

Summary

This paper proposes optimization solutions for the urban road system in Baltimore, Maryland. First, we established a directed network model and simulated the traffic impact based on road capacity and traffic flow, analyzing the effects of bridge segment failures, such as on Ritchie Highway, which is one of the most affected roads. The simulation results helped us clarify the specific impact of traffic flow changes on the entire city road system, providing a theoretical foundation for further traffic optimization.

Next, we evaluated the importance of existing bus routes by analyzing passenger flow and service coverage. We identified key routes that need prioritization for maintenance and attention, such as Route 22, BL, OR, and 54. This analysis helps ensure stable public transportation services in high-demand areas, improving the overall efficiency and reliability of the public transport network.

Additionally, we used K-means clustering to analyze bus stops, first dividing them into multiple regions. We then applied a weighted K-means clustering model to further divide the stops into new regions. By comparing the results with heatmaps, we identified areas with high traffic pressure and proposed solutions, such as adding bus stops in key areas, to alleviate congestion and enhance traffic flow and efficiency.

Finally, to improve traffic safety in Baltimore, we proposed recommendations for improving public transportation infrastructure, including optimizing road safety, installing surveillance cameras, and enhancing street lighting. Providing safer facilities for pedestrians and cyclists, such as dedicated pedestrian lanes and bike lanes, can significantly reduce accidents. Moreover, collecting traffic accident data, collaborating closely with law enforcement, developing emergency response plans, and ensuring accessibility for people with disabilities are all critical measures to improve urban traffic safety.

Keywords: Graph-based models; K-means clustering; Shortest path algorithms; Public transportation network;

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1 Introduction

1.1 Overview

1.1.1 Backgrounds

In contemporary society, the transportation system serves not only as a means for daily travel but also as one of the pivotal infrastructures supporting urban operations. Particularly in rapidly developing cities, the efficiency and accessibility of transportation systems are directly linked to residents' quality of life, the smooth progression of economic activities, and the city's sustainable development. Whether it pertains to the daily commutes of city dwellers, the supply chain logistics, or the city's overall competitiveness, the quality of the transportation network plays an indispensable role. The construction and enhancement of transportation infrastructure significantly impact local residents' travel convenience and living costs, while also playing a crucial role in urban economic growth and environmental sustainability.

Baltimore, one of the largest and most significant cities in Maryland, has long been a focal point for both residents and visitors. As a historic city and a modern commercial hub, Baltimore's transportation demands are particularly challenging. With increasing population and ongoing urbanization, Baltimore's transportation network confronts numerous obstacles. Issues such as peak-hour traffic congestion, aging infrastructure, and inefficient public transit systems have a substantial impact on daily travel experiences of citizens. traffic map provided by the Baltimore

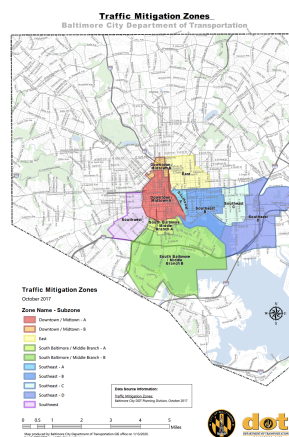


Figure 1: traffic map from the us department of trasportation

Department of Transportation For instance, on March 26, 2024, the Francis Scott Key Bridge collapsed, exacerbating traffic conditions in Baltimore. The closure of the bridge redirected traffic to other already congested port crossings, resulting in months or even years of arduous commutes for residents. Both alternative routes pass through tunnels near downtown Baltimore, leading to an influx of diverted vehicles during rush hours, further congesting already crowded roads. According to Maryland authorities, approximately 35,000 vehicles cross the bridge daily, and the sudden surge in traffic has intensified the strain on local traffic networks.

Moreover, Baltimore's traffic accident problem is a pressing concern. The Baltimore City Department of Transportation reports tens of thousands of traffic accidents annually. In 2022, over

30,000 traffic accidents were recorded in Baltimore, with the number of fatal accidents rising in recent years, especially those involving pedestrians and cyclists. In 2022, there were approximately 50 fatal traffic accidents in Baltimore. The aging transportation system and infrastructure are often cited as primary contributors to the frequent traffic accidents.

This highlights the severe challenges facing Baltimore's transportation network, particularly in the context of rapid urban growth. Addressing traffic safety and alleviating congestion through effective traffic planning and infrastructure improvements have become urgent priorities for Baltimore City.

1.1.2 Problem Restatement

1. Impact of Francis Scott Key Bridge Collapse

- Assess the impact of the bridge collapse on Baltimore's transportation system.
- Focus on how the collapse affects different stakeholders (e.g., commuters, businesses, emergency services).
- Include the effects of the ongoing bridge reconstruction.

2. Impact of Bus or Pedestrian Walkway Project

- Choose a bus or pedestrian walkway project in Baltimore.
- Show how the project impacts local transportation (e.g., bus routes, pedestrian access).
- Highlight the effects on various stakeholders (e.g., residents, commuters, businesses).

3. Recommendation for a Transportation Improvement Project

Propose a transportation project to improve life for Baltimore residents. a. Benefits: How it improves residents' daily lives (e.g., faster commute, safer walkways). b. Impact on Other Stakeholders: How other groups (e.g., businesses, other commuters) are affected. c. Disruptions: Describe any disruptions the project might cause (e.g., construction delays, traffic impacts).

1.2 Terminology

- $G = (V, E)$: Traffic network graph
 - V : Set of nodes, representing intersection points in the transportation system (e.g., street intersections, bus stations, bridges).
 - E : Set of edges, representing transportation routes (e.g., streets, tracks, bus lines).
- w_{ij} : Weight of edge (i, j) , representing the transportation cost (e.g., time, flow, distance) from node i to node j .
- $f(u, v)$: Flow from node u to node v , representing the amount of traffic flow on that path.
- c_{uv} : Capacity of edge (u, v) , representing the maximum traffic flow that the edge can support.

