ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

ABC-UTC GUIDE FOR:

COMPLEX NETWORKS PERSPECTIVES TOWARDS ACCELERATED BRIDGE CONSTRUCTION (ABC)

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Florida International University

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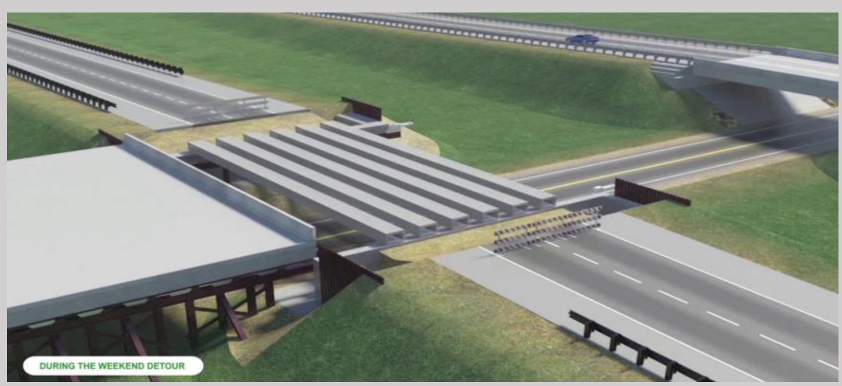

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Table of Contents

ABSTRACT

This report summarizes the work activities undertaken in the study and presents the results of those activities toward development of this ABC-UTC Guide for Complex Networks Perspectives towards Accelerated Bridge Construction (ABC). This study emphasized on a coordinated and extensive network experiments at different geographic scales to apply complex network science principles to the study of bridge networks and ABC related activities. GIS modeling is used along with FDOT bridge and road network data to run network experiments and prioritize certain bridges based on their network credentials. In particular, the study established a systematic approach to rank the topological credentials of bridges based on the connectivity of road networks. The research provides new insights into ABC activities and scheduling based on the topography of vulnerable bridges and monitoring system-wide impacts during crisis such as evacuations during major hurricanes in coastal areas. The study guides towards developing a credible tool that would benefit states, municipalities, and other transportation authorities to prioritize risk-based maintenance strategies and implement different ABC methods ensuring more efficient cost, schedule, and quality.

ACKNOWLEDGMENTS

The research study resulting in development of this Guide was supported by the US Department of Transportation through the Accelerated Bridge Construction University Transportation Center (ABC-UTC).

1. INTRODUCTION

Accelerated Bridge Construction (ABC) employs precast bridge elements moved to the bridge location and installed in place. Although ABC advances the life cycle cost (while using new materials and methods), reduce construction time, and result in higher quality of elements, nevertheless many cast-in-place activities need to be undertaken. As such, despite the fact that ABC reduces many uncertainties associated with construction processes and performance during service life, ABC related activities can create impacts on the road network carrying regular traffic. The problem may get escalated during major natural extreme events (hurricane, wildfire). As such, network positions or credentials of bridges based on their topography or connectivity need to be assessed to prioritize or stage ABC activities. There have been limited investigations by many states to monitor the effects on traffic due to ABC related activities and to identify more efficient strategies to pursue such activities while reducing overall system-wide impact. Essentially, it attempted to establish relationships between bridge topography with their functional behavior. The research will provide new insights into ABC activities and scheduling based on the topography of vulnerable bridges and monitoring system-wide cascading effects. The results will be compiled and published on ABC-UTC website and will become available to outside users and researchers. The study developed an approach and tool that states, municipalities and other transportation authorities can use to select the proper actions for repair and replacement of exiting bridges by implementing ABC methods of choice and on a risk-based maintenance strategy.

1.1. OBJECTIVE OF THE GUIDE

Conceptual and methodological developments in network analysis have furthered our understanding of the effects of individuals' interpersonal environment on normative social influence and social engagement. Network data offers better insights related to an individual's abilities, aspirations, attitudes, behaviors, and interpersonal environment. The complex topology of real networks allows its actors to change their functional behavior. Network models provide better understanding of the evolutionary mechanisms being accountable for the growth of such networks by capturing the dynamics in the ways network agents interact and change their behavior.

This guide embarked on a coordinated and extensive network experiments at different geographic scales to apply complex network science principles to the study of bridge networks and ABC related activities. The research will use GIS modeling along with FDOT bridge and road network data to run network experiments and prioritize certain bridges based on their network credentials. Essentially, it will be attempted to establish relationships between bridge topography with their functional behavior. The specific objectives of the proposed project include *(a) investigation on the resiliency and vulnerability of road-bridge networked systems, (b) development of a framework for analysis of such networks and their topology with functional behavior, (c) incorporation of the analysis method in a user-friendly tool for use by bridge owners and consultants for decision making on maintenance of the infrastructure, and (d) incorporation of complex network analysis with ABC options and features.*

1.2. SCOPE OF THE GUIDE

Identifying the vulnerable sections and cascading effects in the bridge network system can be quite challenging. Potential failure in a bridge network system is often over-looked, but the consequence can be catastrophic as it can adversely affect the mobility of people. Therefore, addressing the vulnerabilities is very complicated in large cities. While there have been studies that discussed the necessity of developing framework for measuring resilience, a systematic approach to improving resiliency through vulnerability assessment is lacking. The objective of this study is to present method for assessing the vulnerability of a bridge network system and a strategy for improving its resiliency. With a growing attention to risk-based inspection and maintenance of infrastructure, an accurate knowledge of the vulnerabilities and importance, as well as consideration of interrelation among bridges in a network becomes crucial. The bridge network system in the state of Florida, USA will be used as a case study in this project.

The vulnerability and resilience of the Florida bridge network is analyzed based on network science principles and graph theory. For example, a small portion (Miami-Dade) of the Florida road and bridge network is shown in Figure 1. The bridge connectivity will be treated as a network to assess the interdependence between the connectivity of the system components and their functional behavior [1]. In accordance with the network science literature, these network links and nodes can be analyzed with respect to the resilience metrics to determine the critical components of a bridge network system that are more susceptible to external shocks. Once the vulnerabilities have been identified, priorities will be set to improve the different vulnerable sections of the bridge network system. Furthermore, a plan will be developed, to improve the resiliency of all the different components of the bridge network systems. A preliminary literature review is provided in section 4.2 to motivate how network science principles can be applied to the study of bridge networks and Accelerated Bridge Construction (ABC) activities.

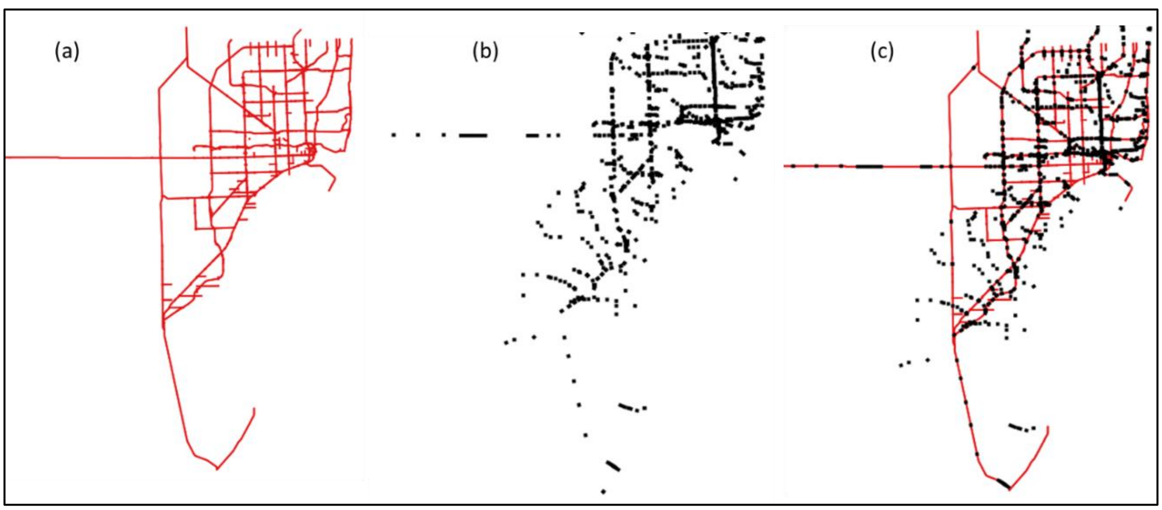


Figure 1 Examples of Miami-Dade County Road-bridge Network. (a) Road Network, (b) Bridge Network, (c) Superimposed Road-bridge Network.

1.3. INTENDED USERS

The research will provide new insights into ABC activities and scheduling based on the topography of vulnerable bridges and monitoring system-wide cascading effects. By applying network science principles, most important (higher degree and more central) bridges among the bridge network have been identified. We can suggest ABC to put more emphasize (maintenance, retrofitting) on those bridges, which can facilitate recovery of bridge networks after an extreme event, hence ensuring resiliency. Similar context can be applied to new ABC activities. The results will be compiled and published on ABC-UTC website and will become available to outside users and researchers. The study has developed an approach and tool that states, municipalities and other transportation authorities can use to select the proper actions for repair and replacement of exiting bridges by implementing ABC methods of choice and on a risk-based maintenance strategy.

2. EXISITNG METHODS OF BRIDGE NETWORK RESILIENCE

Alice et al develops a mixed-integer programming model that provides a balanced portfolio of construction techniques on bridge sites over a prioritization process for bridges at the network level. A project-level scheme accordingly is conducted to optimize the choice of accelerated construction techniques for this purpose, while a network-level scheme is used to select the bridges for rapid replacement based on their criticalities to the network, To account for the effects of different accelerated construction techniques, the costs associated with each replacement technique is calculated including direct costs from the actual replacement of bridges and indirect costs experienced by network users due to the bridge closure during the maintenance period [2].

Twumasi et al. explains hazard impacts on regional network infrastructures and identifying significantly affected areas are important for communicating the need for building resilient infrastructure by describing the comprehension of network-level consequences resulting from disruptive events is a main gray area in the evaluation of transportation network resilience at the regional level. High-impact-zone location identification metrics were developed and implemented in preliminarily identifying areas affected by bridge closures. This study presents a framework for assessing the regional network resilience by leveraging scenario-based traffic modeling and GIS techniques Resilience was estimated, and an index developed by utilizing practical functionality metrics based on vehicle distance and hours traveled. These are illustrated for the Tampa Bay, Florida, area. Findings for 10 bridge closure scenarios and recovery schemas indicated significant regional resilience losses. The I-275 bridge closure indicated the highest functional loss to the regional network: the aggregated resilience index below 0.5 reflects severe network performance deficit and mobility limitations [3].

Zhang et al. presents a methodology systematically incorporates network topology, redundancy, traffic flow, damage level and available resources into the stochastic processes of network post-hazard recovery strategy optimization. A novel resilience-based framework is developed here to optimize the scheduling of the post-disaster recovery actions for road-bridge transportation networks. Two metrics are proposed for measuring rapidity and efficiency of the network recovery: total recovery time (TRT) and the skew of the recovery trajectory (SRT). The TRT is the time required for the network to be restored to its pre-hazard functionality level, while the SRT is a metric defined for the first time in this study to capture the characteristics of the recovery trajectory that relates to the efficiency of those restoration strategies considered. To illustrate the proposed methodology, a genetic algorithm is used to solve the restoration schedule optimization problem for a hypothetical bridge network with 30 nodes and 37 bridges subjected to a scenario seismic event. Based on the two-dimensional metric, a restoration scheduling method is proposed for optimal post-disaster recovery planning for bridge-road transportation networks. A sensitivity study using this network illustrates the impact of the resourcefulness of a community and its time-dependent commitment of resources on the network recovery time and trajectory [4].

