratitude to **Dr. Krishnan Rajkumar**, Assistant Professor at the School of Engineering, Jawaharlal Nehru University, Delhi, for his invaluable guidance and supervision during the completion of our project, "**ASSESSING THE RESILIENCE OF DELHI ROAD NETWORKS AGAINST ROAD CLOSURES**".

His expertise and encouragement have significantly contributed to the quality of my work.

I am thankful for his unwavering support and mentorship.

Roshan Kumar.

ABSTRACT

Road networks, crucial for the efficient movement of people and goods, often face disruptions due to accidents, natural disasters, and infrastructure failures, impacting societies and economies. This project utilises network science to assess the resilience of road networks, with a focus on their structural characteristics and strategies to enhance robustness. By leveraging data from Open Street Maps, the study employs a comprehensive methodology.

The project contributes to a nuanced understanding of network science factors, offering strategies to fortify existing networks and design more resilient road networks for the future.

LIST OF CONTENTS

CHAPTER 1
INTRODUCTION AND THESIS OVERVIEW

1. INTRODUCTION

This thesis employs a network science approach to assess road network resilience. Starting with data collection, we analyse network structure, simulate disruptions, and measure post-disruption performance. Our study enhances understanding of network science and provides insights for urban planning recommendations.

2. THESIS OVERVIEW

The primary objective of this thesis is to scrutinise and comprehend the resilience of road networks by employing the tools and methodologies of network science. Through rigorous analysis, the aim is to unravel the underlying factors contributing to network robustness, thereby providing insights that can inform strategies for enhancing the resilience of existing road networks and the design of future road infrastructure.

3. ORGANISATION OF CHAPTERS

To achieve a coherent exploration of road network resilience, this thesis is structured as follows:

- Chapter 2: Literature Survey

Provides a comprehensive review of existing literature related to road network resilience, disruption scenarios, and the application of network science in understanding complex systems.

- Chapter 3: Proposed Work and Methodology

Details the methodology employed in this study, including the collection of road maps and road data, network analysis techniques, simulation of disruption scenarios, and the evaluation of robustness metrics.

- Chapter 4: Results & Discussion

Presents the findings from the network structure analysis, disruption impact assessment, and evaluation of robustness metrics. Each sub-section delves into specific aspects of the analysis, providing a nuanced understanding of the road network resilience

- Chapter 5: Conclusion

Summarises the key findings, their implications, and recommendations for practical applications. Additionally, this chapter discusses the limitations of the study and proposes avenues for future research in the domain of road network resilience.

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10 CHAPTER 2 LITERATURE SURVEY 1. INTRODUCTION The literature review explores the resilience of road networks, specifically focusing on Delhi, with insights from Tamene Sinishaw Gelaye's research on Addis Ababa's road network. Gelaye also assessed network resilience using the open street map format, just as my study does for Delhi. Both investigations aim to understand the robustness of urban road networks in the face of traffic disruptions. By building upon Gelaye's work and adapting methodologies to the unique context of Delhi, I have tried to contribute to the broader understanding of road network resilience and its implications for urban transportation systems. 2. DATASET In this project, I have used the data mainly from Open Street Maps. This big dataset is the core of my investigation, giving some useful insights into how Delhi's transit system works. Open Street Maps data is like a treasure trove, providing details about routes, stops, and every little place listed on the maps, which helps us take a close look at the city's transportation network. My method uses this data to carefully study how well the road network can handle disruptions, how efficient it is, and how adaptable it can be. By bringing in information from various sources, this study makes sure we have a full understanding of how things work in Delhi's transit system. This helps us explore network resilience in a detailed and informed way.

3. NETWORK SCIENCE IN ROAD NETWORKS

In this project, we explore the world of network science within the context of road networks. Network science helps us understand how different parts of the road network are connected and how information or disruptions can flow through these connections. Think of it like understanding the relationships and interactions between various roads, intersections, and stops in a city. By applying network science to road networks, we aim to unravel the complexities of Delhi's transportation system. This involves studying how disruptions, such as road closures or accidents, impact the overall network and how resilient the system is in bouncing back from these challenges. Through this approach, we gain valuable insights into the structure, efficiency, and adaptability of Delhi's road network, contributing to a deeper understanding of how these networks function in real-world scenarios.