- s : Source node, representing the starting point of the traffic flow (e.g., the entry point of traffic into the city).
- t : Sink node, representing the endpoint of the traffic flow (e.g., where traffic exits the city or flows to another region).
- $d(v)$: Shortest path distance from the source to node v , representing the minimum traffic cost (e.g., time or distance).
- q : Traffic flow (units: vehicles per hour), representing the number of vehicles passing through a certain segment of road per unit time.
- k : Lane density (units: vehicles per kilometer), representing the number of vehicles per unit length of road.
- v : Traffic speed (units: kilometers per hour), representing the speed at which vehicles travel.
- $d(v)$: Shortest path distance from source s to node v , representing the minimum traffic cost (e.g., time or distance).
- w_{ij} : Weight of edge (i, j) , representing the transportation cost (e.g., time, flow, distance) between nodes i and j .
- $u \in V$: A node $u \in V$ from the set of nodes, used for finding the shortest path from the source s to other nodes.
- x : Decision vector, representing the selected scheme or strategy in the optimization process (e.g., choosing transportation routes, setting capacities for transportation facilities).
- $f_1(x), f_2(x), f_3(x)$: Multiple objective functions
 - $f_1(x)$: Objective function for minimizing commute time.
 - $f_2(x)$: Objective function for maximizing transportation efficiency.
 - $f_3(x)$: Objective function for minimizing environmental impact.

1.3 Assumptions

- **Assumption 1:** The transportation network is represented as a connected graph, where each node represents a transportation hub (e.g., street intersection, bus station), and each edge represents a transportation route (e.g., street, track, bus line).
- **Assumption 2:** The transportation cost (such as travel time, distance, or congestion) between any two nodes is symmetric, meaning that the cost to travel from node i to node j is the same as from node j to node i .
- **Assumption 3:** The traffic flow between nodes is considered to be a continuous function, and the capacity of each edge is fixed and constant during the analysis period.

- **Assumption 4:** The traffic network operates under typical weather conditions, and extreme weather or unexpected disruptions are not considered in this model.
- **Assumption 5:** The travel demand (e.g., commuter traffic, goods transportation) is known and fixed for the analysis period, and external factors such as economic shifts or population growth are not taken into account.
- **Assumption 6:** The system is designed to minimize traffic congestion and optimize the overall travel time for commuters and goods transportation, with a focus on short-term optimization (e.g., daily or weekly traffic patterns).

1.4 Data Pre-processing

Using the OSMnx library [1], we downloaded road network data south of the Francis Scott Key Bridge from OpenStreetMap [2]. Subsequently, we merged the downloaded data with the existing `nodes_drive.csv` and `edges_drive.csv` files to create new files named `nodes_drive_merge.csv` and `edges_drive_merge.csv`.

Through OpenStreetMap, we identified the coordinates of the Francis Scott Key Bridge as (39.21732, -76.52815) and pinpointed the OSM IDs of the damaged sections of the bridge as [11763173294, 11763173297]. Meanwhile, We frame the land from Google Maps by determining the coordinates.

2 Analysis of the Problem

2.1 Analysis of the problem 1

First, the data preprocessing phase involves acquiring the road network information for the Bridge South area from OpenStreetMap and integrating it with the existing *edges_drive* and *nodes_drive* datasets. Subsequently, the *edges_all* and *nodes_all* datasets are read to perform data normalization, de-duplication, and coordinate mapping, supplemented by *maxspeed* data for each road.

Secondly, the calculation of road capacity C is conducted. The road capacity for each road segment is determined using a specific formula that takes into account the road type, speed limit, and number of lanes.

Next, the traffic network model is established. Utilizing the preprocessed data, a weighted directed graph $G(u, v, w)$ is constructed to represent Baltimore's traffic network. In this graph, edge weights w correspond to road lengths, and trunk roads are labeled according to their respective capacities.

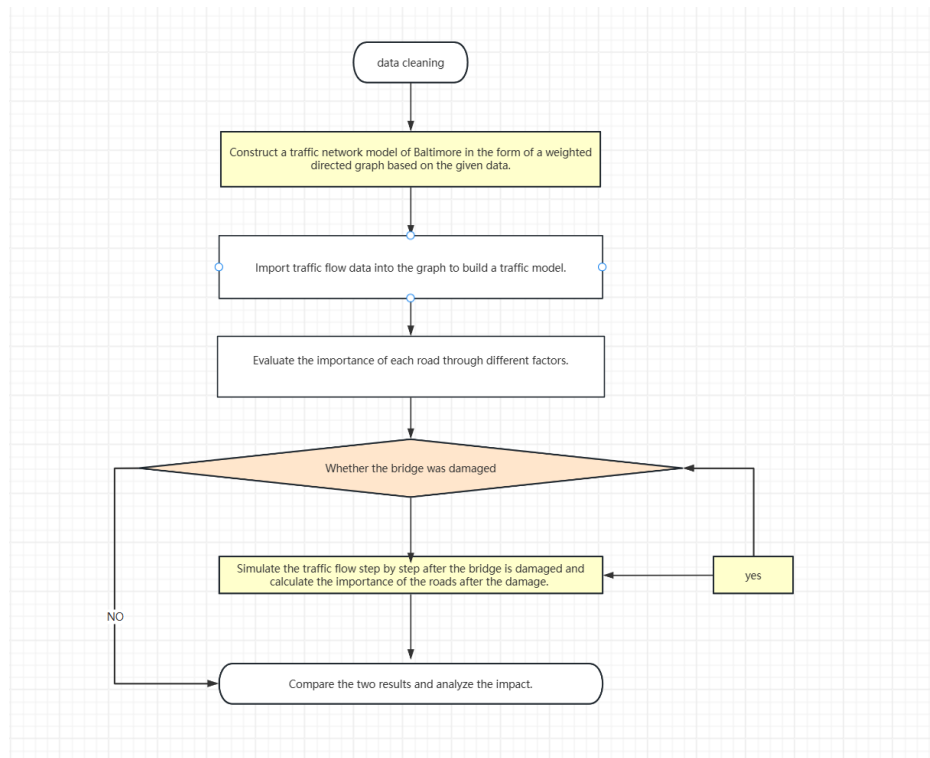


Figure 2: *the process of problem 1*

Subsequently, the impact of a broken bridge on traffic flow is assessed. A circular region centered on the bridge is defined, and two concentric areas on either side of the bridge are selected as the study zones. The average path length and reachability between these two regions are calculated. This includes selecting random points, applying Dijkstra's algorithm to compute the shortest distances, determining the set of reachable points, and calculating the average shortest

distance and connectivity. In the event of a bridge failure, the edge representing the bridge is removed, and the average path length and accessibility are recalculated under the new conditions.

Finally, the influence of traffic flow on the region post-bridge failure is evaluated. The Average Annual Daily Traffic (AADT) data for the bridge is obtained from relevant sources, and this traffic volume is evenly redistributed to the areas adjacent to the bridge. Random start and end points within the two regions are selected, and the shortest paths are computed using Dijkstra's algorithm. Traffic flows are then weighted along these shortest paths. The ratio of the newly added traffic to the road capacity is calculated. If this ratio exceeds the predefined threshold value ($\mu = 0.5$), it is concluded that the bridge failure will have a significant impact on the road network.