Frangopol et al. claims that the most earthquake damage prone components of a transportation network are certainly its bridges; therefore, the proposed approach focuses on bridge rehabilitation interventions. This study deals with the concept of “resilience” and proposes its use as optimization criterion for the rehabilitation of a transportation network subject to earthquake. The design variables of the optimization problem are the application times and durations of the interventions on bridges of the network. These durations are determined by the amount of funding invested on each bridge. Hence, the proposed methodology provides the optimal rehabilitation schedule and cost breakdown for all the bridges of the network. A numerical application is presented to illustrate the proposed approach and to show its capabilities [5].

Bocchini et al. describes that the development of tools for the assisted decision making during the disaster management is the most promising fields where the concept of resilience is applied to engineering practice. The proposed technique involves a completely new formulation of the optimization problem, with new design variables, additional objectives, and constraints. This new technique for the optimal disaster management is presented here that provides bridge restoration sequences which maximize the network resilience and minimize the time to connect critical locations. The purpose of these modifications is to generate an automated procedure that mimics better the decision process currently used by disaster managers. Two numerical examples are presented: the first one is meant to validate and demonstrate the proposed approach, whereas the second proves its applicability to a network with a larger number of bridges. In this latter example the input data have been filtered by random factors to make the data more realistic [6].

Karamlou et al. indicates transportation networks as necessary infrastructure elements to provide supports to impacted areas after the occurrence of a disaster. Recovering without functional roads, other damaged facilities and lifelines would be slow and difficult. Therefore, restoring the damages of transportation networks, specifically bridges as their most vulnerable elements, is among the first priorities of disaster management officials. This study develops a new methodology for the restoration of damaged bridges scheduling by developing an algorithm which is providing a practical restoration plan to be used by decision makers at the time of an event yet based on solid computations rather than mere engineering judgment. The problem is formulated as a multi-objective combinatorial optimization solved by Genetic Algorithms, which minimizes the time to connect the selected critical locations and maximizes the resilience of the transportation network. The algorithm is examined with a numerical example. The presented algorithm can be considered as the enhancement of previous work performed at Lehigh University. The results show that the new optimization setup improved the solution quality and efficiency compared to the previous techniques [7].

Banerjee et al. provided an organized and wide-ranging review on bridge and bridge network resilience assessment under single hazard and multi-hazard conditions. Resilience assessment for engineered systems in recent years has attracted considerable attention from the engineering community. It has resulted in a large body of literature that focuses on relevant areas of resilience. Authors mentioned not that much work has yet been done on multi-hazard bridge resilience, relevant aspects are discussed, including combinations of multiple hazards for bridge performance assessment, loss assessment methods, and post-event recovery approaches. In addition, maintenance is a key component when a life-cycle framework evaluates resilience. Accessible maintenance plans and strategies are discussed as well as their likely applications for bridges and bridge networks. The article ends with a debate on the need for more work in the focus area and the challenges associated with it [8].

Bocchini et al. discussed an optimization method for the reconstruction activities associated with the bridges of an earthquake-seriously damaged transportation network. The development variables are (i) the time periods between the occurrence of the distress and the start of the interventions on each network bridge; and (ii) the rate of reconstruction of the interventions, which is a measure of the funding allocated to each bridge. The optimization goals were to optimize the efficiency of the network, reduce the time required to reach a target level of functionality, and minimize the total cost of restoration activities. Since the first two goals obviously clash with the last, the optimization approach does not provide a unique solution, but a whole array of Pareto solutions. The capabilities of the proposed methodology are illustrated by a numerical example involving a complex, existing transport network in Santa Barbara, California [9].

Setunge et al. stated that the road networks and critical road systems such as bridges, culverts and floodways play a vital role in increasing the risk of the area being served before, during and after extreme events. The research presented a detailed analysis of the Lockyer Valley region of Australia's case study of 2013 floods to identify critical failure mechanisms of road bridge structures exposed to flood events. 43 out of 46 bridges in the region have been damaged as a result of the 2013 flood. Major bridge structure failure mechanisms are described as scouring of piers and abutments, damage to bridge decks due to impact of urban debris, and severe damage to bridge approach ramps. A methodology is proposed for vulnerability modeling of bridges for an extreme event, consisting of a combination of the definition of fault tree system and harm index [10].

Karamlou et al. presented a new scheduling methodology to restore damaged bridges. The problem is formulated as a multi-objective combinatorial optimization solved by Genetic Algorithms which minimizes the time to connect the critical locations selected and maximizes the transport network's resilience. The main purpose of designing the algorithm was to provide a restore strategy that is realistic to be used at the time of an incident by decision-makers but based on solid computations rather than pure judgment of technology. A statistical example explores the algorithm. The results show that, compared to previous approaches, the current optimization system improved the quality and efficiency of the solution [11].

Zhang et al. proposed a new resilience-based framework for street-bridge transport networks to optimize the scheduling of post-disaster recovery actions. Systematically, the approach integrates network topology, reliability, traffic flow, damage level and available resources into the design of the post-hazard recovery strategy network stochastic processes. Two metrics were proposed to calculate network recovery speed and efficiency: total recovery time (TRT) and the skew of the recovery trajectory (SRT). The TRT is the time required to restore the network to its pre-hazard level of functionality, while the SRT is a metric established for the first time in this study to capture the characteristics of the recovery path that are linked to the efficiency of those strategies considered for restoration. A sensitivity study using this network illustrates the impact on the network recovery time and trajectory of a community's resourcefulness and its time-dependent resource commitment. A restore scheduling method for optimal post-disaster recovery planning for bridge-road transport networks is proposed based on this two-dimensional metric. A genetic algorithm is used to solve the problem of restore schedule optimization for a hypothetical bridge network with 30 nodes and 37 bridges subjected to a seismic scenario case to explain the suggested technique [12].

3. DEFINITION OF NETWORK PARAMETERS

Network Resilience

This property, related to degree distributions, refers to the resilience of networks as a result of removing random nodes in the network and the level of resilience to such vertex removal varies across networks depending on the network topology [1, 13]. Networks in which most of the nodes have low degree have less disruption since these nodes lie on few paths between others, whereas removal of high degree nodes in a large real network can result in major disruption. The usual length of these paths will increase if nodes are removed from a network, resulting in disconnected pairs of nodes, and making it more difficult for network agents to communicate.

Node Degree

The node degree is the number of edges adjacent to that node (deg_i). In-degree is the number of edges pointing into the node (in_deg_i) and out-degree is the number of edges pointing out of the node (out_deg_i). Average neighbor degree refers average degree of the neighborhood ($z_{n,i}$) of each node i is:

$$z_{n,i} = \frac{1}{|N_i|} \sum_{j \in N_i} z_j \quad (4)$$

where, $N(i)$ are the neighbors of node i ; z_j is the degree of node j that belongs to N_i. In case of weighted graphs, weighted degree of each node can be used [14, 15].

Betweenness Centrality

Out of a number centrality measures, betweenness centrality (BC_i) of node i is the sum of the fraction of all-pairs of shortest path that pass-through node i:

$$BC_i = \sum_{x,y \in V} \frac{\theta_{(x,y\,|\,j)}}{\theta_{(x,y)}} \quad (6)$$

where, V is the set of nodes in G, $\theta_{(x,y)}$ is the number of shortest (x, y) paths, and $\theta_{(x,y\,|\,j)}$ is the number of paths that pass through some node j other than (x, y). Please refer to [16-18] for more details.

Closeness Centrality

The closeness centrality (CC_i) of node i is the reciprocal of the sum of the shortest path distances from node i to all $(n-1)$ other nodes in the graph G:

$$CC_i = \frac{n-1}{\sum_{j=1}^{n-1} \theta_{(j,i)}} \quad (7)$$

where, $\theta_{(j,i)}$ is the shortest path distance between node j and node i and n is the number of total nodes in graph G. Closeness is normalized by the sum of minimum possible distances of $(n-1)$ since the sum of the distances depend on the number of nodes in the graph. Higher values of closeness imply higher centrality. Please refer to [19] for details.

Edge Betweenness Centrality

Compute betweenness centrality for edges. Betweenness centrality of an edge e is the sum of the fraction of all-pairs shortest paths that pass through e:

$$c_B(e) = \sum_{s,t \in V} \frac{\sigma(s,t|e)}{\sigma(s,t)} \quad (9)$$

where V is the set of nodes, `sigma(s, t)` is the number of shortest (s,t)-paths, and $\sigma(s,t|e)$ is the number of those paths passing through edge e [17].

4. ROAD AND BRIDGE NETWORK DATA

4.1. STEPS INVOLVED IN OBTAINING SHAPE FILES

In this project, the Florida road and bridge network shape files are obtained from Florida Department of Transportation (FDOT) websites' Transportation Data and Analytics/GIS section (Figure 3). For the Florida road shape file, Florida Traffic Online is considered as the source of road shape file [20].

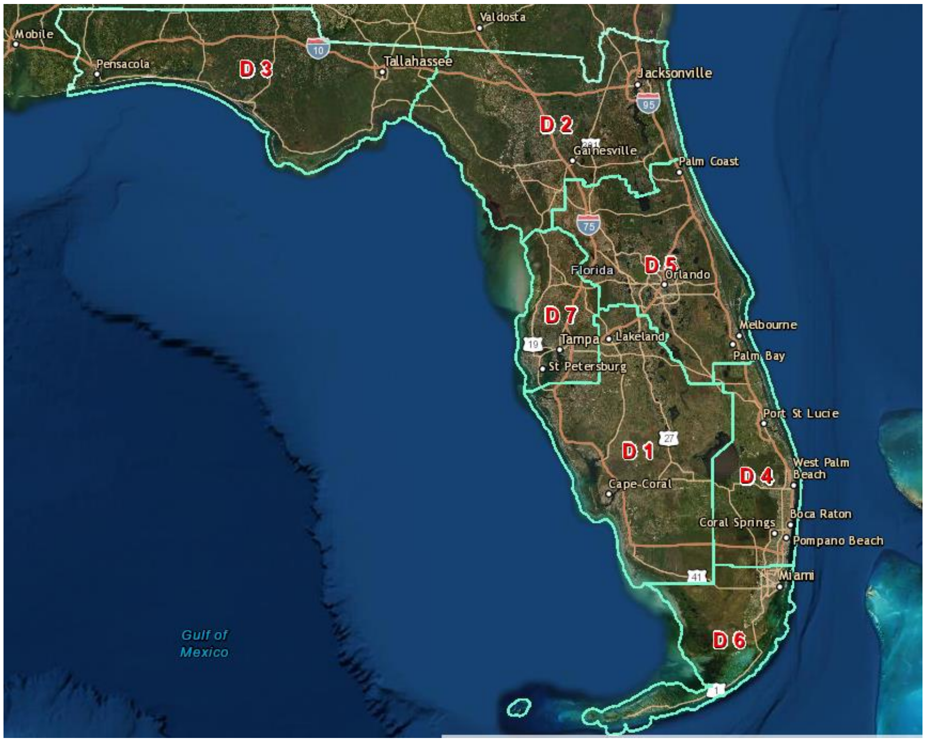


Figure 2 Florida Traffic Online- Source of Florida Road Network Shape File

Besides, the Florida bridge location shape file (Bridges) is obtained from the following FDOT website. Another road shape file (Roads with Local Names) for the Florida state can also be found in the same website which is used to match the roads and bridges name. Both the bridges and road shape files are marked with red box in Figure 4 [21].

