

# Optimization and evaluation of traffic based on network models

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**Abstract.** This paper constructs a network model optimization function and corresponding indicators, and based on network model analysis, proposes targeted optimization recommendations. The aim is to meet the transportation needs of different stakeholders and analyze the impact of bridge collapses on different stakeholders. A network model optimization function and corresponding indicators are constructed, and the impact of bridge collapses on different stakeholders is analyzed. The study employs the Voronoi polygon method to delineate transportation analysis zones, combines ArcGIS tools for spatial analysis and visualization, and quantifies transportation accessibility metrics (such as the average area of transportation analysis zones, the number of transportation analysis zones per square kilometer, and accessibility indices) to provide scientific basis for identifying weak links in the transportation network. A topology-based traffic flow network model further analyzed the connectivity between nodes and edges, and combined with traffic flow data (such as AADT, AAWDT) to optimize network weights, providing precise support for traffic planning.

**Keywords:** Optimization of the transport system, Optimization Model, Network Structure, Bridge collapse, ArcGIS.

## 1. Introduction

The current international research on network modeling shows a multidimensional development trend, but still faces many challenges. In terms of theoretical modeling, complex network research has formed a cross-discipline across multiple fields, and the classical models represented by ER random graphs, WS small-world networks, and BA scale-free networks constitute the milestones of network science. In recent years, researchers have further proposed novel models such as hybrid optimal networks and variable speed growth networks in an attempt to unify different network properties. However, the existing modeling methods still suffer from incomplete description of network characteristics and insufficient quantitative analysis, which make it difficult to meet the demand for accurate prediction and control.

At the technical application level, data-driven machine learning methods are gradually emerging, learning dynamic network patterns through historical data, which significantly improves the prediction accuracy in high interference environments. Meanwhile, the research on future Internet models focuses on the integration of management models, monitoring models, and generalized models, trying to achieve a unified description of physical and virtual infrastructures through semantically compatible frameworks (e.g., RSpec, NDL-OWL, etc.). However, network simulation technology still faces bottlenecks, and large-scale complex network modeling has technical challenges such as difficult node arrangements and complex software operations.

In terms of interdisciplinary applications, network modeling has penetrated into international trade, enterprise internationalization and other fields. International trade research has constructed multi-dimensional networks such as adaptive and hyperbolic models, while internationalization network models emphasize SMEs' access to market resources through business networks, but also face the risk of loss of control and path dependence. In the field of industrial control, wireless networked

control system combines the modeling of communication protocol characteristics to realize the deep coupling of control model and network model.

Current research is still marked by significant contradictions: on the one hand, the open source community promotes the development of AI big model all-links, on the other hand, the contradiction between the unity demand of network description and the heterogeneity of devices is aggravated, and the experience of standardization of the OSI and TCP/IP models shows that the theoretical refinement needs to be balanced with the practical applicability. The future trend will focus on three major directions: first, the deep integration of machine learning and network modeling, and the enhancement of dynamic environment adaptability through AI; second, the breakthrough of multi-domain integration models, solving the difficulties of abstraction level processing, computation-storage-network synergy, etc.; and third, the optimization of application-oriented models, which will ensure the theoretical depth while enhancing the feasibility of engineering.

The purpose of this study is to explore the problems in We will use the provided data files of bus routes, bus stops, and traffic flow to construct a comprehensive transportation network model to visualize the current traffic conditions. Through model analysis, analyze the changes in travel demand of different stakeholders, and propose specific optimization measures. In addition, this paper explores how improvements to transit and pedestrian systems can enhance the accessibility of travel for city residents and promote sustainable community development.

## 2. Establishment of a transportation model

### 2.1. Transport Analysis Zones Construction

Raffic Analysis Zones (TAZs) are geographical areas constructed by the road network, used for traffic planning, traffic management, and traffic research. They are the basic analysis units of urban or regional traffic systems, helping to better understand and manage complex traffic patterns [1-3].

Voronoi polygons are a spatial division method that divides the plane into multiple areas, each corresponding to a generation point (such as a road node), and any point in the area is closer to the generation point than to other generation points [4-6].