2.2 Analysis of the problem 2

Based on the complexity, overlap, and other factors of Baltimore's transportation routes, we conducted the following analysis of bus stops and routes:

First, we plotted all known bus stops and marked different routes with different colors. Next, we defined emergency situations: if a traffic accident or unexpected event occurs on a bus route, causing the bus to be unable to proceed, all the stops on that route will be considered non-functional.

Based on this assumption, we performed an importance analysis of the bus routes. The importance score was calculated using the following two parameters:

Parameter 1: Considering all bus stops of the routes, we calculated the service coverage of the remaining bus stops on the map after removing one route. Specifically, we defined a service area with a radius of 500 meters centered on each bus stop, then calculated the coverage of these service areas over the city area.

Parameter 2: The ratio of the number of passengers getting on and off a bus route after removing one route, to the total number of passengers getting on and off all routes.

The importance formula is:

$$\text{Importance} = 0.7 \times \text{Parameter 2} + 0.3 \times \text{Parameter 1}.$$

Finally, based on this formula, we created a route map and concluded that routes 22, BL, OR, and 54 have the highest importance. Therefore, we need to place special emphasis on the protection and maintenance of these four bus routes.

2.3 Analysis of the problem 3

First, the data from the `bus_stops.csv` file is imported, and the passenger flow at each bus stop (represented by `Rider_Stop`) is used as a weight to plot a heatmap of the bus stops. Next, clustering analysis of the bus stops is performed:

- **K-means clustering** is applied to all bus stops, and they are divided into several regions, labeled as Region A.
- After normalizing the passenger flow, **K-means clustering** is again used to analyze all bus

stops, with the passenger flow used as a weight to divide them into regions, labeled as Region B. The resulting regions are compared with the heatmap.

Subsequently, the load capacity of the regions derived from the clustering analysis is analyzed. A pie chart is created to observe the proportion of bus load in each region.

3 Model building and simplifying

Before all models were built, all appendices were converted into csv format.

3.1 Model building and analysis in problem 1

3.1.1 Data Preprocessing Stage

First, we read the *edges_drive_merge.csv* dataset, which contains edge information for all roads. To ensure the accuracy and consistency of the data, we standardized the data, removed duplicate information, and supplemented the *maxspeed* data with the average speed of each lane type, depending on the type of road. This step provides the basis for subsequent traffic flow analysis and road capacity calculation.

In addition, we read the *nodes_drive_merge.csv* dataset, which contains node information for all road intersections. We matched the *osmid* (OpenStreetMap's unique identifier) of these nodes to the coordinates, so that each node has a clear geographical location information, which facilitates subsequent road network construction and traffic analysis. different road types (the basic capacity of different types of roads is different). In the stage of calculating road capacity C , we use a specific formula $C = L \times S \times B$ to calculate the road capacity of each road according to the type of road, speed limit, and number of lanes. Where L represents the number of lanes, S represents the adjustment ratio derived from the speed limit (the faster the speed, the higher the adjustment ratio, indicating the more vehicles the road can accommodate), and B represents the basic capacity of Through this step, we get the road capacity data of each road, which provides an important basis for the subsequent traffic flow model establishment and analysis.

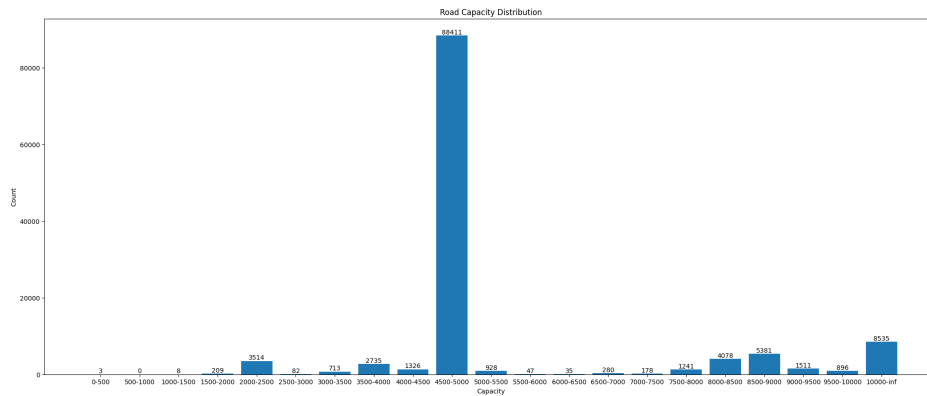


Figure 3: Road capacity distribution

3.1.2 Model Building Stage

After data preprocessing and road capacity calculation, we set about building the traffic flow model. Using the existing road network data, road capacity data, and road length information, we construct a weighted digraph $G(u, v, w)$ to represent the traffic network of Baltimore. Where u and v represent the nodes in the graph (i.e., road junctions), and w represents the weights of the edges (i.e., road lengths). At the same time, we marked trunk roads according to road capacity (roads with $C > 1000$ are considered trunk roads).

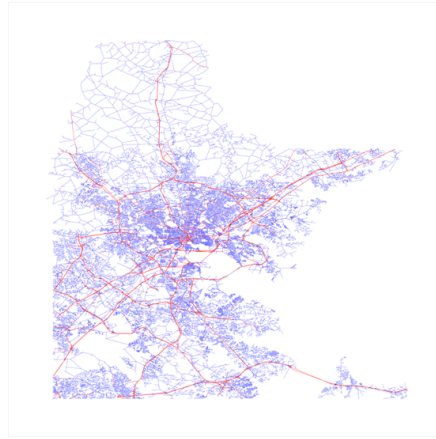


Figure 4: *the route model*

3.1.3 Stages of Assessing the Impact of a Broken Bridge on Traffic



Figure 5: *The red part is the bridge*

To assess the impact of the bridge failure on Baltimore's transportation network, we first built a road network based on the data, with the bridge as the center and a 150 km radius. We then chose

a circular area on either side of the bridge where road users are seen as having a vested interest (which road users are vested can be determined by analysis on the map) as the study area.



Figure 6: *Circular area, representing the vested interests in the area*

Next, we calculate the average path length and reachability between the two regions. The specific method is: randomly take points in the two regions, calculate the shortest distance between the two points through Dijkstra's algorithm, and store the points whose path is less than L (where L is the set threshold) into the point set U , indicating that these points can be reached within a certain time. We then calculated the average shortest distance between the two regions and calculated connectivity (that is, the proportion of points reachable in a given time to all points in the region).