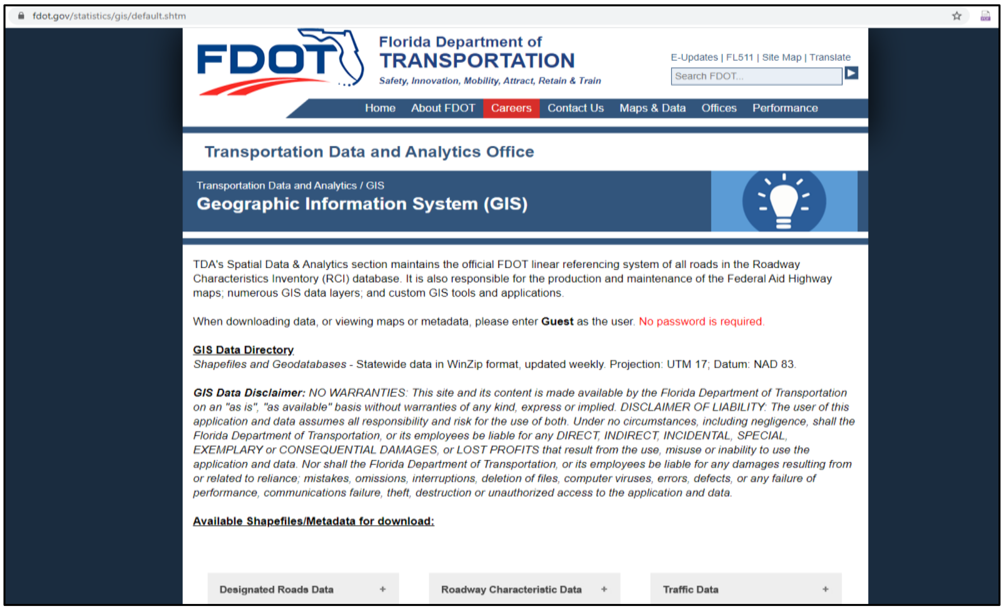


Figure 3 FDOT Transportation Data and Analytics/GIS Section

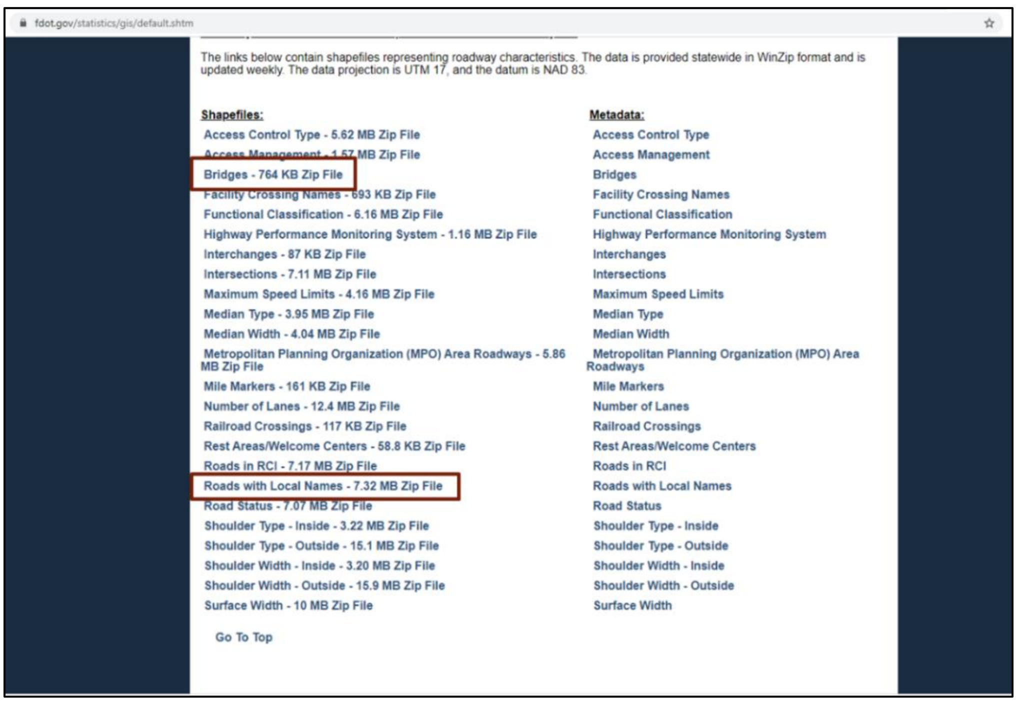


Figure 4 FDOT Transportation Data and Analytics/GIS Section (Florida Bridge Shape file)

4.2. STEPS INVOLVED IN CONVERTING SHAPE FILES TO NETWORK READABLE FILES

The shapefile is converted to network readable file by using a library of python programming language named NetworkX. NetworkX is a python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks [22]. The key steps involved in converting shape files to network readable file are summarized below-

- At first, the road and bridge shape files of the State of Florida are superimposed to create the combined road-bridge network shape file.
- Then, python programming language is used to convert the shape file to network readable file for network analysis.
- NetworkX library in python language is used to convert the shape files.
- NetworkX library converts the geolocation information of the road-bridge network shapefile to a network graph, which contains the roads starting and end point information by specific labelling.
- This network graph is internally created within the python code; it is not necessary to import the network graph as NetworkX library can directly analyze the graph.

4.3. FLORIDA ROAD NETWORK SHAPE FILE

The Florida road network shape file is a polyline shape file and contains very useful and authentic information about the roadways of the whole State of Florida. All the information is stored in a database which is accessible through the Attribute Table. From the Figure 5, it can be observed that the roadway names are available according to the road location and local place. Besides, the roadway numbers, assigned by FDOT are also available along with the county name, ZIP code and roadway direction (eastbound, westbound, southbound, and northbound).

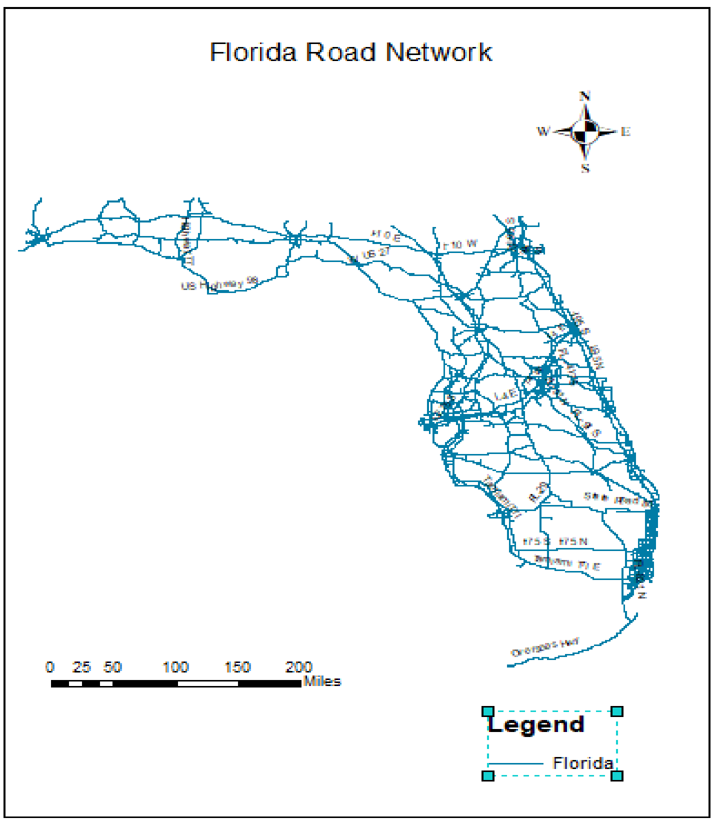
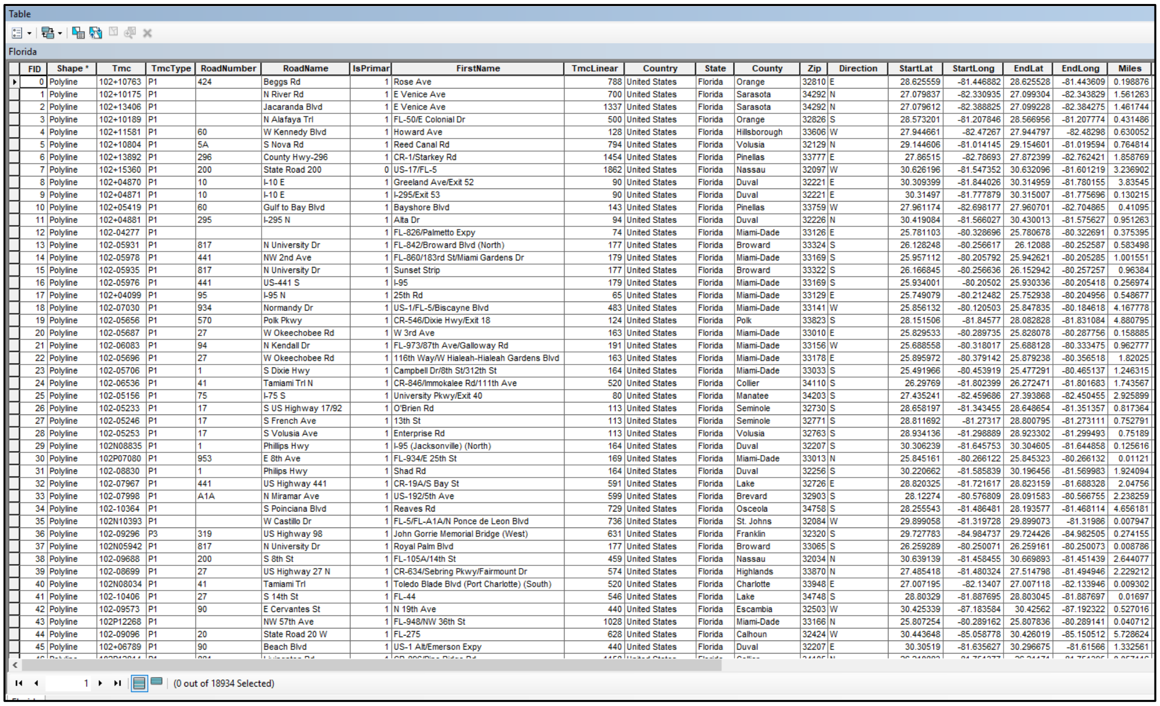


Figure 5 Florida Road Network

The most important information for the road and bridge network analysis is the specific geolocations (coordinates) of the starting point and end point of each roadway segment, which is available with the length of these segments. From the attribute tables (Figure 6 and Figure 7), it is found that there are approximately 18,550 roadway segment and 15,550 roadway segment intersection information are existing in the shape file. Then, the route number (for an example the name of the 8th street is US 41 according to the route number), number of lanes and Average Annual Daily Traffic (AADT) counts are also obtainable from the attribute tables of the shape file.



