Graph-Based Analysis of the Florida Road Network System for Traffic Management

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*Abstract* — This report presents a detailed analysis of the Florida road network system, with a particular focus on Annual Average Daily Traffic (AADT) data for road segments to identify congestion hubs and critical routes. The aim is to provide actionable insights for prioritizing infrastructure upgrades and optimizing traffic flow. The analysis employs graph-based techniques, including betweenness centrality to pinpoint key traffic pathways and Louvain's community detection algorithm to uncover clusters within the network. Visualization techniques are utilized to effectively interpret and communicate findings, facilitating data-driven decision-making for transportation planning. The dataset, spanning the years 2019 to 2023, was sourced from the Florida Department of Transportation's (FDOT) official repository, ensuring comprehensive and accurate analysis.

Keywords — AADT, FDOT

# Introduction

Florida is one of the most hurricane-prone regions in the world, frequently experiencing natural disasters that challenge its infrastructure resilience. In October 2024, Hurricane Milton made landfall as a Category-3 storm, causing widespread disruption across the peninsula. The rapid growth of the hurricane, combined with the limited evacuation notice, led to severe traffic congestion on already burdened highways and roads connecting Tampa to the rest of Florida. These logistic bottlenecks emphasized the crucial need for robust transportation planning to mitigate future hazards and enhance emergency response efficiency.

This paper aims to address these challenges by analyzing the Florida road network through graph-theoretic approaches, leveraging techniques such as betweenness centrality and community detection to identify critical infrastructure and optimize traffic flow during emergencies.

# Theory

Since the introduction of betweenness centrality in social network analysis by Freeman (1977) [1], this measure has been extensively adopted in various fields. Betweenness centrality quantifies the importance of nodes or edges in facilitating flow or connectivity within a network. The extension to edge betweenness centrality, proposed by Newman and Girvan (2004) [2], evaluates the frequency with which a particular edge lies on the shortest paths between pairs of nodes. It provides crucial insights into the significance of road segments in maintaining network connectivity. Mathematically, betweenness centrality of an edge is the sum of the fraction of all-pairs shortest paths that pass through :

Where is the set of nodes, is the number of shortest -paths, and is the number of those paths passing through edge [3].

Another critical aspect of network analysis is community detection, which identifies clusters of densely connected nodes within a network. The Louvain method, named after the University of Louvain, where it was developed (2008) [4], is a popular algorithm for this purpose. It follows a hierarchical approach:

1. Firstly each node in the network is initially assigned to its own community.
2. Then, for each node, the algorithm considers moving the node to the community of each of its neighbors and calculates the gain in modularity that would result from the move. The node is then placed in the community that provides the most significant increase in modularity. This process is applied repeatedly and iteratively for all nodes until no further improvement in modularity can be achieved.
3. Once no further improvements can be made, each community is treated as a single node, and the first step is repeated. The edges between these new nodes are weighted by the sum of the edge weights between nodes in the corresponding two communities.

This hierarchical methodology makes the Louvain algorithm particularly suitable for large-scale networks, such as Florida's road network, where uncovering structural clusters is essential for traffic flow optimization and identifying critical road segments.

# Methodology

The Florida Department of Transportation provides publicly accessible datasets to ensure transparency across various sectors [5]. For this analysis, multiple datasets were utilized and integrated to create a comprehensive dataset suitable for modeling and evaluation [6][7].

The dataset was composed taking individual road segment as a samples with the following attributes:

* Calendar year for which record applies.
* FDOT District Number.
* Combination of county and site values as a six-digit item.
* Identification number assigned to the roadway the road segment is in.
* Name of the intersecting road at the beginning and at the end of the roadway segment.
* Lowest and highest milepoint for the record.
* Total volume of traffic on road segment for one year, divided by the number of days in the year.
* Length in meters of the geometry for the record.
* Geometry of the road segment in the form of x and y coordinates for each line that compose the road segment.

A map of the state of florida

Description automatically generated  
*Figure 1*. Plot of the geometries of all road segments representing Florida’s road network.

To simplify the representation and have a better understanding of the data, the road network graph was constructed using only the geometries of the segment endpoints. Each endpoint functioning as a node, and each road segment connecting the endpoints functions as an edge. This design creates a comprehensive graph representing Florida’s road network, where overlapping endpoints ensure network continuity. Figure 2 shows the plot drawing of the nodes plotted using the endpoints of the road segments using the longitude and latitude coordinates and edges plotted using the road segments as connections between the nodes. This still displays a realistic geographic map of the state of Florida.

A map of the state of florida

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*Figure 2*. Visualization of the graph created using geometries endpoints of Florida’s roads as nodes.

Rather than constructing separate graphs for each examined year (2019–2023), a multi-graph approach was adopted. In this representation, multiple edges between the same pair of nodes correspond to the same road segment across different years.

A map of florida with many colored lines

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*Figure 3*. Plot of AADT values for each road segment across Florida’s road network (2021).

# Results and Discussion

Both the temporal change in edge betweenness centrality analysis and the community detection analysis align predictably with the road network plot and the AADT data, providing insights into traffic behavior and congestion patterns.