For a set of generation points  $P = \{p_1, p_2, \dots, p_n\}$ , the area  $V(p_i)$  of the Voronoi polygon is defined as:

$$V(p_i) = \{x \in R_2 \mid d(x, p_i) \leq d(x, p_j)\} \quad (1)$$

For all  $j \neq i$ , where  $d(x, p_i)$  is the distance from point  $x$  to the generation point  $p_i$ .

The division method based on distance meets the basic requirements of traffic analysis zones, that is, the travel distance within the zone is relatively short. At the same time, the generation algorithm of Voronoi polygons is computationally efficient and suitable for large-scale node data. As shown in Figure 1:

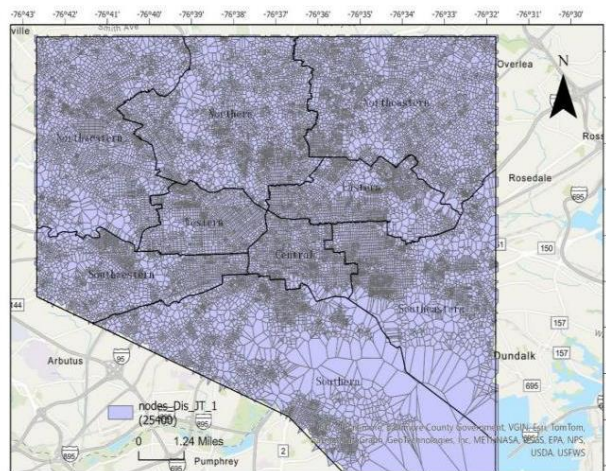


Figure 1. Schematic diagram of traffic analysis zone division

**2.1.1. Evaluation of the regional transport convenience based on the traffic community**

In urban transportation planning and management, regional transportation accessibility assessment is a crucial part. It not only affects the daily life of residents, but also directly relates to the economic development and environmental quality of the city. In this section, we will discuss how to conduct regional transportation accessibility assessment based on traffic analysis zones (TAZs). TAZs are the basic unit of analysis for urban or regional transportation systems and help to better understand and manage complex transportation patterns [7-8].

Transportation accessibility is quantified through the use of three key formulas. Formula 1 Calculates the average size of each traffic cell, which reflects the size of the traffic cell. Formula 2 calculates the number of transit neighborhoods per unit area, which assesses the density of transit neighborhoods. These two metrics provide a characterization of the distribution of transportation subdivisions in geographic space.

**Table 1.** The number and size of transportation areas in different administrative districts

Dist Name	Number of traffic communities	Average number of traffic communities per square kilometer	Convenience
Western	1115	116	1.05
Southeastern	2905	92	0.72
Northwestern	3597	109	0.95
Central	1509	184	2.13
Eastern	1939	140	1.86
Northern	4305	138	1.85
Southern	3470	59	0.44
Northeastern	3962	112	0.82
Southwestern	2264	136	1.00

The larger the area, the worse the transportation; the smaller the number, the sparser the transportation. The analysis of the public transportation situation in each area, taking into account the geographical location and convenience indicators of each area, is also the basis for proposing public transportation construction plans in the future.

Analyze the number and area of traffic analysis zones in different administrative regions, and evaluate the public transportation situation in each region by combining geographic location and convenience indicators. Identify the areas with lower accessibility and provide the basis for subsequent public transportation construction planning. A series of data were obtained by analyzing the number and area of traffic analysis zones in different administrative regions. These data show the differences in the degree of accessibility of transportation in different regions.

For example, the accessibility index of the western region is 1.05, indicating that the transportation network in the region is relatively dense, while the accessibility index of the southern region is only 0.44, indicating that the transportation network in the region is relatively sparse, which may require further improvement of the transportation facilities and more investment.

**2.1.2. Road network of transport flow based on topology**

Inputs MDOT\_SHA\_Annual\_Average\_Daily\_Traffic\_Baltimore.csv and outputs the traffic flow for traffic flow, using Python's csv module to open and read the CSV file. Parse the file contents line by line and store the data in each line. For each record, extract the node start and node end fields that contain the road start and end nodes. Extract other road attributes such as road name, functional class, etc., some of which will be used for subsequent topological relationship construction and network analysis.