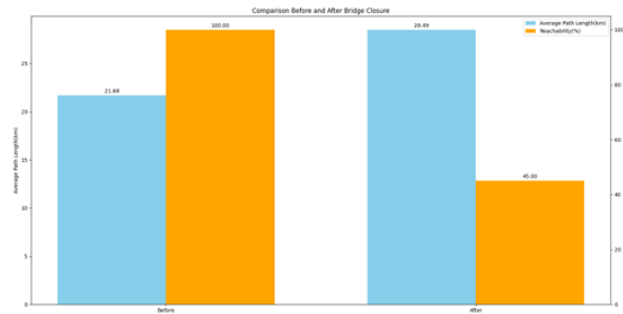
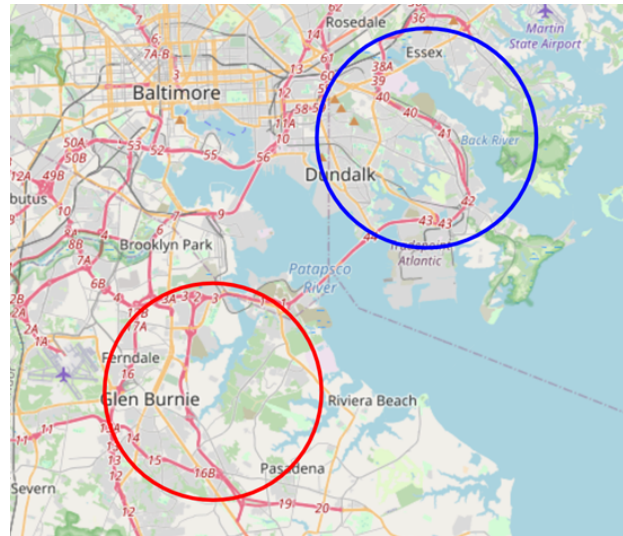
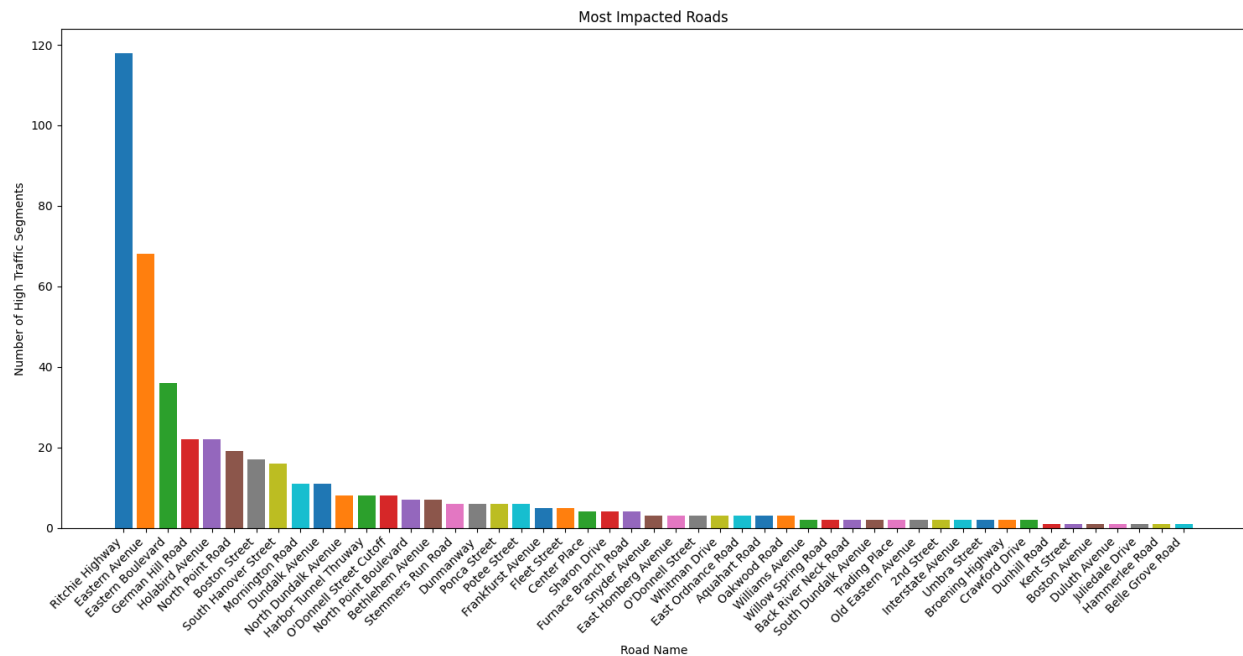


Figure 7: *comparison before and after bridge closure*

To simulate the case of a broken bridge, we removed the two sides representing the bridge in the diagram and recalculated the average path length and accessibility between the two areas after the broken bridge. By comparing the average path length and accessibility before and after a broken bridge, we can assess the impact of a broken bridge on the transportation network.

Finally, we calculate the impact of traffic flow on the region after the bridge is broken. We obtained the AADT (average daily traffic volume) data of the traffic on the bridge from the *mDOt_SHA_annual_average_daily_traffic_baltimo.csv* file and evenly distributed these traffic flows to the areas on both sides of the bridge.

Then, we randomly select two points in the two regions as the starting point and the ending point. Assuming that the traffic flow takes the shortest path after the bridge breaks, Dijkstra's algorithm is used to solve the shortest path.

Figure 8: *Traffic flow simulation diagram*Figure 9: *most impacted roads*

Next, we assign the traffic volume to the road in the shortest path weighted by the length of the path. Finally, we calculated the ratio of traffic flow to traffic capacity of each road. If the ratio is greater than μ (where $\mu = 0.5$), it is considered that the bridge rupture will have a greater impact on the road. This step provides us with detailed information on the impact of a broken bridge on a specific road, providing a scientific basis for subsequent traffic planning and management.

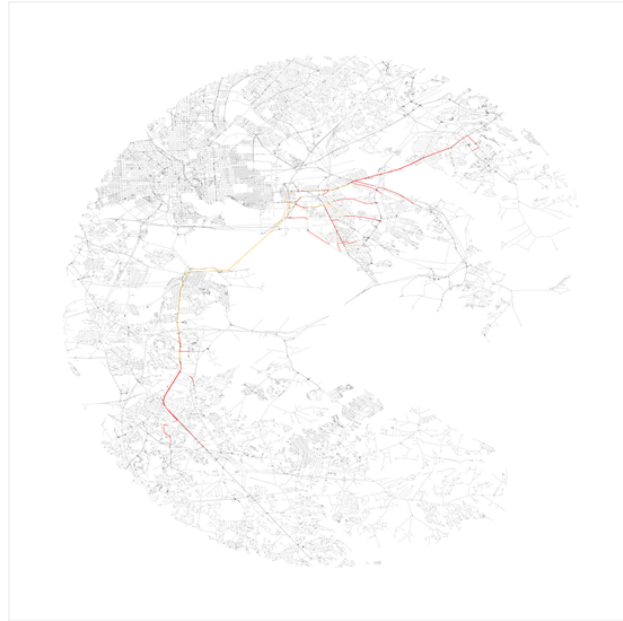


Figure 10: *the impacted roads reflected on the map*

3.1.4 Conclusion

The bridge outage has varying degrees of impact on different stakeholders.