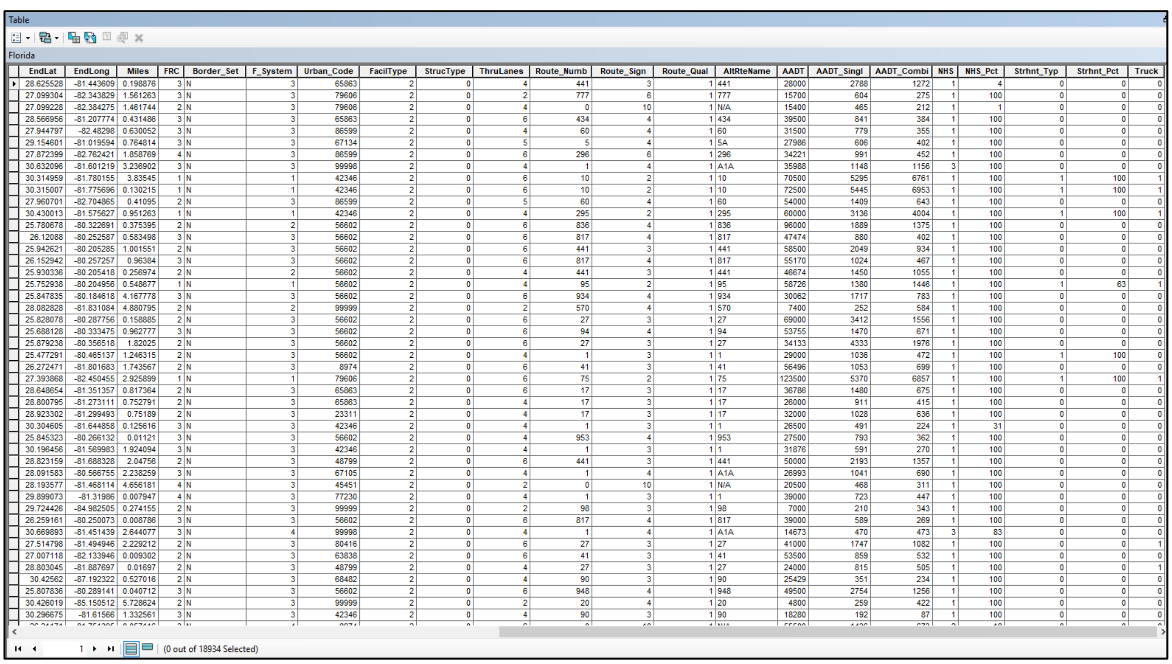
Table

Florida

FID	Shape *	Tmc	TmcType	RoadNumber	RoadName	IsPrimar	FirstName	TmcLinear	Country	State	County	Zip	Direction	StartLat	StartLong	EndLat	EndLong	Miles
0	Polyline	102+10763	P1	424	Beggs Rd	1	Rose Ave	788	United States	Florida	Orange	32810	E	28.625559	-81.446882	28.625528	-81.443609	0.198876
1	Polyline	102+10175	P1		N River Rd	1	E Venice Ave	700	United States	Florida	Sarasota	34292	N	27.079837	-82.330935	27.099304	-82.343829	1.561263
2	Polyline	102+13406	P1		Jacaranda Blvd	1	E Venice Ave	1337	United States	Florida	Sarasota	34292	N	27.079612	-82.388825	27.099228	-82.384275	1.461744
3	Polyline	102+10189	P1		N Alafaya Trl	1	FL-50/E Colonial Dr	500	United States	Florida	Orange	32826	S	28.573201	-81.207846	28.566956	-81.207774	0.431486
4	Polyline	102+11581	P1	60	W Kennedy Blvd	1	Howard Ave	128	United States	Florida	Hillsborough	33606	W	27.944661	-82.47267	27.944797	-82.48298	0.630052
5	Polyline	102+10804	P1	5A	S Nova Rd	1	Reed Canal Rd	794	United States	Florida	Volusia	32129	N	29.144606	-81.014145	29.154601	-81.019594	0.764814
6	Polyline	102+13892	P1	296	County Hwy-296	1	CR-1/Starkey Rd	1454	United States	Florida	Pinellas	33777	E	27.86515	-82.78693	27.872399	-82.762421	1.858769
7	Polyline	102+15360	P1	200	State Road 200	0	US-17/FL-5	1862	United States	Florida	Nassau	32097	W	30.626196	-81.547352	30.632096	-81.601219	3.236902
8	Polyline	102+04870	P1	10	I-10 E	1	Greeland Ave/Exit 52	90	United States	Florida	Duval	32221	E	30.309399	-81.844026	30.314959	-81.780155	3.83545
9	Polyline	102+04871	P1	10	I-10 E	1	I-295/Exit 53	90	United States	Florida	Duval	32221	E	30.31497	-81.777879	30.315007	-81.775696	0.130215
10	Polyline	102+05419	P1	60	Gulf to Bay Blvd	1	Bayshore Blvd	143	United States	Florida	Pinellas	33759	W	27.961174	-82.698177	27.960701	-82.704865	0.41095
11	Polyline	102+04881	P1	295	I-295 N	1	Alta Dr	94	United States	Florida	Duval	32226	N	30.419084	-81.566027	30.430013	-81.575627	0.951263
12	Polyline	102-04277	P1			1	FL-826/Palmetto Expy	74	United States	Florida	Miami-Dade	33126	E	25.781103	-80.328696	25.780678	-80.322691	0.375395
13	Polyline	102-05931	P1	817	N University Dr	1	FL-842/Broward Blvd (North)	177	United States	Florida	Broward	33324	S	26.128248	-80.256617	26.12088	-80.252587	0.583498
14	Polyline	102-05978	P1	441	NW 2nd Ave	1	FL-860/183rd St/Miami Gardens Dr	179	United States	Florida	Miami-Dade	33169	S	25.957112	-80.205792	25.942621	-80.205285	1.001551
15	Polyline	102-05935	P1	817	N University Dr	1	Sunset Strip	177	United States	Florida	Broward	33322	S	26.166845	-80.256636	26.152942	-80.257257	0.96384
16	Polyline	102-05976	P1	441	US-441 S	1	I-95	179	United States	Florida	Miami-Dade	33169	S	25.934001	-80.20502	25.930336	-80.205418	0.256974
17	Polyline	102+04099	P1	95	I-95 N	1	25th Rd	65	United States	Florida	Miami-Dade	33129	E	25.749079	-80.212482	25.752938	-80.204956	0.548677
18	Polyline	102-07030	P1	934	Normandy Dr	1	US-1/FL-5/Biscayne Blvd	483	United States	Florida	Miami-Dade	33141	W	25.856132	-80.120503	25.847835	-80.184618	4.167778
19	Polyline	102-05656	P1	570	Polk Pkwy	1	CR-546/Dixie Hwy/Exit 18	124	United States	Florida	Polk	33823	S	28.151506	-81.84577	28.082828	-81.831084	4.880795
20	Polyline	102-05687	P1	27	W Okeechobee Rd	1	W 3rd Ave	163	United States	Florida	Miami-Dade	33010	E	25.829533	-80.289735	25.828078	-80.287756	0.158885
21	Polyline	102-06083	P1	94	N Kendall Dr	1	FL-973/87th Ave/Galloway Rd	191	United States	Florida	Miami-Dade	33156	W	25.688558	-80.318017	25.688128	-80.333475	0.962777
22	Polyline	102-05696	P1	27	W Okeechobee Rd	1	116th Way/W Hialeah-Hialeah Gardens Blvd	163	United States	Florida	Miami-Dade	33178	E	25.895972	-80.379142	25.879238	-80.356518	1.82025
23	Polyline	102-05706	P1	1	S Dixie Hwy	1	Campbell Dr/8th St/312th St	164	United States	Florida	Miami-Dade	33033	S	25.491966	-80.453919	25.477291	-80.465137	1.246315
24	Polyline	102-06536	P1	41	Tamiami Trl N	1	CR-846/Immokalee Rd/111th Ave	520	United States	Florida	Collier	34110	S	26.29769	-81.802399	26.272471	-81.801683	1.743567
25	Polyline	102-05156	P1	75	I-75 S	1	University Pkwy/Exit 40	80	United States	Florida	Manatee	34203	S	27.435241	-82.459686	27.393868	-82.450455	2.925899
26	Polyline	102-05233	P1	17	S US Highway 17/92	1	O'Brien Rd	113	United States	Florida	Seminole	32730	S	28.658197	-81.343455	28.648654	-81.351357	0.817364
27	Polyline	102-05246	P1	17	S French Ave	1	13th St	113	United States	Florida	Seminole	32771	S	28.811692	-81.27317	28.800795	-81.273111	0.752791
28	Polyline	102-05253	P1	17	S Volusia Ave	1	Enterprise Rd	113	United States	Florida	Volusia	32763	S	28.934136	-81.298889	28.923302	-81.299493	0.75189
29	Polyline	102N08835	P1	1	Phillips Hwy	1	I-95 (Jacksonville) (North)	164	United States	Florida	Duval	32207	S	30.306239	-81.645753	30.304605	-81.644858	0.125616
30	Polyline	102P07080	P1	953	E 8th Ave	1	FL-934/E 25th St	169	United States	Florida	Miami-Dade	33013	N	25.845161	-80.266122	25.845323	-80.266132	0.01121
31	Polyline	102-08830	P1	1	Philips Hwy	1	Shad Rd	164	United States	Florida	Duval	32256	S	30.220662	-81.585839	30.196456	-81.569983	1.924094
32	Polyline	102-07967	P1	441	US Highway 441	1	CR-19A/S Bay St	591	United States	Florida	Lake	32726	E	28.820325	-81.721617	28.823159	-81.688328	2.04756
33	Polyline	102-07998	P1	A1A	N Miramar Ave	1	US-192/5th Ave	599	United States	Florida	Brevard	32903	S	28.12274	-80.576809	28.091583	-80.566755	2.238259
34	Polyline	102-10364	P1		S Poinciana Blvd	1	Reaves Rd	729	United States	Florida	Osceola	34758	S	28.255543	-81.486481	28.193577	-81.468114	4.656181
35	Polyline	102N10393	P1		W Castillo Dr	1	FL-5/FL-A1A/N Ponce de Leon Blvd	736	United States	Florida	St. Johns	32084	W	29.899058	-81.319728	29.899073	-81.31986	0.007947
36	Polyline	102-09296	P3	319	US Highway 98	1	John Gorrie Memorial Bridge (West)	631	United States	Florida	Franklin	32320	S	29.727783	-84.984737	29.724426	-84.982505	0.274155
37	Polyline	102N05942	P1	817	N University Dr	1	Royal Palm Blvd	177	United States	Florida	Broward	33065	S	26.259289	-80.250071	26.259161	-80.250073	0.008786
38	Polyline	102-09688	P1	200	S 8th St	1	FL-105A/14th St	459	United States	Florida	Nassau	32034	N	30.639139	-81.458455	30.669893	-81.451439	2.644077
39	Polyline	102-08699	P1	27	US Highway 27 N	1	CR-634/Sebring Pkwy/Fairmount Dr	574	United States	Florida	Highlands	33870	N	27.485418	-81.480324	27.514798	-81.494946	2.229212
40	Polyline	102N08034	P1	41	Tamiami Trl	1	Toledo Blade Blvd (Port Charlotte) (South)	520	United States	Florida	Charlotte	33948	E	27.007195	-82.13407	27.007118	-82.133946	0.009302
41	Polyline	102-10406	P1	27	S 14th St	1	FL-44	546	United States	Florida	Lake	34748	S	28.80329	-81.887695	28.803045	-81.887697	0.01697
42	Polyline	102-09573	P1	90	E Cervantes St	1	N 19th Ave	440	United States	Florida	Escambia	32503	W	30.425339	-87.183584	30.42562	-87.192322	0.527016
43	Polyline	102P12268	P1		NW 57th Ave	1	FL-948/NW 36th St	1028	United States	Florida	Miami-Dade	33166	N	25.807254	-80.289162	25.807836	-80.289141	0.040712
44	Polyline	102-09096	P1	20	State Road 20 W	1	FL-275	628	United States	Florida	Calhoun	32424	W	30.443648	-85.058778	30.426019	-85.150512	5.728624
45	Polyline	102+06789	P1	90	Beach Blvd	1	US-1 Alt/Emerson Expy	440	United States	Florida	Duval	32207	E	30.30519	-81.635627	30.296675	-81.61566	1.332561