Create a collection of nodes storing all unique node identifiers and a list of edges storing all road segments. Create edges with road attributes from node start (nodestart) and node end (nodeend), represent the road network using a graph data structure, add the identified nodes to the graph as nodes, add the identified edges to the graph as edges, and set the corresponding attributes.nodes, add the identified edges to the graph as edges, and set the corresponding attributes.

## 2.2. Traffic network model construction

First, the underlying network model is built, containing nodes and edges (paths connecting the nodes) each edge may contain the number of lanes, peak hour direction, traffic flow data (AADT, AAWDT, K-coefficient, D-coefficient, etc.), Average Vehicle Mileage Traveled (AVMT), and directional distributions (Northeast Diversion, Southwest Diversion).

### 2.2.1. Customized Network Model Establishment

Take, for example, 90 types of locations in a region, where different locations provide different services to people. Different stakeholders have different preferences for locations. Therefore, the accessibility of different types of locations to different stakeholders (urban residents, business owners, suburban residents, commuters, public transportation passengers, tourists) needs to be considered.

**Table 2.** The location preferences of different stakeholders and the degree of preference

Stakeholder	Location	Preference Degree
Urban residents	apartments	5
Urban residents	clinic	4
Urban residents	college	4
Urban residents	hospital	4
Urban residents	house	4
Urban residents	kindergarten	4
Urban residents	library	4
Urban residents	park	4
Urban residents	school	5
Urban residents	sports_centre	3
Urban residents	university	4
Entrepreneurs	commercial	5
Entrepreneurs	industrial	4
Entrepreneurs	office	5
Entrepreneurs	warehouse	4
Entrepreneurs	workshop	4
Entrepreneurs	central_office	5
Entrepreneurs	government	4
Entrepreneurs	retail	4
Entrepreneurs	storage tank	3
Entrepreneurs	manufacture	4
Tourists	hotel	5
Tourists	museum	5
Tourists	park	4
Tourists	restaurant	5
Tourists	tourist_attractions	5
Tourists	cathedral	4
Tourists	chapel	4
Tourists	church	4
Tourists	mosque	4
Tourists	temple	4
Tourists	synagogue	4
Tourists	castle	4
Tourists	ruins	3

### 2.2.2. Objective Function Determination

For urban residents based on the pre-constructed residential road network, the accessibility of preferred areas for urban residents as an indicator, with the goal of optimizing the living circle, maximizing regional accessibility indicators, and constructing a network model function, with particular emphasis on public transportation and walking/bicycle paths.

For tourists need Based on the tourism road network constructed in the previous period, the network model function is constructed with the accessibility of the preferred area for tourists as an indicator, and the shortest travel time as an indicator.

For entrepreneurs needs To construct the network model function based on the pre-constructed entrepreneurial road network with the objective of minimizing road costs.

### 2.3. Analysis of the impact of bridge collapse on the transport network

#### 2.3.1. Impact on the transportation network

Taking the collapse of the Dundick Bridge as an example, detour routes have been arranged for vehicles that need to pass through Dundick or the Curtis Bay/Hawkins Point side. To improve local traffic conditions, the outer loop of I-695 was closed and rerouted to Exit 1/Isolation Road (beyond the Curtis Creek movable bridge), while the outer loop remains closed at Exit 1 (MD 173). This measure aims to alleviate the traffic pressure caused by the bridge collapse, but the traffic situation in the port area still faces significant challenges. As shown in Figure 2:

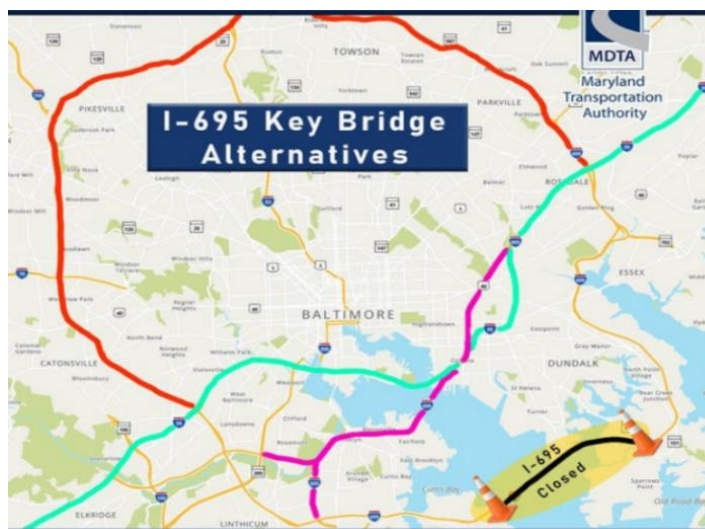


Figure 2. Closed Outer Loop I-695

For the port area, for business owners who have a large amount of cargo carrying demand and need to pass the bridge, the impact is a lot, the need to detour, and the traffic pressure turns to I-95 and I-895.