For the industrial sector, taking Sparrows Point to the north of the bridge as an example, this area is a typical industrial zone, containing factories and warehouses. The scenario set is to assess the impact of the bridge outage by traveling from Sparrows Point to the commercial district on the south side of the bridge.

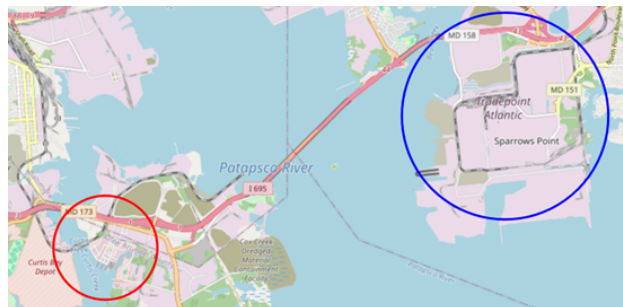


Figure 11: *the selected industrial sector*

The results show that the average travel distance between the two areas increased by 8 kilometers, and connectivity dropped by 15%. Moreover, since industrial traffic consists mostly of large vehicles, this will severely affect the road conditions in the surrounding areas.

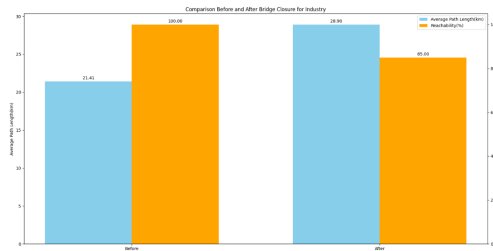


Figure 12: *comparison before and after bridge closure for industry*

For the tourism industry, taking North Point State Park to the north of the bridge as an example, the scenario is to assess the impact of the bridge outage by traveling from the Hawkins Point area on the south side of the bridge. The results indicate that the average travel distance increased by 16 kilometers, and connectivity decreased significantly, which could have a considerable impact on tourism.



Figure 13: *the selected tourism sector*

In general, the outage of the bridge has a significant impact on various stakeholders, particularly in the industrial and tourism sectors, where the transportation disruptions caused by the outage could have long-term negative effects.

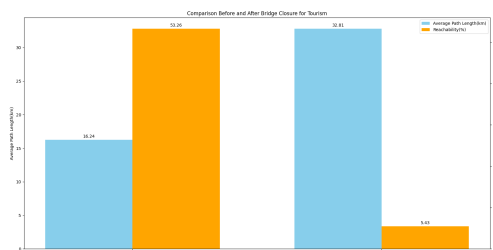


Figure 14: *comparison before and after bridge closure for tourism industry*

3.2 Model building and analysis in problem 2

3.2.1 Data Collection and Processing

First, we collect data on all Baltimore bus stops, including station coordinates, the routes they serve, and passenger flow data. This data was obtained from publicly available transportation datasets and underwent data cleaning and preprocessing.

3.2.2 Coverage Calculation

We used the coordinates of each bus stop to create a service area with a radius of 500 meters (i.e., a circular coverage area centered around each station). Then, we calculated the coverage of the remaining bus stops' service areas over the city area, excluding a particular route in the event of an emergency.

Parameter 1: Calculate the proportion of the city covered by the remaining bus stops.

The formula is as follows:

$$\text{Coverage}_{\text{remaining}} = \frac{\text{Covered Area of Remaining Stations}}{\text{Total Area of City}}$$

Where the covered area is the 500-meter radius circle centered around each bus stop. By calculating the intersection, we obtain the proportion of the service area that covers the city.

3.2.3 Passenger Flow Analysis

We calculated the total number of passengers getting on and off each bus route and compared the ratio of remaining passengers after excluding a specific route.

Parameter 2: Calculate the ratio of remaining passenger flow:

$$\text{Passenger Flow}_{\text{remaining}} = \frac{\text{Total Passengers of Remaining Routes}}{\text{Total Passengers of All Routes}}$$

3.2.4 Importance Score Calculation

By combining the two parameters, we used the following formula to calculate the "Importance Score" for each bus route:

$$\text{Importance Score} = 0.7 \times \text{Parameter 2 (Passenger Flow)} + 0.3 \times \text{Parameter 1 (Coverage)}$$

This formula considers two factors:

- **0.7:** Reflects the impact of passenger flow, as routes with higher flow will affect more citizens during an emergency.
- **0.3:** Reflects the impact of service coverage, as some routes may affect larger geographic areas, even if passenger numbers are lower. Coverage is still crucial.

3.2.5 Emergency Event Model

In the event of a traffic accident or emergency, we assume that all bus stops on a particular route will temporarily become non-functional. We need to recalculate the coverage of all bus stops and assess the impact of each route on the city.

3.2.6 Conclusion

The chart shows that Route 22, BL, OR and 54 are of the highest importance in the event of an emergency, which means that these four routes are of the greatest importance in terms of service coverage and passenger flow, and deserve to be protected and maintained