(0 out of 18934 Selected)

Figure 6 Attribute Table (information from the shape file) of Florida Road Network



Table

Florida

EndLat	EndLong	Miles	FRC	Border_Set	F_System	Urban_Code	FacilType	StrucType	ThruLanes	Route_Numb	Route_Sign	Route_Qual	AltRteName	AADT	AADT_Singl	AADT_Combi	NHS	NHS_Pct	Strhnt_Typ	Strhnt_Pct	Truck
28.625528	-81.443609	0.198876	3	N	3	65863	2	0	4	441	3	1	441	28000	2788	1272	1	4	0	0	0
27.099304	-82.343829	1.561263	3	N	3	79606	2	0	2	777	6	1	777	15700	604	275	1	100	0	0	0
27.099228	-82.384275	1.461744	2	N	3	79606	2	0	4	0	10	1	N/A	15400	465	212	1	1	0	0	0
28.566956	-81.207774	0.431486	3	N	3	65863	2	0	6	434	4	1	434	39500	841	384	1	100	0	0	0
27.944797	-82.48298	0.630052	3	N	3	86599	2	0	4	60	4	1	60	31500	779	355	1	100	0	0	0
29.154601	-81.019594	0.764814	3	N	3	67134	2	0	5	5	4	1	5A	27986	606	402	1	100	0	0	0
27.872399	-82.762421	1.858769	4	N	3	86599	2	0	6	296	6	1	296	34221	991	452	1	100	0	0	0
30.632096	-81.601219	3.236902	3	N	3	99998	2	0	4	1	4	1	A1A	35988	1148	1156	3	100	0	0	0
30.314959	-81.780155	3.83545	1	N	1	42346	2	0	6	10	2	1	10	70500	5295	6761	1	100	1	100	1
30.315007	-81.775696	0.130215	1	N	1	42346	2	0	6	10	2	1	10	72500	5445	6953	1	100	1	100	1
27.960701	-82.704865	0.41095	2	N	3	86599	2	0	5	60	4	1	60	54000	1409	643	1	100	0	0	0
30.430013	-81.575627	0.951263	1	N	1	42346	2	0	4	295	2	1	295	60000	3136	4004	1	100	1	100	1
25.780678	-80.322691	0.375395	2	N	2	56602	2	0	6	836	4	1	836	96000	1889	1375	1	100	0	0	0
26.12088	-80.252587	0.583498	3	N	3	56602	2	0	6	817	4	1	817	47474	880	402	1	100	0	0	0
25.942621	-80.205285	1.001551	2	N	3	56602	2	0	6	441	3	1	441	58500	2049	934	1	100	0	0	0
26.152942	-80.257257	0.96384	3	N	3	56602	2	0	6	817	4	1	817	55170	1024	467	1	100	0	0	0
25.930336	-80.205418	0.256974	2	N	2	56602	2	0	4	441	3	1	441	46674	1450	1055	1	100	0	0	0
25.752938	-80.204956	0.548677	1	N	1	56602	2	0	4	95	2	1	95	58726	1380	1446	1	100	1	63	1
25.847835	-80.184618	4.167778	3	N	3	56602	2	0	6	934	4	1	934	30062	1717	783	1	100	0	0	0
28.082828	-81.831084	4.880795	2	N	2	99999	2	0	2	570	4	1	570	7400	252	584	1	100	0	0	0
25.828078	-80.287756	0.158885	2	N	3	56602	2	0	6	27	3	1	27	69000	3412	1556	1	100	0	0	0
25.688128	-80.333475	0.962777	3	N	3	56602	2	0	6	94	4	1	94	53755	1470	671	1	100	0	0	0
25.879238	-80.356518	1.82025	2	N	3	56602	2	0	6	27	3	1	27	34133	4333	1976	1	100	0	0	0
25.477291	-80.465137	1.246315	2	N	3	56602	2	0	4	1	3	1	1	29000	1036	472	1	100	1	100	0
26.272471	-81.801683	1.743567	2	N	3	8974	2	0	6	41	3	1	41	56496	1053	699	1	100	0	0	0
27.393868	-82.450455	2.925899	1	N	1	79606	2	0	6	75	2	1	75	123500	5370	6857	1	100	1	100	1
28.648654	-81.351357	0.817364	2	N	3	65863	2	0	6	17	3	1	17	36786	1480	675	1	100	0	0	0
28.800795	-81.273111	0.752791	2	N	3	65863	2	0	4	17	3	1	17	26000	911	415	1	100	0	0	0
28.923302	-81.299493	0.75189	2	N	3	23311	2	0	4	17	3	1	17	32000	1028	636	1	100	0	0	0
30.304605	-81.644858	0.125616	3	N	3	42346	2	0	4	1	3	1	1	26500	491	224	1	31	0	0	0
25.845323	-80.266132	0.01121	3	N	3	56602	2	0	4	953	4	1	953	27500	793	362	1	100	0	0	0
30.196456	-81.569983	1.924094	3	N	3	42346	2	0	4	1	3	1	1	31876	591	270	1	100	0	0	0
28.823159	-81.688328	2.04756	2	N	3	48799	2	0	6	441	3	1	441	50000	2193	1357	1	100	0	0	0
28.091583	-80.566755	2.238259	3	N	3	67105	2	0	4	1	4	1	A1A	26993	1041	690	1	100	0	0	0
28.193577	-81.468114	4.656181	4	N	3	45451	2	0	2	0	10	1	N/A	20500	468	311	1	100	0	0	0
29.899073	-81.31986	0.007947	4	N	3	77230	2	0	4	1	3	1	1	39000	723	447	1	100	0	0	0
29.724426	-84.982505	0.274155	2	N	3	99999	2	0	2	98	3	1	98	7000	210	343	1	100	0	0	0
26.259161	-80.250073	0.008786	3	N	3	56602	2	0	6	817	4	1	817	39000	589	269	1	100	0	0	0
30.669893	-81.451439	2.644077	3	N	4	99998	2	0	4	1	4	1	A1A	14673	470	473	3	83	0	0	0
27.514798	-81.494946	2.229212	2	N	3	80416	2	0	6	27	3	1	27	41000	1747	1082	1	100	0	0	1
27.007118	-82.133946	0.009302	2	N	3	63838	2	0	6	41	3	1	41	53500	859	532	1	100	0	0	0
28.803045	-81.887697	0.01697	2	N	3	48799	2	0	4	27	3	1	27	24000	815	505	1	100	0	0	1
30.42562	-87.192322	0.527016	2	N	3	68482	2	0	4	90	3	1	90	25429	351	234	1	100	0	0	0
25.807836	-80.289141	0.040712	3	N	3	56602	2	0	6	948	4	1	948	49500	2754	1256	1	100	0	0	0
30.426019	-85.150512	5.728624	2	N	3	99999	2	0	2	20	4	1	20	4800	259	422	1	100	0	0	0
30.296675	-81.61566	1.332561	3	N	3	42346	2	0	4	90	3	1	90	18280	192	87	1	100	0	0	0

(0 out of 18934 Selected)

Figure 7 Attribute Table (information from the shape file) of Florida Road Network

4.4. FLORIDA BRIDGE LOCATION SHAPE FILE

The bridge location shape file (Figure 8) for the State of Florida is also a polyline shape file which provides some essential information for the bridge network analysis.

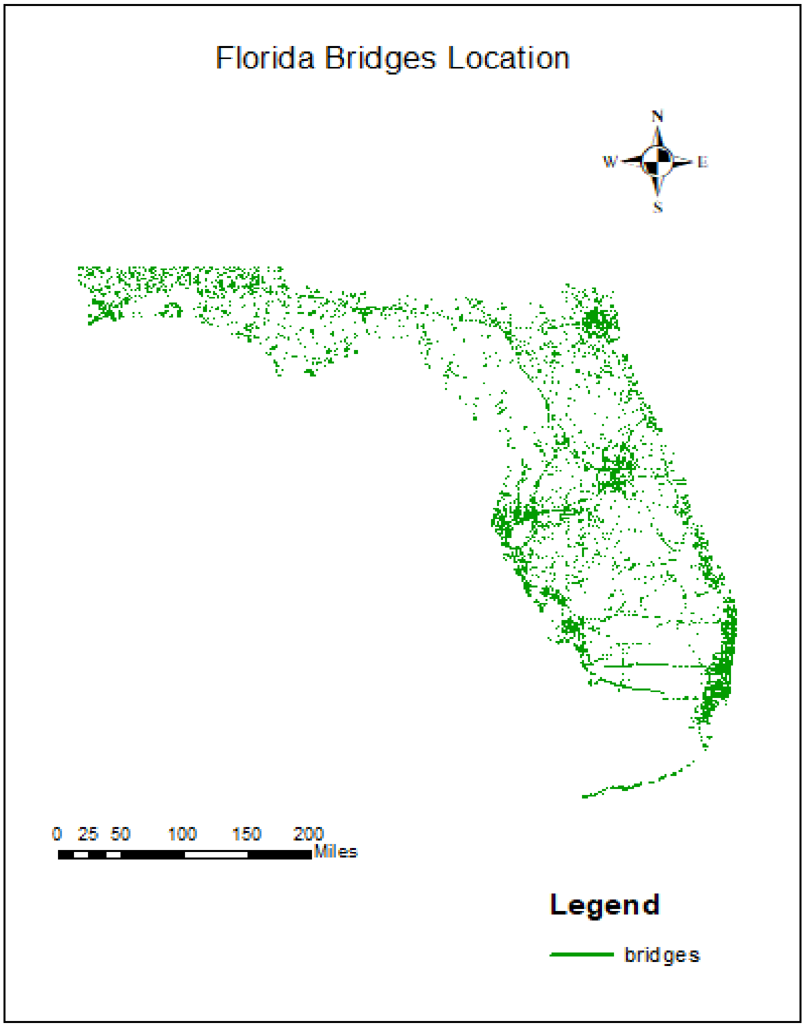


Figure 8 Florida Bridges Location

The attribute table (Figure 9) of the shape file consists of the specific roadway numbers, through which the bridges can be specified along with the roadways. Besides, the structure number of each bridge assigned by FDOT, information about FDOT districts, county names and the length of roadway segments are also available.