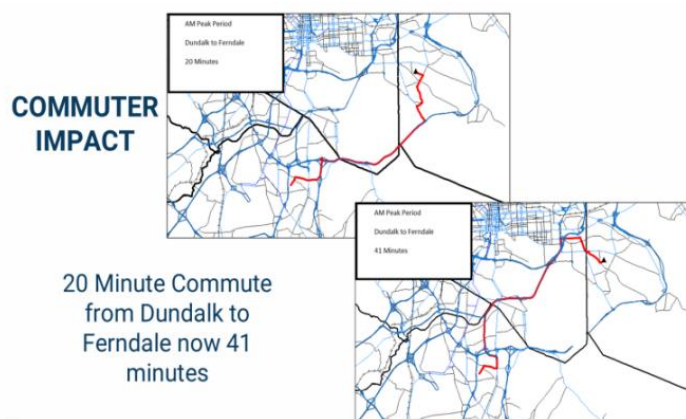


Figure 3. Increased detour times due to bridge collapse

For the port area, business owners who had to pass the bridge were significantly affected due to the large demand for cargo transportation. They had to take a detour, causing a large shift in traffic pressure towards I-95 and I-895. As shown in Figure 3, according to the traffic impact analysis report, from the perspective of time cost, the detour route increased the travel time from 20 minutes to 41 minutes, significantly increasing the degree of traffic congestion.



**Figure 4.** Analyzing the situation of traffic data in Maryland

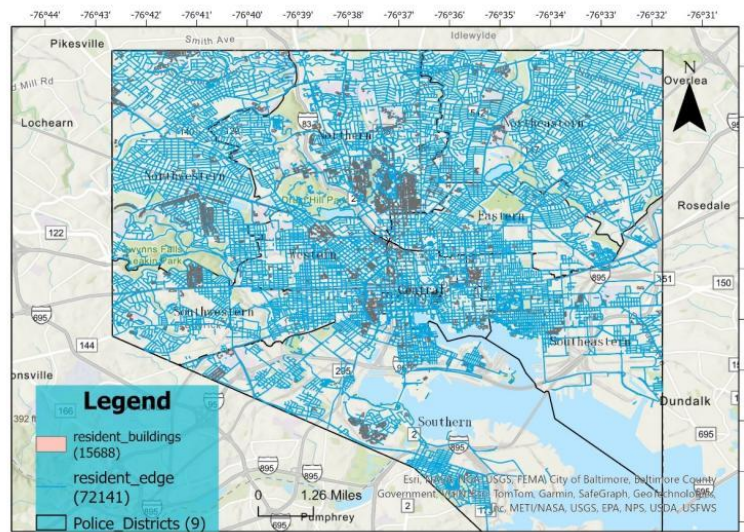
In Figure 4, Analysis of the Maryland traffic data revealed significant early traffic impacts after the collapse of the Dundalk Bridge. For example, on Tuesday and Wednesday after the collapse, there were large decelerations along I-95, I-895, and MD-295. On the Harbour Tunnel Highway (I-895), the speed of sections along these routes dropped to 10 mph and to 14 mph on I-95 near the I-695 overpass. Also, the traffic speed between the I-895 and I-95 overpasses dropped to a low of 13 mph.

Combined with MDOT\_SHA\_Annual\_Average\_Daily\_Traffic\_Baltimore.csv data analysis, Key Bridge transports on average about 40,000 vehicles per day. The vehicles that passed through the bridge before the collapse included 72 percent of passenger cars, 20 percent of local fleets and delivery vehicles, and the remaining 8 percent of half-trucks. The collapse of the bridge has not only had an impact on daily commuters, but also caused significant disruption to businesses that rely on the route for cargo transport.