4. OBJECTIVES

i. Analyse the road network using OSMnx to understand its structure and connectivity.

ii. Calculate the Edge Vulnerability Index (RVI) for important road segments to assess network robustness.

iii. Identify key roads that contribute significantly to network vulnerability.

iv. Provide insights and recommendations for improving the resilience of the road network.

CHAPTER 3
PROPOSED WORK AND METHODOLOGY

1. DATA COLLECTION

To conduct a comprehensive network analysis, I needed access to the transit data related to the road network in Delhi. My search led us to the Open Street Maps website, where I found a wealth of information, encompassing both static and dynamic data. I found a way using python to download and use the static data of the road network, which contained information such as buildings and road network with intersections and associated geographic information.

2. NETWORK ANALYSIS

After obtaining the transit data, I chose to create a Python script. Utilising the features of the Python programming language, I extensively employed the robust networkx & osmnx libraries, well-regarded in network science projects. My initial efforts concentrated on data preprocessing, excluding irrelevant fields from my analysis. To improve accessibility, I structured the data into GeoPandas GeoDataFrames.

- **2.1 Directed Graph**

I obtained a directed graph where nodes symbolise buildings, intersections and other important landmarks, and the edges represent the connecting roads.

Furthermore, the edges were enriched with attributes such as distance, along with a dictionary encapsulating node IDs and endpoints.

- **2.2 Road Network Robustness**

Road network robustness refers to the ability of a road network to maintain its functionality and connectivity in the face of disruptions or failures. A robust road network can withstand and recover from adverse events such as accidents, natural disasters, or intentional attacks, while still providing efficient transportation services. Robustness is crucial for ensuring the reliability and resilience of the transportation system, and maintaining accessibility for people and goods.

In the context of this project, road network robustness is assessed through the calculation of the Road Vulnerability Index (RVI). This index measures the impact of removing individual road segments on the overall connectivity and accessibility of the network. Roads with higher RVI values are considered more critical, as their removal can significantly disrupt the network and its ability to function effectively.

By understanding the robustness of the road network, transportation planners and policymakers can identify vulnerabilities, prioritise infrastructure investments, and develop strategies to enhance the resilience of the network to various disruptions.

- **2.3 OSMnx Python Package**

OSMnx is a Python package that allows users to download, analyse, and visualise OpenStreetMap (OSM) data. It provides a convenient interface to access OSM's rich database of geographic information, including roads, buildings, and points of interest. OSMnx can be used for various network analysis tasks, especially in the context of urban planning, transportation engineering, and spatial analysis.

Some key features and applications of OSMnx in network analysis include:

i. Network Extraction: OSMnx can extract street networks from OSM data for any location in the world. It provides tools to filter the data based on different criteria such as network type (e.g., drive, walk, bike), distance, and bounding box.

ii. Network Analysis: OSMnx allows users to analyse the extracted street networks using various metrics and algorithms. This includes calculating shortest paths, finding nearest nodes, identifying connected components, and measuring network statistics such as node degree, betweenness centrality, and clustering coefficient.

iii. Visualisation: OSMnx provides tools to visualise street networks and associated data. It can create static and interactive plots of the networks, highlighting different features such as nodes, edges, and network attributes.

iv. Geocoding and Reverse Geocoding: OSMnx supports geocoding (converting addresses to geographic coordinates) and reverse geocoding (finding addresses from geographic coordinates) using OSM's data.

```
locations = {
    "Delhi University": (28.690956714654007, 77.2172266919105),
    "AIIMS Hospital": (28.56605868580513, 77.21120586861386),
    "Karol Bagh": (28.655110850607876, 77.18894406534763),
    "Kashmere Gate": (28.668587063940173, 77.22803556304746),
    "NDLS Railway Station": (28.64198133410332, 77.2219675483505),
    "Nehru Place": (28.550644879573245, 77.250201462446)
}
```

v.

Accessibility Analysis: OSMnx can be used to analyse the accessibility of locations within a city or region. This includes measuring travel times, identifying areas with limited access to amenities or services, and optimising transportation routes.

3. DISRUPTION SCENARIOS

In our project, we simulated road closures to assess the robustness of the road network using OSMnx. We achieved this by systematically removing edges from the network to simulate the effects of road closures. This process involved identifying important nodes throughout the city and finding the shortest paths connecting them and then iteratively removing important roads one by one. After each removal, we recalculated the shortest paths between the selected pairs of nodes to measure the network's resilience to disruptions. This approach allowed us to evaluate the impact of each road closure on the overall connectivity and accessibility of the road network.