Table

bridges

FID	Shape *	ROADWAY	ROAD_SIDE	STRUCTURE_	DISTRICT	COUNTYDOT	COUNTY	MNG_DIST	BEGIN_POST	END_POST	Shape_Leng
0	Polyline	03020000	C	030136	1	03	Collier	1	0.477	0.484	11.1842
1	Polyline	94001000	R	940087	4	94	St. Lucie	4	24.107	24.16	85.3167
2	Polyline	87000068	C	874424	6	87	Miami-Dade	6	1.85	1.864	22.5843
3	Polyline	18000048	C	184109	5	18	Sumter	5	2.221	2.225	6.5039
4	Polyline	53000070	C	534164	3	53	Jackson	3	1.216	1.23	23.3464
5	Polyline	16580000	C	164176	1	16	Polk	1	9.168	9.172	6.4542
6	Polyline	52000012	C	524180	3	52	Holmes	3	0.935	0.954	30.6245
7	Polyline	75040002	L	754124	5	75	Orange	5	2.733	2.774	65.996
8	Polyline	57000030	C	574137	3	57	Okaloosa	3	3.613	3.626	20.9602
9	Polyline	94000008	C	944011	4	94	St. Lucie	4	1.399	1.453	87.1176
10	Polyline	03175000	L	030284	1	03	Collier	1	0.96	1.028	109.6008
11	Polyline	93862000	R	934946	4	93	Palm Beach	4	1.985	2.059	119.1984
12	Polyline	87075626	C	871111	6	87	Miami-Dade	6	0.326	0.388	99.6067
13	Polyline	15180503	C	157162	7	15	Pinellas	7	1.08	1.086	9.6514
14	Polyline	18000048	C	184069	5	18	Sumter	5	3.618	3.625	11.3017
15	Polyline	53002000	L	530055	3	53	Jackson	3	9.623	9.669	74.2365
16	Polyline	87000304	C	874440	6	87	Miami-Dade	6	1.258	1.266	12.8866
17	Polyline	87003000	R	870275	6	87	Miami-Dade	6	2.42	2.456	57.3882
18	Polyline	50001027	C	500075	3	50	Gadsden	3	0.399	0.434	58.7842
19	Polyline	87010000	C	871027	6	87	Miami-Dade	6	6.636	6.644	12.8657
20	Polyline	74030000	R	740029	2	74	Nassau	2	14.406	14.425	30.5766
21	Polyline	57000051	C	570802	3	57	Okaloosa	3	5.416	5.431	24.2487
22	Polyline	16000008	C	164344	1	16	Polk	1	8.357	8.361	6.4463
23	Polyline	87062000	C	870639	6	87	Miami-Dade	6	5.242	5.263	33.77
24	Polyline	75140000	R	750511	5	75	Orange	5	17.153	17.165	19.2351
25	Polyline	03000055	C	036001	1	03	Collier	1	2.69	2.716	41.7081
26	Polyline	74160000	C	740089	2	74	Nassau	2	11.989	12.226	380.9951
27	Polyline	52000016	C	524202	3	52	Holmes	3	1.18	1.188	12.8914
28	Polyline	16730500	C	164141	1	16	Polk	1	3.948	3.951	4.8118
29	Polyline	03175000	R	030239	1	03	Collier	1	27.05	27.072	35.4078
30	Polyline	87000081	C	874418	6	87	Miami-Dade	6	0.864	0.875	17.693
31	Polyline	87000021	C	874265	6	87	Miami-Dade	6	0.904	0.914	16.0279
32	Polyline	57000058	C	570811	3	57	Okaloosa	3	3.629	3.638	14.5629
33	Polyline	15190904	C	150182	7	15	Pinellas	7	0.296	0.338	67.6451
34	Polyline	94530000	C	940050	4	94	St. Lucie	4	6.337	6.369	51.4297
35	Polyline	87260475	C	871014	6	87	Miami-Dade	6	0.059	0.172	183.67
36	Polyline	75000230	C	750337	5	75	Orange	5	5.98	6.029	78.803
37	Polyline	87000157	C	876401	6	87	Miami-Dade	6	1.266	1.275	14.3736
38	Polyline	03175000	L	030028	1	03	Collier	1	5.9	5.93	48.2797

1 (0 out of 9768 Selected)

bridges

Figure 9 Attribute Table (information from the shape file) of Florida Bridge Location

5. PROPOSED METHODOLOGY FOR BRIDGE NETWORK RESILIENCE

The shape file for the road network of Florida consists of all the freeways, highways, and state roads. Besides, the Florida bridge location shape file covers all the bridges on these highways, state roads and local roads. The road-bridge network analyses are performed for the following four scales-

1. Key West road-bridge network
2. Miami Beach road-bridge network
3. Miami-Dade County road-bridge network
4. State of Florida road-bridge network

5.1. KEY WEST ROAD-BRIDGE NETWORK ANALYSIS

Unweighted Analysis

Unweighted graph analysis only shows the effect of road-bridge network connectivity on different scale of the study area. As explained in previous section that the Florida road-bridge network is performed four scales, the Key West network is analyzed first. From key west road shape file, 50 roadway segments and 37 roadway segment intersection were found. After performing the Closeness Centrality analysis and mapping with bridges, 19 specific bridge location were found with centrality value.

Table 1 Closeness Centrality Values for Key West Road-bridge Network

Bridge Rank	Node Longitude	Node Latitude	Closeness Centrality	Roads	Bridges
1	-81.228329	24.6823346	0.118102797	Overseas Hwy	Overseas Hwy
2	-81.1246718	24.7068776	0.113471314	Overseas Hwy	Overseas Hwy
3	-81.6725094	24.5901406	0.107832988	Overseas Hwy	Overseas Hwy
4	-80.958729	24.756647	0.100353243	Overseas Hwy	Overseas Hwy
5	-81.6743332	24.589813	0.099206349	Overseas Hwy	Overseas Hwy
6	-81.047453	24.725695	0.099206349	Overseas Hwy	Overseas Hwy
7	-80.9235268	24.777144	0.092840166	Overseas Hwy	Overseas Hwy
8	-81.7427334	24.5729766	0.091857731	Overseas Hwy	Overseas Hwy
9	-81.047491	24.725827	0.089031339	Overseas Hwy	Overseas Hwy
10	-81.752044	24.5699624	0.088127468	Overseas Hwy	Overseas Hwy
11	-80.91951	24.7785898	0.085522715	Overseas Hwy	Overseas Hwy
12	-81.7432766	24.5728014	0.085522715	Overseas Hwy	Overseas Hwy
13	-81.7434696	24.5726258	0.082280147	Overseas Hwy	Overseas Hwy
14	-80.640942	24.9131724	0.078557064	Overseas Hwy	Overseas Hwy
15	-81.742596	24.572912	0.077160494	Overseas Hwy	Overseas Hwy
16	-81.6736356	24.5897558	0.072640632	Overseas Hwy	Overseas Hwy
17	-81.6733966	24.5897918	0.068620993	Overseas Hwy	Overseas Hwy
18	-80.374722	25.1707516	0.037037037	Overseas Hwy	Overseas Hwy
19	-80.3742914	25.17166	0.027777778	Overseas Hwy	Overseas Hwy

In Table 1, all the Key West bridge locations' Closeness Centrality values are orderly listed from highest to lowest. Then, the network analysis was performed for the link property by calculating Edge Betweenness Centrality. 25 roadway segments with bridges were found with centrality values after mapping with bridge shape file. In Table 2, all the Key West bridge segments Edge Betweenness Centrality values are orderly listed from highest to lowest.

Table 2 Edge Betweenness Centrality Values for Key West Road-bridge Network

Bridge Rank	Start Long.	Start Lat.	End Long.	End Lat.	Edge Betweenness Centrality	Roads	Bridges
1	-81.6734	24.58979	-81.2283	24.68233	0.217717718	Ovrs Hwy	Ovrs Hwy
2	-81.6736	24.58976	-81.6734	24.58979	0.216216216	Ovrs Hwy	Ovrs Hwy
3	-81.7426	24.57291	-81.6736	24.58976	0.214714715	Ovrs Hwy	Ovrs Hwy
4	-81.7435	24.57263	-81.7426	24.57291	0.213213213	Ovrs Hwy	Ovrs Hwy
5	-81.752	24.56996	-81.7435	24.57263	0.211711712	Ovrs Hwy	Ovrs Hwy
6	-81.7433	24.5728	-81.7522	24.57011	0.201201201	Ovrs Hwy	Ovrs Hwy
7	-81.7427	24.57298	-81.7433	24.5728	0.1996997	Ovrs Hwy	Ovrs Hwy
8	-81.6743	24.58981	-81.7427	24.57298	0.198198198	Ovrs Hwy	Ovrs Hwy
9	-81.6725	24.59014	-81.6743	24.58981	0.196696697	Ovrs Hwy	Ovrs Hwy
10	-81.2283	24.68233	-81.6725	24.59014	0.195195195	Ovrs Hwy	Ovrs Hwy
11	-81.0475	24.7257	-80.9587	24.75665	0.154654655	Ovrs Hwy	Ovrs Hwy
12	-81.1247	24.70688	-81.0475	24.7257	0.153153153	Ovrs Hwy	Ovrs Hwy
13	-81.2283	24.68233	-81.1247	24.70688	0.144144144	Ovrs Hwy	Ovrs Hwy
14	-81.0475	24.72583	-81.1247	24.70688	0.127627628	Ovrs Hwy	Ovrs Hwy
15	-80.9587	24.75665	-81.0475	24.72583	0.126126126	Ovrs Hwy	Ovrs Hwy
16	-80.9587	24.75665	-80.9235	24.77714	0.12012012	Ovrs Hwy	Ovrs Hwy
17	-81.1247	24.70688	-81.2283	24.68233	0.12012012	Ovrs Hwy	Ovrs Hwy
18	-80.9235	24.77714	-80.9195	24.77859	0.11036036	Ovrs Hwy	Ovrs Hwy
19	-80.9195	24.77859	-80.6409	24.91317	0.099099099	Ovrs Hwy	Ovrs Hwy
20	-80.6409	24.91317	-80.3748	25.17029	0.097597598	Ovrs Hwy	Ovrs Hwy
21	-80.9235	24.77714	-80.9587	24.75665	0.09009009	Ovrs Hwy	Ovrs Hwy
22	-80.9195	24.77859	-80.9235	24.77714	0.078828829	Ovrs Hwy	Ovrs Hwy
23	-80.6409	24.91317	-80.9195	24.77859	0.066066066	Ovrs Hwy	Ovrs Hwy
24	-80.3747	25.17075	-80.6409	24.91317	0.063063063	Ovrs Hwy	Ovrs Hwy
25	-80.3743	25.17166	-80.3747	25.17075	0.043543544	Ovrs Hwy	Ovrs Hwy

Weighted Analysis

Weighted graph analysis reflects the effect of different weights (e.g., traffic count, volume, delay etc.) applied on the nodes and links along with the connectivity of the network. In this study, weighted analysis is performed only for links or roadways as the network parameter for nodes (closeness centrality) does not consider weights. Average Annual Daily Traffic (AADT), which is calculated by counting the total volume of vehicles of a road for a year divided by 365 days, is considered as weight on the roadways. For the Key West road-bridge network, weighted analysis did not show any differences in Edge Betweenness Centrality values and the results show a similar output as shown in Table 2. The reason behind this is the network topology and characteristics of the Key West road-bridge network as it is actually a long stretch at the southernmost part of the State of Florida as shown in Figure 10. As such, networks with more complex topology (i.e., grids, triangles) are likely to show more convincing changes in network credentials, which is not applicable for the Key West network. Such effects are presented in the following sections that include analyses of Miami-Dade County and Florida networks.