### 2.3.2. Impact on various stakeholders

After the bridge collapsed, some roads were damaged and they are no longer passing. The travel places were determined according to the attention place and the preference degree of the different stakeholders in the table, and the traffic situation of the stakeholders under the preference of the travel place was analyzed.

The travel preferences of urban residents mainly focus on their daily life and commuting convenience. After the bridge collapsed, residents who originally relied on the bridge for their daily commute may need to find alternative routes, which increases their commuting time and costs. For example, if the bridge is the main link connecting residential and commercial areas, residents may need to detour through more congested roads, which not only increases commuting time but may also reduce their quality of life. As shown in figure 5:



**Figure 5.** Changes in travel modes of urban residents

Entrepreneurs' travel preferences mainly focus on the efficiency of goods transportation and commercial accessibility. The bridge collapse had a significant impact on their business operations, especially those that relied on the bridge for cargo transport. Entrepreneurs need to rely on the primary and secondary roads for cargo transport. Bridge collapse may lead to supply chain disruptions, increase transportation costs and time, and affect the operational efficiency of enterprises. The service path is equally important for businesses, especially those that require frequent trips in and out of goods. The bridge collapse may lead to increased traffic flow on the service road and affect the logistics efficiency of enterprises. As shown in Figure 6:



**Figure 6.** Changing modes of corporate travel

Tourists' travel preferences mainly focus on the convenient transportation links to the major tourist attractions. The bridge collapse could force tourists to change their travel routes, which could affect their travel experience. Tourists need convenient transportation to connect to the major tourist attractions. Bridge collapse may result in reduced accessibility at certain tourist attractions, forcing visitors to find alternative routes, which may reduce their probability of visiting certain attractions. Visitors may rely on walking, bicycle, and public transport facilities to explore the city. Bridge collapse may affect the accessibility and convenience of these transportation modes, thus affecting the travel experience of tourists. As shown in Figure 7:

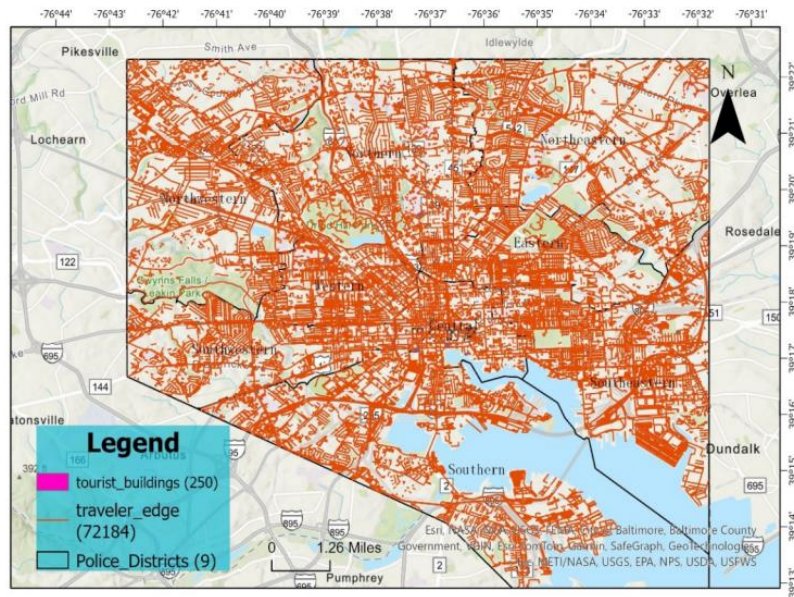


Figure 7. Changes in the way tourists are traveling

### 2.3.3. Transportation system optimization and construction

For the special concern of urban residents to travel, especially free travel methods, such as walking and bike lanes, we need to assess the improvement of the existing transportation system to determine whether it can meet the daily needs of residents.

Observe and analyze the existing transportation system networks. By using the network model, we can identify areas with a sparse road network that may lack adequate walking and bike lanes or existing facilities that are insufficient to support residents' travel needs. As shown in figure 8:



Figure 8. Transportation system optimization and construction map

Geospatial technologies (GST), including remote sensing (RS) and geographic information systems (GIS), can significantly improve the planning and implementation of public transportation infrastructure. These technologies provide powerful tools for the collection, processing, and analysis of spatial data, thereby supporting more scientific and precise road planning.