4. ROAD VULNERABILITY INDEX (RVI)

The Road Vulnerability Index (RVI) is a metric coined & used by me to quantify the importance of edges in our network. In this project, I have calculated the RVI for several selected roads/road segments in the network to assess its criticality in maintaining network connectivity. The process of calculating the RVI involves the following steps:

4.1 Select Nodes for Analysis: A set of 6 nodes within the network are selected as points of origin i and destination j. These nodes are selected on the basis of their location and their importance in terms of traffic conditions and busy roads/markets nearby. We have selected the following nodes:

4.2 Calculate Shortest Paths: First, I've calculated the shortest paths between all pairs of nodes in the network. This is considered the non-degradated configuration of the road network, where the serviceability of all edges is not changed by any failure. A reference value α is calculated for this scenario as the sum of the distances of the shortest paths considered.

4.3 Iteratively Remove Roads/Road Segments: Next, we iterated over each edge belonging to the road in consideration in the network and temporarily removed it. By removing an edge, we simulate a road closure scenario, where that edge becomes unavailable for travel.

4.4 Recalculate Shortest Paths: After removing a road, we recalculated the shortest paths between all pairs of nodes. This step allows us to observe how the removal of the edges corresponding to a road affects the overall network connectivity. If the removal of a road significantly increases the shortest path length between nodes, it indicates that the edge is important for maintaining efficient travel routes.

4.5 Calculate RVI: The RVI for a road is calculated as the difference in the total length of shortest paths before and after the road removal, divided by the total length of shortest paths before removal. This ratio provides a measure of how much the network's connectivity is affected by the removal of the road. Higher RVI values indicate that the road is more critical for network connectivity.

4.6 Aggregate RVI Values: Finally, we aggregated the RVI values for all roads/road segments to identify the most critical roads in the network. These roads are essential for maintaining efficient travel routes and network connectivity.

By calculating the RVI for each road in the road network, we can prioritise infrastructure improvements and develop strategies to enhance the network's resilience to disruptions.

CHAPTER 4
RESULTS & DISCUSSION

1. FINDINGS FROM ANALYSIS OF THE NETWORK

The findings of the network analysis carried out is presented in distinct sections below.

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16 1.1 Construction of a Directed Graph We constructed a directed graph and marked a set of 6 nodes for analysis. With 81,982 nodes and 2,22,218 edges, the graph's sheer size makes visualising the entire network challenging. Consequently, we focus on analysing key network science properties using the selected 6 nodes and select roads/road segments of the network. The figure shows the output of the above code segment which includes the network highlighting the selected nodes.

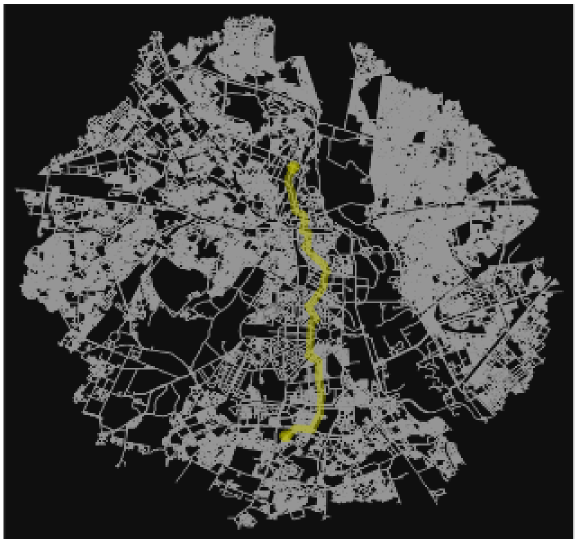
- **1.2 Calculation of α value using non-degradated configuration**

```python
# Find the shortest paths between each pair of nodes and store them
shortest_paths = {}
distances = {}
for orig_name, orig_coords in locations.items():
    orig_node = ox.distance.nearest_nodes(G, orig_coords[1], orig_coords[0])
    for dest_name, dest_coords in locations.items():
        dest_node = ox.distance.nearest_nodes(G, dest_coords[1], dest_coords[0])
        if orig_name != dest_name and (orig_name, dest_name) not in shortest_paths:
            route = ox.shortest_path(G, orig_node, dest_node, weight="length")
            if route is not None:
                shortest_paths[(orig_name, dest_name)] = route
                distances[(orig_name, dest_name)] = sum(ox.distance.great_circle(G.nodes[u]['y'], G.nodes[u]['x'], G.nodes[v]['y'], G.nodes[v]['x']) for u,

# Print the shortest paths and distances
for (orig_name, dest_name), route in shortest_paths.items():
    print(f"Shortest path from {orig_name} to {dest_name}: {route}")
    print(f"Distance: {distances[(orig_name, dest_name)]} meters\n")

# Calculate and print the sum of distances
alpha = sum(distances.values())
print(f"Sum of distances: {alpha} meters")

# Plot the routes
```