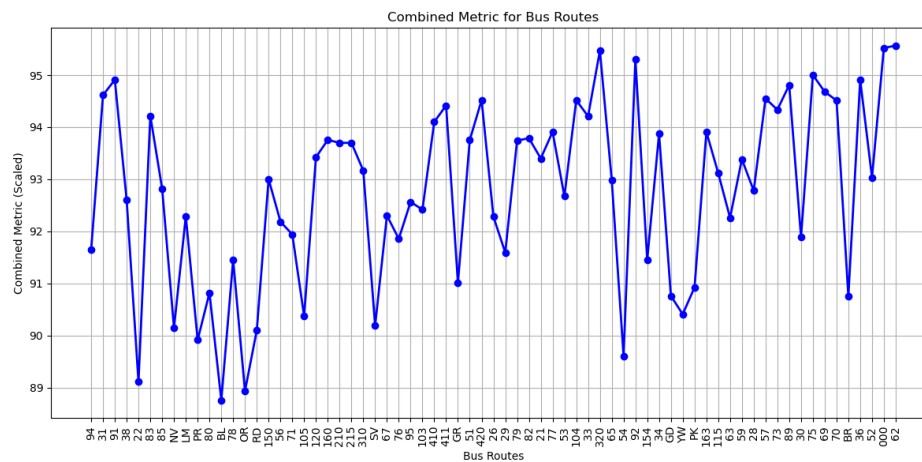


Figure 15: *combined metric for bus routes*

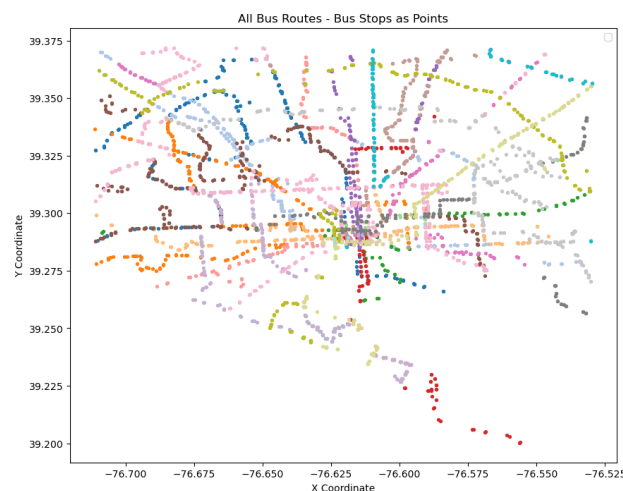


Figure 16: *All bus routes - bus stops as points*

3.3 Model building and analysis in problem 3

Data Import

Initially, we will import the data from the `bus_stops.csv` file using Python's `pandas` library. This library offers robust functionalities for data importation and processing. We will ensure the accuracy of the imported data and conduct preliminary checks for any missing values or outliers that require addressing.

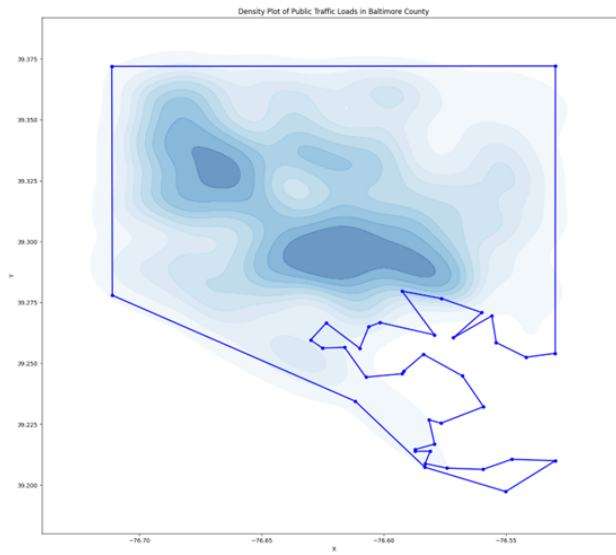


Figure 17: *density plot of public traffic roads*

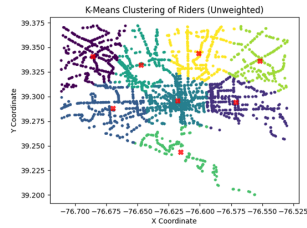
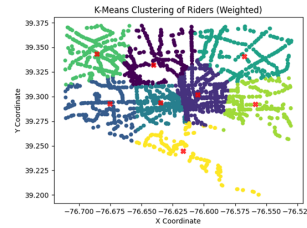
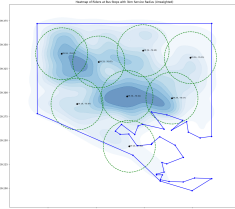
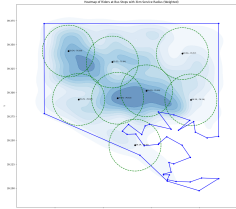
Heat Map Visualization

Subsequently, we will generate a heat map based on the ridership at each traffic stop (*Rider_Stop*) as a weight. The heat map will visually represent the distribution of passenger flow at traffic stations, aiding in the identification of high-traffic areas. We will utilize Python libraries such as `matplotlib` or `seaborn` to create clear and easily interpretable heat maps.

Cluster Analysis of Bus Stations

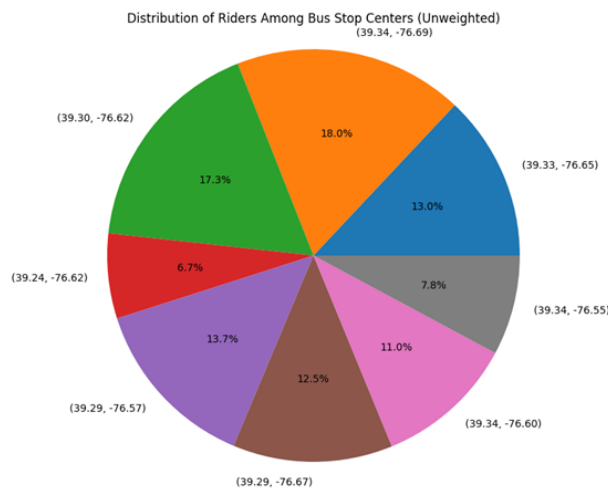
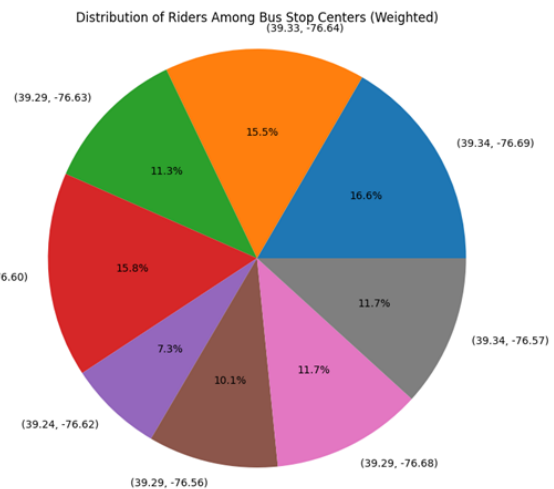
We will employ the k-means clustering algorithm to analyze all traffic stops and categorize them into distinct zones (denoted as A).

This analysis will help identify which stations belong to the same cluster, allowing us to examine their shared characteristics. Additionally, to more accurately reflect the importance of each station, we will normalize the traffic flow and perform k-means clustering with the normalized traffic flow as the weight, dividing the stations into regions (marked as B). This approach will enable us to precisely delineate areas and identify high-pressure traffic hotspots. Finally, we will compare the regions obtained from the cluster analysis with the heat map to validate the clustering results and gain deeper insights into the distribution of traffic stops and flow patterns.