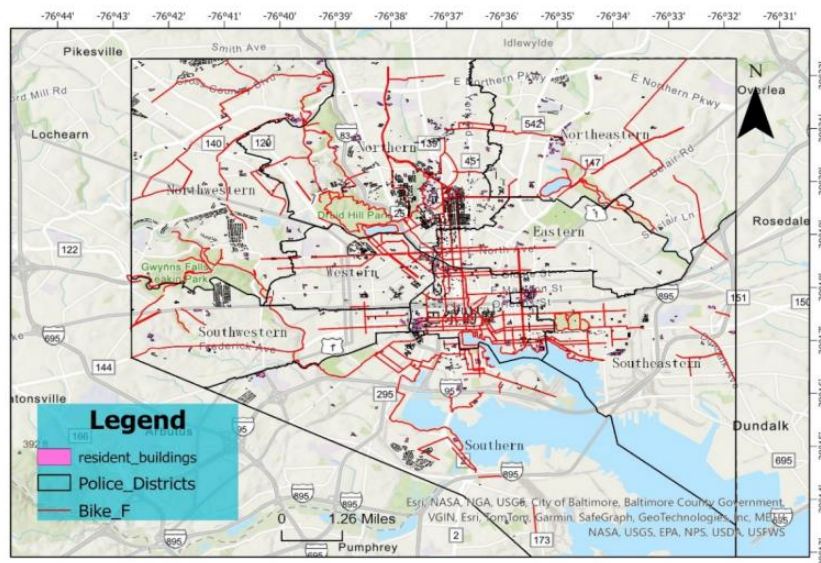
Processing and analyzing GIS datasets, including land use and land cover, roads, soil, elevation, and demographic data. These data are used to assess the suitability of bike lanes and sidewalks [9-12].

Using remote sensing technology for land use and land cover (LULC) classification to identify different types of geospatial features. The classification results show that built-up areas account for

31%, vegetation for 56%, and water bodies and wetlands for 13%. This information helps determine the optimal locations for bike lanes and sidewalks. Vegetation coverage is assessed by calculating the Normalized Difference Vegetation Index (NDVI). Areas with lower NDVI values typically have less vegetation and are more suitable for construction [13-15].

Buffer zones were generated to identify potential locations for bicycle lanes. The width of the buffer zones includes the width of existing roads and the planned width of bicycle lanes. GIS clipping and overlaying functions were used to analyze land use types and soil types within the buffer zones. This information helps assess the conditions for constructing bicycle lanes. Attribute table generation: Generate an attribute table containing road width, lane width, central median width, and sidewalk width to provide detailed data for bicycle lane design.

Combine land use classification (LULC) with NDVI analysis results to select areas with sparse vegetation and suitable land use as the optimal site for the road [16-17].



**Figure 9.** Existing transportation system network

As shown in Figure 9, determine the optimal location for new bike lanes to connect with the existing bike lane network, improving network connectivity and coverage. Improve or build new sidewalks in areas with heavy pedestrian traffic to provide pedestrians with a safer and more comfortable walking environment. This plan will improve public transportation infrastructure in the area, enhance convenience and quality of life for residents, and promote healthy and environmentally friendly modes of transportation.

### 3. Conclusions

This paper systematically investigates the impact of bridge collapses on urban transportation networks and proposes reconstruction and optimization schemes for transportation networks. Additionally, this study employs the Voronoi polygon method to divide transportation analysis areas and combines ArcGIS tools for spatial analysis and visualization, quantifying transportation accessibility indicators to provide scientific basis for identifying weak links in transportation networks. A traffic flow network model based on topological structure further analyzes the connectivity between nodes and edges, and combines traffic flow data to optimize network weights, providing precise support for traffic planning.

This study provides a scientific basis for urban transportation planning. By increasing redundant roads, promoting green modes of transportation, and coordinating the planning of multiple stakeholders, the resilience, efficiency, and fairness of the transportation system have been effectively improved, providing residents, businesses, and tourists with more convenient and sustainable transportation services.

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