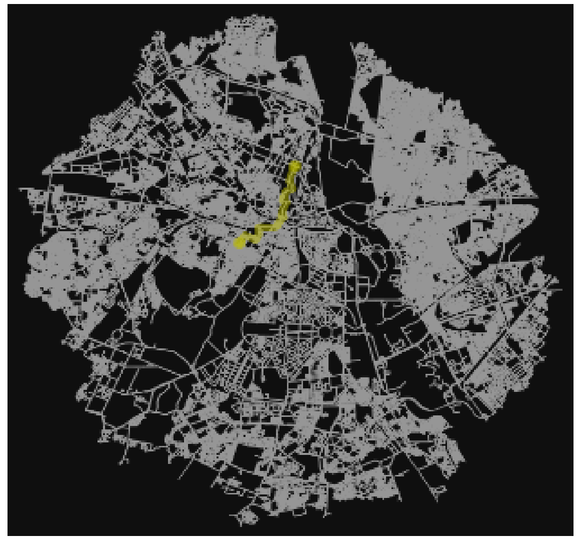
```
Shortest path from Delhi University to AIIMS Hospital: [2945828443, 2945828442, 2945827921, 2939969321, 2945827905, 9840505818, 2111354713, 9840458524, 24923
Distance: 17343.692930280617 meters

Shortest path from Delhi University to Karol Bagh: [2945828443, 2945828442, 2945827921, 2939969321, 2945827905, 2940370460, 2945827898, 4231889759, 42318897
Distance: 6469.939267835427 meters

Shortest path from Delhi University to Kashmere Gate: [2945828443, 2945828442, 2945827921, 2939969321, 2945827905, 9840505818, 2111354713, 9840458524, 249237
Distance: 3849.955429146483 meters

Shortest path from Delhi University to NDLS Railway Station: [2945828443, 2945828442, 2945827921, 2939969321, 2945827905, 9840505818, 2111354713, 9840458524,
Distance: 7070.576629156173 meters

Shortest path from Delhi University to Nehru Place: [2945828443, 2945828442, 2945827921, 2939969321, 2945827905, 9840505818, 2111354713, 9840458524, 2492370
Distance: 18357.87377597809 meters

Shortest path from AIIMS Hospital to Delhi University: [9708311619, 9870290403, 2499372782, 2499372781, 2499372789, 2714630327, 6021916568, 563097440, 25007
Distance: 16430.84081801397 meters

Shortest path from AIIMS Hospital to Karol Bagh: [9708311619, 9870290403, 2499372782, 2499372781, 2499372789, 2714630327, 6021916568, 563097440, 250078357,
Distance: 13478.419146153401 meters

Shortest path from AIIMS Hospital to Kashmere Gate: [9708311619, 9870290403, 2499372782, 2499372781, 2499372789, 2714630327, 2714630359, 10242231170, 102422
Distance: 13819.74320925534 meters

Shortest path from AIIMS Hospital to NDLS Railway Station: [9708311619, 9870290403, 2499372782, 2499372781, 2499372789, 2714630327, 6021916568, 563097440, 2
Distance: 10749.19674819965 meters

Shortest path from AIIMS Hospital to Nehru Place: [9708311619, 9870290403, 2499372782, 2499372781, 7652376687, 2499372751, 2293345132, 2293345133, 11773788
Distance: 5739.684122708588 meters
```

The α **value** obtained as a result of the above calculation is: **306726.36 meters**