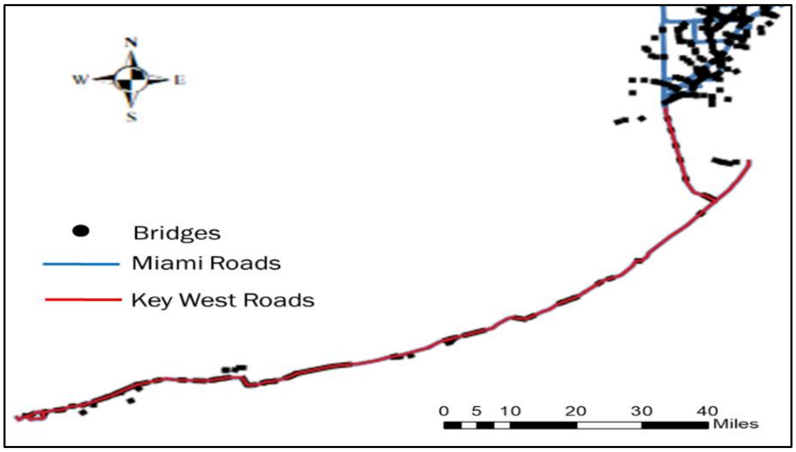


Figure 10 The Long Stretch of Key West Road-bridge Network

5.2. MIAMI-DADE COUNTY ROAD-BRIDGE NETWORK ANALYSIS

Unweighted Analysis

From Miami-Dade Road shape file, 2199 roadway segments and 1960 roadway segment intersection were found. After performing the Closeness Centrality analysis and mapping with bridges, 137 specific bridge location were found with centrality value. The most 20 central bridges' specific location of Miami Dade county according to node property are listed in Table 3.

Table 3 Closeness Centrality Values for Miami-Dade Road-bridge Network

Bridge Rank	Node Long.	Node Lat.	Closeness Centrality	Roads	Bridges
1	-80.2637	25.7717	0.015244	W Flagler St	W FLAGLER ST
2	-80.2392	25.7723	0.014857	W Flagler St	W FLAGLER ST
3	-80.2735	25.7340	0.014087	Granada Blvd	GRANADA BLVD
4	-80.2727	25.8082	0.014011	East Dr	EAST DR
5	-80.2897	25.7043	0.013923	Sunset Dr	SUNSET DR
6	-80.2727	25.8081	0.013721	East Dr	EAST DR
7	-80.2899	25.7042	0.013622	Sunset Dr	SUNSET DR
8	-80.1886	25.7795	0.012464	Biscayne Blvd	BISCAYNE BLVD
9	-80.1893	25.7820	0.012332	Biscayne Blvd	BISCAYNE BLVD
10	-80.1889	25.7801	0.012222	Biscayne Blvd	BISCAYNE BLVD
11	-80.1893	25.7839	0.012096	Biscayne Blvd	BISCAYNE BLVD
12	-80.1892	25.7801	0.011950	Biscayne Blvd	BISCAYNE BLVD
13	-80.1891	25.7853	0.011868	Biscayne Blvd	BISCAYNE BLVD
14	-80.1889	25.7792	0.011735	Biscayne Blvd	BISCAYNE BLVD
15	-80.1890	25.7861	0.011649	Biscayne Blvd	BISCAYNE BLVD

16	-80.1891	25.7870	0.011632	Biscayne Blvd	BISCAYNE BLVD
17	-80.1891	25.7883	0.011492	Biscayne Blvd	BISCAYNE BLVD
18	-80.1890	25.7861	0.011438	Biscayne Blvd	BISCAYNE BLVD
19	-80.1891	25.7861	0.011421	Biscayne Blvd	BISCAYNE BLVD
20	-80.1891	25.7896	0.011355	Biscayne Blvd	BISCAYNE BLVD

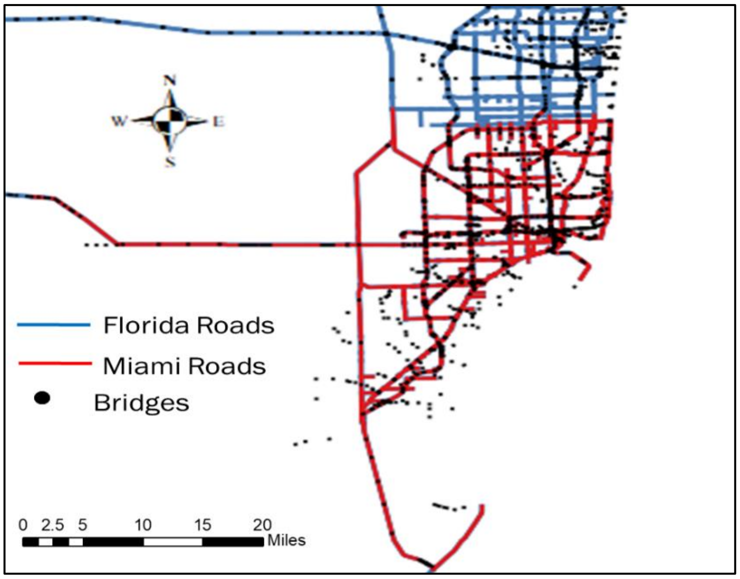


Figure 11 Miami-Dade County Road-bridge Network

Then, the network analysis was performed for the link property by calculating Edge Betweenness Centrality. 168 roadway segments with bridges were found with centrality values after mapping with bridge shape file. The most 50 central bridge segments of Miami Dade County according to link property are listed below in Table 4.

Weighted Analysis

As one of the prime objectives of this study is to examine the effect on traffic due to ABC related activities, hence Average Annual Daily Traffic (AADT) is considered as weight on the roadways of the Miami-Dade County. From the weighted Edge Betweenness Centrality results listed in Table 4, it can be said that traffic volume influences the network parameters significantly as the ranking of most central bridges changes after considering the impact of traffic on road-bridge network. For example, a bridge at Collins Avenue previously ranked as 10th most central bridge from unweighted analysis, but with the effect of traffic it's ranking as a central bridge change to 19. From Table 4, this type of changes in ranking of central bridges are found multiple times where some of the bridges' ranking increased (marked in green) and some decreased (marked in red).

Table 4 Edge Betweenness Centrality Values for Miami-Dade Road-bridge Network

Unweighted Rank	Weighted Rank	Start Long.	Start Lat.	End Long.	End Lat.	Weight (AADT)	Unweighted Edge Betweenness Centrality	Weighted Edge Betweenness Centrality	Roads/ Bridges
1	1	-80.1889	25.7801	-80.1893	25.7820	37297	0.079154	0.068973	Bscn Blvd
2	2	-80.1886	25.7795	-80.1889	25.7801	26070	0.079150	0.068970	Bscn Blvd
3	3	-80.1890	25.7861	-80.1891	25.7870	35988	0.077585	0.067270	Bscn Blvd
4	4	-80.1890	25.7861	-80.1890	25.7861	37500	0.077581	0.067268	Bscn Blvd
5	5	-80.1891	25.7853	-80.1890	25.7861	37500	0.077577	0.067265	Bscn Blvd
6	6	-80.1893	25.7839	-80.1891	25.7853	37930	0.077572	0.067262	Bscn Blvd
7	7	-80.1893	25.7820	-80.1893	25.7839	38000	0.077568	0.067260	Bscn Blvd
8	8	-80.1891	25.7870	-80.1891	25.7883	33500	0.075370	0.064964	Bscn Blvd
9	9	-80.1891	25.7883	-80.1891	25.7896	33500	0.075184	0.064762	Bscn Blvd
10	**19**	**-80.1220**	**25.9299**	**-80.1219**	**25.9304**	**54000**	**0.075149**	**0.062392**	**Clns Ave**
11	10	-80.1891	25.7896	-80.1890	25.7962	33500	0.074997	0.064560	Bscn Blvd
12	11	-80.1890	25.7962	-80.1894	25.8043	36018	0.074809	0.064358	Bscn Blvd
13	12	-80.1894	25.8043	-80.1894	25.8107	33067	0.074621	0.064155	Bscn Blvd
14	13	-80.1894	25.8107	-80.1894	25.8114	42500	0.074441	0.063951	Bscn Blvd
15	14	-80.1894	25.8114	-80.1894	25.8116	42500	0.074260	0.063747	Bscn Blvd
16	15	-80.1894	25.8116	-80.1893	25.8124	118000	0.074078	0.063543	Bscn Blvd
17	16	-80.1891	25.8134	-80.1869	25.8255	35768	0.074037	0.063459	Bscn Blvd
18	17	-80.1893	25.8124	-80.1891	25.8134	35500	0.074032	0.063457	Bscn Blvd
19	18	-80.1840	25.8327	-80.1841	25.8333	40000	0.073301	0.062631	Bscn Blvd
20	**22**	**-80.1227**	**25.8871**	**-80.1220**	**25.9299**	**49883**	**0.073270**	**0.060786**	**Clns Ave**
21	20	-80.1841	25.8333	-80.1841	25.8334	40000	0.072607	0.061886	Bscn Blvd
22	21	-80.1841	25.8334	-80.1846	25.8478	40000	0.072421	0.061677	Bscn Blvd
23	**51**	**-80.1539**	**25.9262**	**-80.1559**	**25.9262**	**51500**	**0.049956**	**0.034025**	**Bscn Blvd**
24	**57**	**-80.2637**	**25.7717**	**-80.2634**	**25.7644**	**44000**	**0.048500**	**0.026107**	**W Flglr St**