Figure 18: *K-means clustering of riders*Figure 19: *Weighed K-means clustering of riders*Figure 20: *Heatmap of Riders at Bus Stops with 3km Service Radius (Unweighted)*Figure 21: *Heatmap of Riders at Bus Stops with 3km Service Radius (weighted)*

Load Analysis of Clustered Regions

Following the cluster analysis, we will conduct a load analysis on each region and present the findings in a pie chart to illustrate the proportion of bus load in each area. This analysis will assist in identifying regions with high traffic stress that require priority improvements.

Figure 22: *Distribution of Riders Among Bus Stop Centers (Unweighted)*Figure 23: *Distribution of Riders Among Bus Stop Centers (Weighted)*

Proposed Solution

Based on the results of the heat map and cluster analysis, we have identified that Region B experiences significant passenger flow and traffic pressure. Therefore, it is imperative to enhance public transportation in this area. We propose increasing the number of bus stops and capacity in Region B to improve the carrying capacity and service quality of public transport.

Expected Outcomes

By implementing the proposed solutions, we anticipate achieving the following outcomes:

1. Increase the capacity of public transport in key areas: Adding bus stops and increasing capacity in Region B will enhance the region's public transport capacity and better meet the travel needs of citizens.
2. Improve the public transport experience: Increasing bus stops and capacity will reduce waiting times and improve the convenience and comfort of public transport.
3. Distribute traffic to alleviate regional traffic pressure: By expanding bus stops and capacity, we can distribute traffic flow over a wider area, reducing traffic pressure in Region B and improving overall urban traffic efficiency.
4. Reduce accident rates: The dispersion of traffic flow will help mitigate traffic accidents, as high-pressure areas will no longer bear excessive traffic volume, thereby lowering the accident rate.

In summary, through the implementation of these solutions, we can significantly improve the city's public transport conditions, enhance the travel experience for citizens, and boost the efficiency of urban traffic operations.

4 Additional section for security considerations

Safety is indeed a critical concern for urban environments like Baltimore, especially in relation to the transportation system. Here's how the transportation system can be leveraged to address safety issues:

4.1 Improved Public Transit Infrastructure

- **Safe Transit Routes:** Ensuring that public transportation routes pass through areas with high foot traffic, well-lit streets, and visible, frequent patrolling can reduce safety risks.
- **Real-time Monitoring:** Installing surveillance cameras on buses, trains, and stations, and integrating them with a real-time monitoring system, can help detect and prevent crimes.
- **Secure Stops and Stations:** Proper lighting, security personnel, and design that allows for clear visibility (e.g., avoiding dark, isolated areas) can create safer spaces for passengers waiting for transit.

4.2 Pedestrian and Cyclist Safety

- **Safe Pedestrian Infrastructure:** Creating pedestrian-friendly zones, safe crosswalks, and pedestrian bridges, especially in high-traffic areas, helps reduce pedestrian accidents.
- **Dedicated Bike Lanes:** For cyclists, dedicated bike lanes or bike-friendly streets that keep cyclists away from heavy traffic are crucial in reducing the likelihood of accidents.

4.3 Traffic Safety Initiatives

- **Traffic Calming Measures:** Implementing speed bumps, reduced speed limits in residential and high-pedestrian areas, and traffic circles can reduce speeding and traffic accidents.
- **Smart Traffic Lights:** Using smart traffic light systems that adapt to real-time traffic conditions can reduce accidents by preventing congestion and ensuring smoother flows of traffic.
- **Pedestrian Signals:** Ensuring that pedestrian crossings have clear signals and are well-timed can make walking safer, particularly for vulnerable groups such as children and the elderly.

4.4 Community Awareness and Education

- **Safety Campaigns:** Conducting safety awareness campaigns through public transportation systems, such as posters in buses and trains, can educate residents about safety practices, like reporting suspicious activities or being alert during travel.
- **Driver Education:** Offering safety courses and training for bus and train drivers to improve their ability to handle emergencies and react appropriately in unsafe situations.

4.5 Data Collection and Analysis

- **Traffic Incident Data:** Collecting data on traffic accidents, crime hotspots, and pedestrian injuries can help city officials identify dangerous areas and prioritize safety measures where they're most needed.
- **Real-time Alerts:** Utilizing apps or systems that can alert passengers about potential safety threats or disruptions in service can help passengers avoid dangerous situations.

4.6 Collaboration with Law Enforcement

- **Police Integration with Transportation Services:** Collaborating with law enforcement to have a police presence on busy transportation routes, or having them respond to emergency situations quickly, can improve overall safety.
- **Emergency Response Plans:** Developing and publicizing clear, easily accessible emergency response plans for transportation networks can help people know what to do in the event of an accident or threat.

4.7 Public Transit Accessibility for All

- **Inclusive Design:** Ensuring that all parts of the transit system are accessible to individuals with disabilities, including ramps, elevators, and low-floor buses, can reduce accidents and injuries among this vulnerable group.
- **Neighborhood-Specific Solutions:** Tailoring transportation systems and safety measures to the needs of specific neighborhoods, especially those with higher crime rates, can enhance safety and security for residents.

5 Purpose and Objectives

5.1 Purpose

The main purpose of using AI systems is to increase productivity, save time, and improve the quality of decision-making by leveraging advanced natural language processing technology and powerful data analysis capabilities. Specifically, the goals are to:

- **Find information:** Help the team quickly and accurately extract useful data or knowledge from a large amount of information. AI systems can instantly access literature, studies, cases, reports, and other data in different fields, and provide more accurate answers or relevant content, greatly improving the speed and accuracy of information search.
- **Generate code framework:** Support users to write, optimize, debug program code, automatically generate code framework or code segment, save coding time. It also saves the time needed to find a code framework from a book or hand-knock a framework, and can spend more time optimizing the code and testing more different models.
- **Expand ideas:** Through in-depth analysis of user problems, AI can provide multi-angle solutions or expand ideas, help the team think out of the limitations, and provide innovative thinking paths.

5.2 Objectives

In order to achieve these goals, the specific goals of AI systems include:

- **Improve the efficiency and accuracy of information retrieval:** Through accurate natural language understanding, quickly process a large number of documents and data, help the team easily obtain the required information, avoid wasting time on irrelevant content.
- **Generate high-quality code framework and solutions:** Automatically generate structured code according to user needs, and provide functional modular programming framework to reduce manual writing and debugging workload. Get more time to run more different models and methods.