Some graphs plotted for shortest paths are shown below:



1. Route from Delhi University to AIIMS Hospital.



2. Route from Delhi University to Karol Bagh.

- **1.3 Removal of Roads & RVI Calculation**

I. Mahatma Gandhi Marg

Number of edges corresponding to road filter: 474.

```python
# Find the shortest paths between each pair of nodes and store them
shortest_paths = {}
distances = {}
for orig_name, orig_coords in locations.items():
    orig_node = ox.distance.nearest_nodes(G_filtered, orig_coords[1], orig_coords[0])
    for dest_name, dest_coords in locations.items():
        dest_node = ox.distance.nearest_nodes(G_filtered, dest_coords[1], dest_coords[0])
        if orig_name != dest_name and (orig_name, dest_name) not in shortest_paths:
            route = ox.shortest_path(G_filtered, orig_node, dest_node, weight="length")
            if route is not None:
                shortest_paths[(orig_name, dest_name)] = route
                distances[(orig_name, dest_name)] = sum(ox.distance.great_circle(G_filtered.nodes[u]['y'], G_filtered.nodes[u]['x'], G_filtered.nodes[v]['y

# Print the shortest paths and distances
for (orig_name, dest_name), route in shortest_paths.items():
    print(f"Shortest path from {orig_name} to {dest_name}: {route}")
    print(f"Distance: {distances[(orig_name, dest_name)]} meters\n")

# Calculate and print the sum of distances
beta = sum(distances.values())
print(f"Sum of distances: {beta} meters")
```

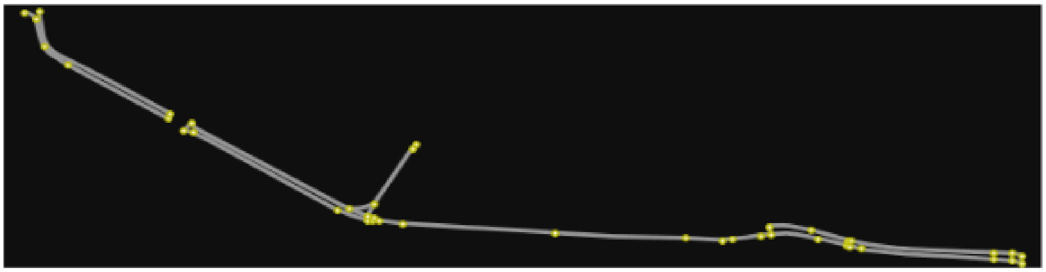
Calculated β value: 321224.36 meters.

Road Vulnerability Index (RVI): 4.73 %

```python
# Calculate the Road Vulnerability Index (RVI)
RVI = (beta - alpha) / alpha * 100

# Print the Edge Vulnerability Index
print(f"Road Vulnerability Index (RVI): {RVI} %")
```

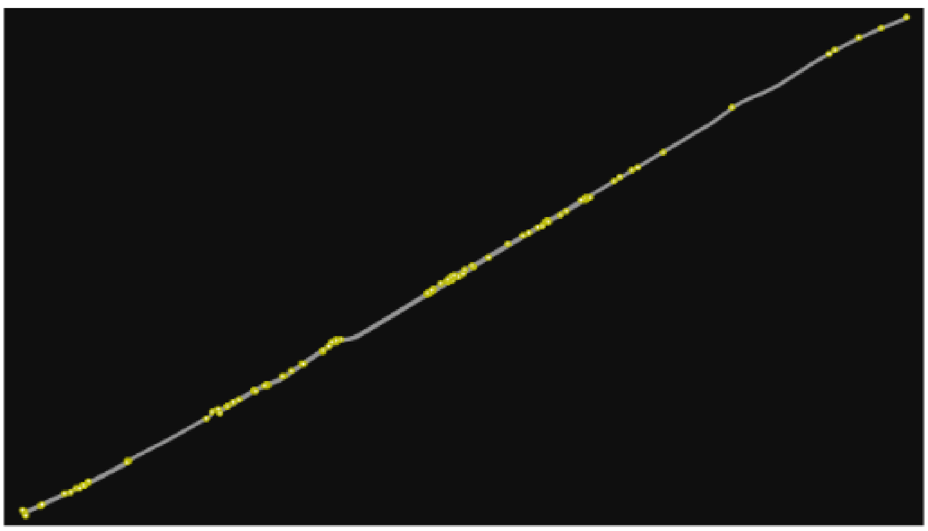
```
Road Vulnerability Index (RVI): 4.726687839434384 %
```