## Temporal Change in Edge Betweenness Centrality

Edge betweenness centrality measures the frequency with which an edge lies on the shortest paths between pairs of nodes. It can be calculated either without weights, counting only the "steps" between nodes, or with weights assigned to edges, such as AADT values or segment lengths. In this study, all three approaches were employed: (1) unweighted, (2) weighted by AADT values, and (3) weighted by road segment lengths in meters.

For identifying road bottlenecks and critical segments, weighting by road segment lengths proved most effective. This approach provides a structural skeleton of the network, focusing on roads' potential importance based on geometry alone. Conversely, weighting by AADT values is better suited for analyzing temporal changes, as it reflects real-world congestion and usage patterns over time.

Since road segment lengths remain constant over the years, betweenness centrality based on segment lengths showed minimal variation across years, except in cases where new roads were constructed or existing ones were closed. Figure 4 highlights that the roads creating the most significant bottlenecks are those connecting urban centers to the broader Florida network. Comparing Figure 4 to Figure 3 confirms that these bottleneck roads often coincide with the highest AADT values, indicating that the most efficient routes by length are also the most heavily utilized by drivers.

A map of florida with roads

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*Figure 4*. Plot of edge betweenness centrality using road segment lengths as weights (2021).

Temporal changes in edge betweenness centrality were most pronounced in two intervals: 2019 to 2020 and 2022 to 2023, as shown in Figures 5 and 6. From 2019 to 2020, increases in edge betweenness centrality were measured meaning an increase in traffic observed on roads connecting Jacksonville and Tallahassee, as well as on Route 19 and I-4 between Orlando and Daytona Beach. This decline likely reflects the impact of COVID-19 restrictions on travel. However, from 2022 to 2023, an increase in edge betweenness centrality was noted on I-10 connecting Jacksonville and Tallahassee, suggesting a return to pre-pandemic traffic levels or shifts in traffic patterns.

A map of florida with many roads

Description automatically generated*Figure 5*. Temporal change in edge betweenness centrality from 2019 to 2020, weighted by AADT values.

A map of florida with many roads

Description automatically generated*Figure 6*. Temporal change in edge betweenness centrality from 2020 to 2023, weighted by AADT values.

A map of florida with blue lines

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*Figure 7*. Temporal change in edge betweenness centrality from 2019 to 2023, weighted by AADT values.

## Cluster and Community Detection

The Louvain method was applied to the Florida road network graph to detect communities, optimizing a modularity score to identify clusters of nodes with dense intra-connectivity relative to inter-connectivity. Weighted by AADT values, the Louvain method effectively grouped roads and intersections into clusters, revealing communities that correspond to functionally or geographically significant regions, such as urban hubs or key transit corridors. While the Louvain method identified meaningful community structures; applying the standard resolution parameter produced over 10,000 communities. While accurate, this level of granularity complicates visualization and interpretation. To address this, a high resolution value was used, yielding larger, more interpretable clusters. Figure 8 illustrates the resulting communities, with clusters capturing major regional connectivity patterns and bottleneck areas. Additionally, as AADT values exhibit limited temporal variability, the Louvain community detection results remain consistent across years, further emphasizing the stability of the underlying network structure.

A map of the state of florida

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*Figure 8*. Communities detected using the Louvain method with a resolution parameter of .

# Conclusion

The findings reveal that the bottlenecks identified in the Florida road network's infrastructure align proportionally with the traffic volume on those roads. Specifically, the analysis shows that roads connecting cities to Florida’s broader road network, and by extension the national road system, not only experience the highest traffic congestion but also serve as critical routes for rapid evacuation. This dual role underscores vulnerabilities in the network, particularly during natural hazards such as hurricanes, where delays in evacuation can have severe safety implications.

One potential improvement is to construct additional parallel roads to distribute traffic more evenly and alleviate bottlenecks on key routes. However, implementing such solutions poses significant challenges in certain areas of the state. For instance, the Everglades, a protected and environmentally sensitive swamp region, presents both legal and logistical hurdles for road construction. Similarly, Florida's numerous bridges, which connect islands to the mainland, introduce structural and financial complexities that further complicate expansion efforts.

Overall, while Florida's road network appears to be well-organized within its constraints for managing traffic flow, there remains considerable room for improvement. The Florida Department of Transportation (FDOT) continually conducts traffic studies to identify flaws and implement enhancements to existing roadways. These studies address factors such as traffic volumes, congestion points, and the effectiveness of traffic control measures [9]. Innovative intersection designs, such as those that modify road geometry to minimize conflict points while maintaining flow, offer promising solutions [10]. For example, the reconstruction of the SR-808/Glades Road interchange exemplifies FDOT’s commitment to improving traffic flow through advanced engineering and collaborative efforts [11][12].

Finally, this study focused on general AADT flows and road segment lengths, without incorporating data on vehicle speeds [13]. Including this attribute in future analyses could provide a more detailed understanding of traffic dynamics and support more effective solutions, particularly for managing traffic during critical events like natural disasters.

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