- **Enhance thinking innovation and problem-solving ability:** Through multi-dimensional algorithm support, AI system can not only answer specific questions, but also broaden thinking, propose different solutions, help the team to make more effective decisions or innovations in complex scenarios, assist the team to think better and improve the problem and problem-solving framework in a more comprehensive way.
- **Reduce manual handling of complex tasks:** Help the team to split complex tasks into multiple blocks, and check whether there are gaps or errors in the team's plan. Reduce unnecessary mistakes caused by limited energy.

6 Memo

TO: The Mayor of Baltimore

Subject: Update on Two Transportation Projects Introduction: I am writing to update you on two key projects designed to improve transportation infrastructure and public safety within Baltimore: the Francis Scott Key Bridge Rebuild Project and the Bus Route Expansion Project. Both initiatives aim to improve connectivity, reduce congestion, and enhance safety across the city.

Francis Scott Key Bridge Rebuild Project:

Overview: The rebuild of the Francis Scott Key Bridge is a critical undertaking to recover one of the city's most important transportation links from destruction. The bridge serves as a crucial route for commuters, businesses, and emergency services, and its deterioration poses a risk to both safety and efficiency.

Benefits:

Reduced Traffic Congestion: Rebuilding the bridge will ease traffic flow, alleviating pressure on alternate routes and lowering the risk of traffic issues.

Economic Growth: A safer and more efficient bridge enhances access to the port and surrounding businesses, supporting local economic development.

Drawbacks:

Financial Issue: The high costs of rebuilding the bridge will put great pressure on local governments. The time of building the bridge is also unpredictable.

Bus Route Expansion Project

Overview: The Bus Route Expansion Project aims to enhance public transportation options by adding new routes and improving access to underserved neighborhoods. This expansion seeks to provide more equitable access to essential services, reduce traffic congestion, and promote environmental sustainability.

Benefits:

Improved Life Quality: More efficient public transit options can make residents in the area easier to reach other parts of the city.

Drawbacks:

Operational Challenges: Without careful management, the expanded system could face issues with overcrowding or delays, undermining the effectiveness of the new routes.

7 References

References

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A AI Usage Report

A.1 Background

From January 24 to 28, 2025, as part of the 2025 MCM/ICM (Mathematical Contest in Modeling/Interdisciplinary Contest in Modeling) competition, we used ChatGPT 4.0 as an aid to help the team efficiently complete the problem D resolution process.

A.2 Find information

Q: The average speed on different types of roads in the United States.

AI: In the United States, the average speed on different types of sections often varies based on the type of road, location, and traffic conditions. Below are average speed estimates for some common road types:

- **City streets:** Average speed: approximately 25-35 MPH (40-56 km/h)
- **Main highway (Interstate):** Average speed: approximately 60-70 MPH (97-113 km/h)
- **State Highways:** Average speed: approximately 50-65 MPH (80-105 km/h)
- **Rural roads and roads:** Average speed: approximately 40-55 MPH (64-88 km/h)
- **Highway on-ramps and off-ramps:** Average speed: approximately 25-40 MPH (40-64 km/h)
- **School districts and residential streets:** Average speed: approximately 15-25 MPH (24-40 km/h)

Q: Safety is a major issue in Baltimore. Such as?

AI: It's true that security has been a big challenge for the city of Baltimore. Here are the main ones:

- **Crime rate:** Baltimore has a high crime rate, especially violent crimes (such as shootings and murders).
- **Drug problems:** Baltimore's drug dealing and use problems have also contributed to rising crime rates.
- **Police reform and trust issues:** Baltimore's police department has faced numerous allegations of abuse and racial bias.
- **Poverty and unemployment:** Poverty and high unemployment are another major challenge for Baltimore City.
- **Lack of social services:** Some communities lack effective social services and support systems.

A.3 Generate code framework

Q: Give a K-means clustering code template.

AI: Here is a code template for K-means clustering, implemented using the scikit-learn library in Python:

```
# Import the necessary libraries
import numpy as np
import matplotlib.pyplot as plt
from sklearn.cluster import KMeans
from sklearn.datasets import make_blobs

# Generate simulated data (you can also use your own data)
X, _ = make_blobs(n_samples=300, centers=4, cluster_std=0.60, random_state=0)

# Visualize the generated data
plt.scatter(X[:, 0], X[:, 1], s=30)
plt.title("Generated Data")
plt.show()

# Set the KMeans model, let's say we want to cluster into 4 categories
kmeans = KMeans(n_clusters=4)

# Fit the model
kmeans.fit(X)

# Get clustering results
y_kmeans = kmeans.predict(X)

# Visualize the clustering results
plt.scatter(X[:, 0], X[:, 1], c=y_kmeans, s=30, cmap='viridis')

# Draw the cluster center
centers = kmeans.cluster_centers_
plt.scatter(centers[:, 0], centers[:, 1], c='red', s=200, alpha=0.75, marker='X')

plt.title("K-Means Clustering Results")
plt.show()

# Print cluster center
print("Cluster Centers: ")
print(centers)

# Print a label for each data point
```

```
print("Label of data points: ")  
print(y_kmeans)
```

Q: Give a code architecture with a phase road map.

AI: In the case of a phase road map (i.e., there are already predefined road connections), the code architecture for generating bus routes and bus stops can be organized as follows. We can use graph theory algorithms to optimize route planning, and we can use some existing graph data structure libraries (such as networkx) to do so.

```
# Install dependencies  
pip install networkx scikit-learn matplotlib
```

A.4 Expand your thinking

Q: Is it feasible to use U-Net to solve the bus stop optimization problem on the network diagram?

AI: Using U-Net to solve the bus station optimization problem on the network diagram may be a relatively innovative idea. U-Net is commonly used for image segmentation tasks, but its structure can be tweaked or improved to handle optimization problems on graphics and networks.

Problem analysis: The problem of bus station optimization can be understood as a graph theory problem. You can model a city's bus network as a graph where:

- Nodes represent bus stops.
- Edges represent bus lines.

Application of U-Net: U-Net is essentially a symmetric convolutional neural network structure, which is mainly used for pixel-level classification problems. Through the autoencoder structure, it is able to extract features from input data and generate a high-resolution output.

Training and optimization: Train with appropriate optimization objective functions, such as minimizing total cost, shortening average travel time, etc.

Sum up: The U-Net model is not a tool traditionally used to solve graph network optimization problems, but it can be used as a potential solution with suitable image or graph structure transformation.

A.5 Conclusion

The use of AI makes the overall progress faster, saves a lot of unnecessary wasted time, allows more trial and error, encourages innovative methods, and helps greatly throughout the game.