II. Jawaharlal Nehru Marg



Number of edges corresponding to road filter: 39
Calculated β value: 308445.31 meters
Road Vulnerability Index (RVI): 0.56 %

III. Mathura Road, Dr. Zakir Hussain Marg

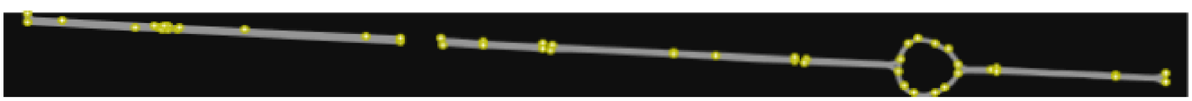


Number of edges corresponding to road filter: 102
Calculated β value: 307932.14 meters
Road Vulnerability Index (RVI): 0.39 %

IV. Ashoka Road

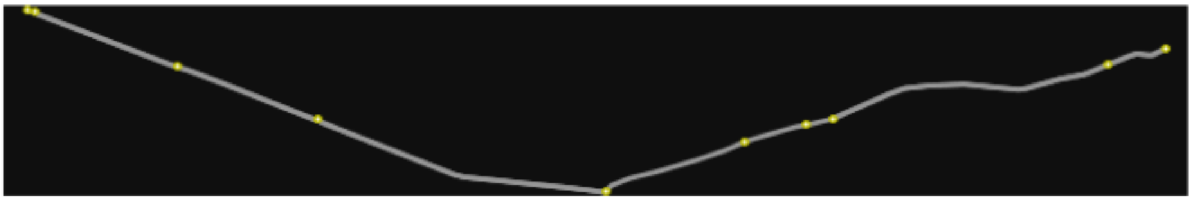
Number of edges corresponding to road filter: 32
Calculated β value: 306825.39 meters
Road Vulnerability Index (RVI): 0.03 %

V. Janpath, Motilal Nehru Place Road



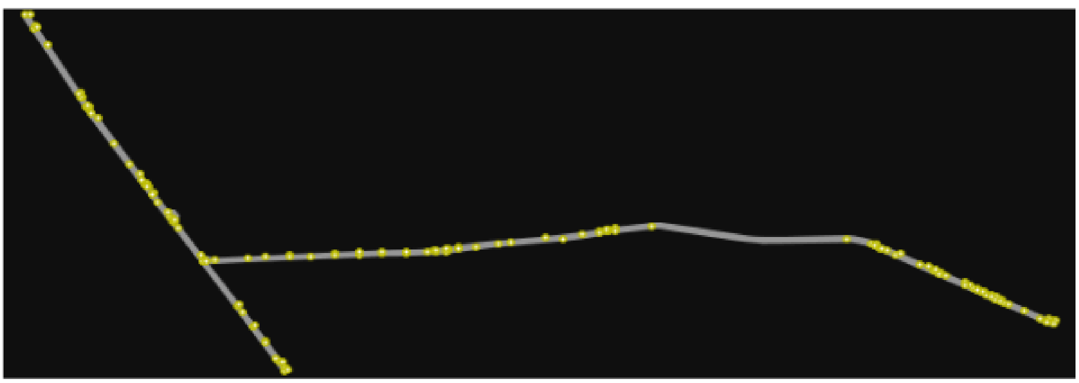
Number of edges corresponding to road filter: 44
Calculated β value: 307651.20 meters
Road Vulnerability Index (RVI): 0.30 %

VI. Vishwavidyalaya Road, Acharya Sushil Marg, Chaubhurja Marg



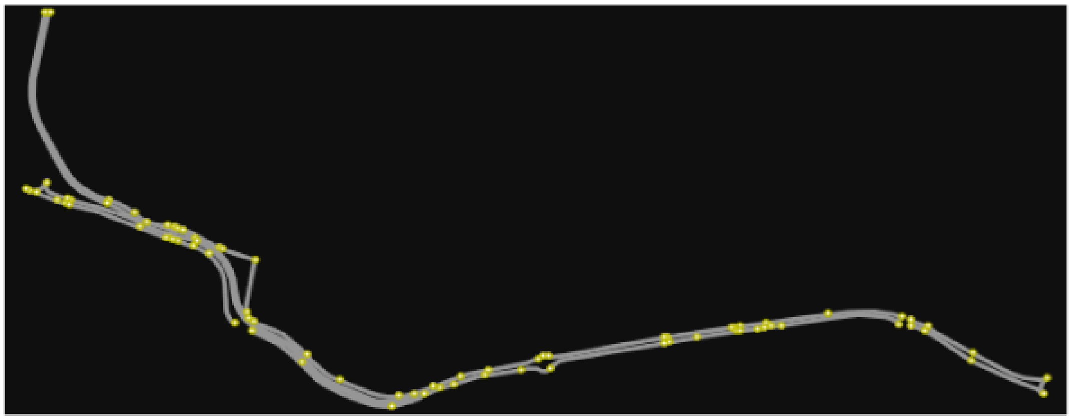
Number of edges corresponding to road filter: 15
Calculated β value: 315138.11 meters
Road Vulnerability Index (RVI): 2.74 %

VII. Maharishi Raman Marg, Bhishma Pitamah Marg, Subramaniyam Bharti Marg



Number of edges corresponding to road filter: 134
Calculated β value: 309004.96 meters
Road Vulnerability Index (RVI): 0.74 %

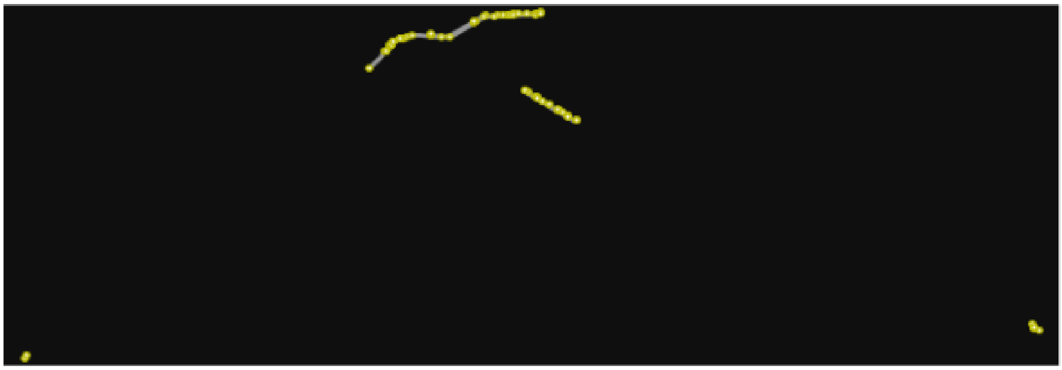
VIII. Rani



Jhansi Flyover, Rani Jhansi Road

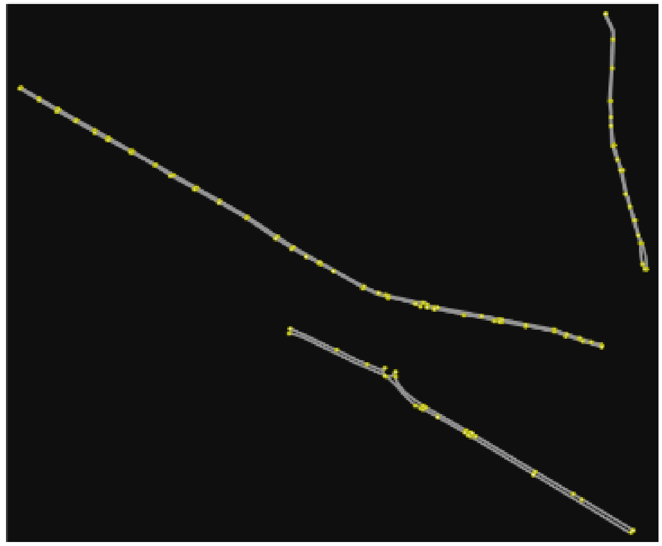
Number of edges corresponding to road filter: 73
Calculated β value: 311688.05 meters
Road Vulnerability Index (RVI): 1.62 %

IX. Netaji Subhash Marg, Lothiyan Road, Vivekanand Marg



Number of edges corresponding to road filter: 62
Calculated β value: 314230.38 meters
Road Vulnerability Index (RVI): 2.45 %

X. Deshbandhu Gupta Road, Panchkuian Road, Qutab Road



Number of edges corresponding to road filter: 115

Calculated β value: 312051.90 meters

Road Vulnerability Index (RVI): 1.74 %

XI. Mahatma Gandhi Marg, Netaji Subhash Marg, Maharishi Raman Marg

Number of edges corresponding to road filter: 536

Calculated β value: 325984.29 meters

Road Vulnerability Index (RVI): 6.28 %

2. DISCUSSION

In the analysis, there were several significant trends and observations:

2.1 High EVI Values: Some edges, such as those belonging to Mahatma Gandhi Marg / Netaji Subhash Marg / Maharishi Raman Marg, had high RVI values (6.28%). This indicates that these edges are crucial for maintaining network connectivity, and their closure could have a significant impact on travel times and network efficiency.

2.2 Low EVI Values: On the other hand, edges like Ashoka Road had relatively low RVI values (0.03%). These edges are less critical for network connectivity, suggesting that their closure may have a smaller impact on overall travel times and network efficiency.

2.3 Road Network Redundancy: The presence of multiple roads with low RVI values, such as Jawaharlal Nehru Marg (0.56%) and Rani Jhansi Flyover / Rani Jhansi Road (1.62%), indicates redundancy in the road network. This redundancy provides alternative routes in case of road closures, improving network resilience.

2.4 Major Road Intersections: Roads like Vishwavidyalaya Road / Acharya Sushil Marg / Chaubhurja Marg (2.74%) and Netaji Subhash Marg / Lothiyan Road / Vivekanand Marg (2.45%) had moderate RVI values. These roads likely represent major intersections or key routes, highlighting their importance in the road network.

2.5 Recommendations for Improvement: Based on the RVI values, we can recommend improvements to the road network to enhance its robustness. This could include adding alternative routes, improving road infrastructure, or implementing traffic management strategies to reduce congestion and improve network efficiency, helping urban planners and policymakers make informed decisions to improve road network resilience and efficiency.

3. IMPLICATIONS & SUGGESTIONS

The Road Vulnerability Index (RVI) values obtained from this analysis have several implications for network robustness and urban planning:

3.1 Identifying Critical Infrastructure: High RVI values indicate roads that are critical for maintaining network connectivity. Urban planners can use this information to prioritise these roads for maintenance, upgrades, or alternative route planning to minimise the impact of potential road closures.

3.2 Improving Resilience: Understanding which roads are most vulnerable allows planners to focus on improving the resilience of the network. This could involve implementing measures such as adding redundant connections, improving road surface quality, or enhancing traffic management systems.

3.3 Optimising Infrastructure Investments: By identifying roads with high RVI values, urban planners can prioritise infrastructure investments where they will have the greatest impact on network robustness. This can help optimise limited resources and improve overall network performance.

3.4 Emergency Response Planning: Knowledge of the RVI values can be crucial for emergency response planning. It helps authorities anticipate the impact of road closures during emergencies and develop strategies to maintain essential services and mobility for residents.

3.5 Public Transportation Planning: RVI values can also inform public transportation planning. Understanding which roads are critical for network connectivity can help optimise public transport routes, improve accessibility, and reduce congestion on key roads.

CHAPTER 5
CONCLUSION

In conclusion, this project aimed to assess the robustness of a road network using OSMnx and NetworkX, focusing on calculating the Road Vulnerability Index (RVI). The objectives were to identify critical roads, evaluate their importance in maintaining network connectivity, and propose strategies for enhancing network resilience.

Through the analysis, we found that certain roads, such as Mahatma Gandhi Marg and Netaji Subhash Marg, have high EVI values, indicating their significance in the network. These roads are crucial for maintaining connectivity and require special attention for maintenance and infrastructure development.

The project also highlighted the importance of using open-source tools like OSMnx for network analysis. These tools provide valuable insights into network structure, connectivity, and vulnerabilities, which are essential for urban planning and infrastructure management.

Moving forward, recommendations for improving network robustness include enhancing road infrastructure, implementing traffic management strategies, and developing alternative routes. Additionally, the project underscores the need for ongoing monitoring and evaluation of road networks to adapt to changing urban dynamics and mitigate potential disruptions.

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