25	24	-80.1889	25.7792	-80.1878	25.7753	36000	0.046977	0.048211	Bscn Blvd
26	**45**	**-80.2897**	**25.7043**	**-80.2899**	**25.7042**	**41786**	**0.046962**	**0.036088**	**Sunset Dr**
27	26	-80.1892	25.7801	-80.1889	25.7792	26493	0.045677	0.046896	Bscn Blvd
28	27	-80.1896	25.7839	-80.1895	25.7820	38000	0.044392	0.045498	Bscn Blvd
29	28	-80.1893	25.7855	-80.1896	25.7839	37900	0.044388	0.045495	Bscn Blvd
30	29	-80.1892	25.7860	-80.1893	25.7855	37500	0.044384	0.045492	Bscn Blvd
31	30	-80.1891	25.7861	-80.1892	25.7860	37500	0.044379	0.045490	Bscn Blvd
32	31	-80.1891	25.7870	-80.1891	25.7861	33500	0.044375	0.064964	Bscn Blvd
33	**52**	**-80.2899**	**25.7042**	**-80.2909**	**25.7034**	**73000**	**0.044199**	**0.033205**	**Sunset Dr**
34	32	-80.1891	25.7883	-80.1891	25.7870	33500	0.042155	0.064762	Bscn Blvd
35	33	-80.1891	25.7896	-80.1891	25.7883	33500	0.041964	0.064560	Bscn Blvd
36	34	-80.1890	25.7962	-80.1891	25.7896	36018	0.041773	0.064358	Bscn Blvd
37	35	-80.1894	25.8043	-80.1890	25.7962	33067	0.041581	0.064155	Bscn Blvd
38	36	-80.1894	25.8107	-80.1894	25.8043	42500	0.041388	0.063951	Bscn Blvd
39	37	-80.1894	25.8114	-80.1894	25.8107	42500	0.041203	0.063747	Bscn Blvd
40	38	-80.1894	25.8116	-80.1894	25.8114	118000	0.041018	0.063543	Bscn Blvd
41	39	-80.1893	25.8124	-80.1894	25.8116	35500	0.040832	0.063457	Bscn Blvd
42	40	-80.1892	25.8134	-80.1893	25.8124	35500	0.040782	0.041649	Bscn Blvd
43	41	-80.1841	25.8327	-80.1870	25.8255	40000	0.040029	0.040811	Bscn Blvd
44	42	-80.1841	25.8333	-80.1841	25.8327	40000	0.040024	0.061886	Bscn Blvd
45	43	-80.1841	25.8334	-80.1841	25.8333	40000	0.039326	0.061677	Bscn Blvd
46	**23**	**-80.3684**	**25.5797**	**-80.3664**	**25.5818**	**53500**	**0.036177**	**0.048487**	**Carbn Blvd**
47	**25**	**-80.3595**	**25.5890**	**-80.3541**	**25.5986**	**53500**	**0.035879**	**0.048175**	**Marlin Rd**
48	44	-80.2392	25.7723	-80.2389	25.7652	38000	0.030916	0.039768	W Flagler St
49	46	-80.1234	25.8160	-80.1211	25.8420	42904	0.027048	0.036087	Clns Ave
50	47	-80.1229	25.8138	-80.1234	25.8160	15000	0.027043	0.036084	Clns Ave

***Unweighted road-bridge network is considered as the base network for comparison**

Previously (unweighted analysis) ranked as 24 (West Flagler Street) and 26 (Sunset Drive) central bridges' priority changes to 57 and 45 after considering the effect of traffic on the corresponding roadways. On the other hand, central bridges ranked as 46 (Caribbean Boulevard) and 47 (Marlin Road) from unweighted analysis are relocated in more central position of the Miami-Dade County road-bridge network with ranking of 23 and 25 respectively for weighted graph. Besides, the top 09 ranked bridges centrality values did not show any changes from unweighted analysis and the bridges ranked from 10 to 18 reflects minor changes in weighted analysis. The change in bridge ranking due to traffic is visualized in Figure 12, where the geolocation of bridge ranked as 22 from Table 4 (previously ranked as 20 in unweighted analysis) is highlighted.

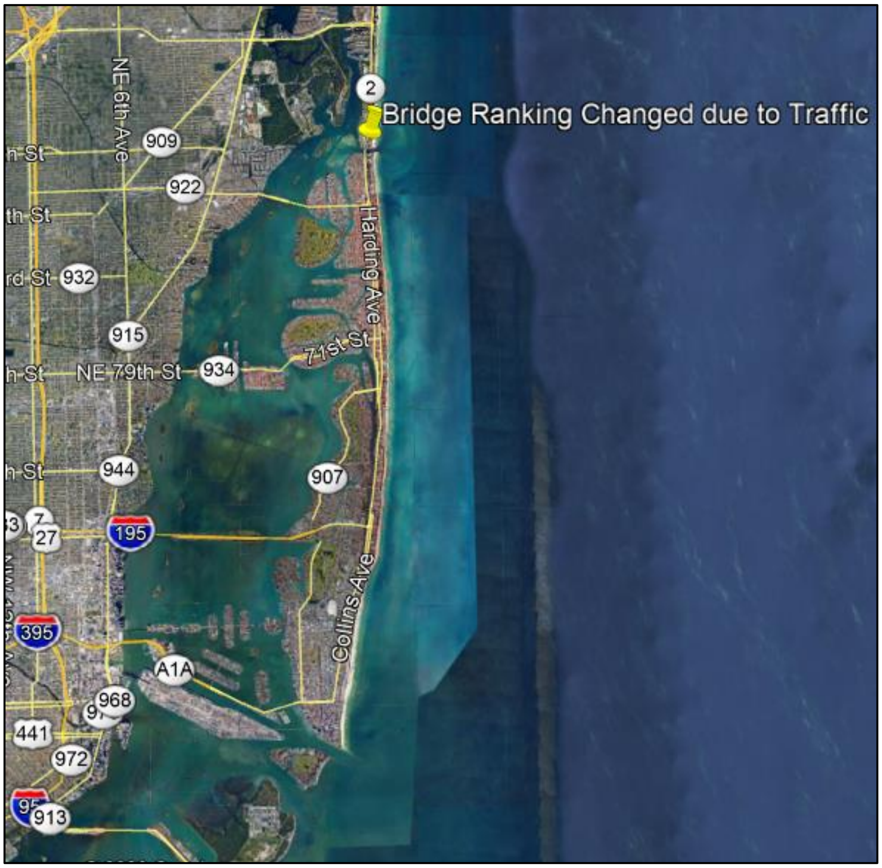


Figure 12 Change in Ranking of a Central Bridge of Miami-Dade County due to Traffic

5.3. MIAMI BEACH ROAD-BRIDGE NETWORK ANALYSES

The Miami Beach network shape file (which is a subset of Miami-Dade County shape file) consisted of 745 roadway segments and 678 roadway segment intersection. After performing the Closeness Centrality analysis and mapping with bridges, 107 specific bridge location were found with centrality value. From Edge Betweenness Centrality analysis, 134 roadway segments with bridges were found with centrality values after mapping with bridge shape file. As the number of specific bridge locations and bridge segments of Miami Beach and Miami-Dade County are very close, hence the results of Miami Beach network are only considered for scaling effect discussion.

5.4. FLORIDA ROAD-BRIDGE NETWORK ANALYSES

From Florida road shape file, 18,462 roadway segments and 15,417 roadway segment intersection were found. After performing the Closeness Centrality analysis and mapping with bridges, 2,444 specific bridge location were found with centrality value. The most 20 central bridges' specific location of Florida according to node property are listed in Table 5. Then, the network analysis was performed for the link property by calculating Edge Betweenness Centrality. 3,252 roadway segments with bridges were found with centrality values after mapping with bridge shape file. The most 50 central bridge segments of Florida according to link property are listed in Table 6.

Table 5 Closeness Centrality Values of Florida Road-bridge Network

Bridge Rank	Node Long.	Node Lat.	Closeness Centrality	Roads	Bridges
1	-80.8036	27.6697	0.006676	State Road 60	STATE ROAD 60
2	-80.6435	27.6402	0.006616	State Road 60	STATE ROAD 60
3	-81.8435	27.9045	0.006615	Van Fleet Dr	VAN FLEET DR
4	-81.9575	28.0550	0.006588	N Florida Ave	N FLORIDA AVE
5	-81.9407	28.0441	0.006564	E Main St	E MAIN ST
6	-81.9409	28.0441	0.006561	E Main St	E MAIN ST
7	-80.6435	27.6405	0.006557	State Road 60	STATE ROAD 60
8	-81.9573	28.0555	0.006535	N Florida Ave	N FLORIDA AVE
9	-81.9469	28.0441	0.006532	E Main St	E MAIN ST
10	-81.9573	28.0548	0.006532	N Florida Ave	N FLORIDA AVE
11	-81.9575	28.0548	0.006532	N Florida Ave	N FLORIDA AVE
12	-81.9703	28.0549	0.006532	Kathleen Rd	KATHLEEN RD
13	-82.1703	28.5078	0.006517	Treiman Blvd	TREIMAN BLVD
14	-80.8034	27.6699	0.006497	State Road 60	STATE ROAD 60
15	-82.1953	28.5079	0.006487	Cortez Blvd	CORTEZ BLVD
16	-81.9574	28.0497	0.006473	George Jenkins Blvd	GEORGE JENKINS BLVD
17	-81.9705	28.0549	0.006473	Kathleen Rd	KATHLEEN RD
18	-82.204	28.3649	0.006469	Meridian Ave	MERIDIAN AVE
19	-82.1931	28.5079	0.006469	Cortez Blvd	CORTEZ BLVD
20	-81.9412	28.0550	0.006462	E Memorial Blvd	E MEMORIAL BLVD

Table 6 Edge Betweenness Centrality Values of Florida Road-bridge Network

Unweighted Rank	Weighted Rank	Start Long.	Start Lat.	End Long.	End Lat.	Weight (AADT)	Unweighted Edge Betweenness Centrality	Weighted Edge Betweenness Centrality	Roads/Bridges
1	1	-81.3583	27.2972	-81.3626	27.3174	17800	0.0612181	0.0855220	US-27 S
2	**294**	**-81.9412**	**28.0550**	**-81.9569**	**28.0550**	**35888**	**0.0592377**	**0.0099064**	**E Mmrl Blvd**
3	93	-81.8435	27.9045	-81.8433	27.9040	38000	0.0553112	0.0311746	Van Fleet Dr
4	**2**	**-81.9573**	**28.0556**	**-81.9573**	**28.0624**	**35000**	**0.0550132**	**0.0838625**	**N Florida Ave**
5	**452**	**-81.9569**	**28.0550**	**-81.9573**	**28.0556**	**24500**	**0.0537450**	**0.0050895**	**Mmrl Blvd**
6	**1078**	**-81.9407**	**28.0442**	**-81.9408**	**28.0546**	**12800**	**0.0521861**	**0.0016348**	**E Main St**
7	67	-81.9573	28.0549	-81.9412	28.0549	34253	0.0498294	0.0787735	N Florida Ave
8	80	-81.9575	28.0550	-81.9573	28.0549	24500	0.0478417	0.0446420	N Florida Ave
9	94	-81.9409	28.0442	-81.9408	28.0385	12800	0.0462698	0.0310316	E Main St
10	**6**	**-81.9574**	**28.0624**	**-81.9575**	**28.0550**	**35000**	**0.0451576**	**0.0737822**	**N Florida Ave**
11	**427**	**-81.8014**	**27.7520**	**-81.8215**	**27.8202**	**16000**	**0.0393595**	**0.0059624**	**US-17 N**
12	**428**	**-81.8215**	**27.8202**	**-81.8216**	**27.8209**	**16000**	**0.0393594**	**0.0059619**	**US-17 N**
13	36	-84.3875	30.0843	-84.3806	30.1042	8700	0.0367902	0.0456869	Coastal Hwy
14	55	-81.5145	27.5955	-81.4952	27.5148	30000	0.0353305	0.0425612	W Main St
15	**12**	**-84.3804**	**30.1047**	**-84.3875**	**30.0843**	**8700**	**0.0349743**	**0.0601352**	**Coastal Hwy**
16	20	-80.4400	26.1369	-80.4423	26.1473	10810	0.0342811	0.0515896	US-27 N
17	56	-81.3585	27.2972	-81.3585	27.2971	17800	0.0341818	0.0855220	US-27 S
18	10	-81.4174	26.4185	-81.4093	26.4180	6952	0.0335133	0.0623579	E Main St
19	**11**	**-81.4093**	**26.4180**	**-81.4089**	**26.4179**	**6700**	**0.0335132**	**0.0623575**	**E Main St**
20	57	-82.0455	28.8471	-82.0455	28.8387	14000	0.0329285	0.0418747	S Main St
21	58	-82.0455	28.8387	-82.0455	28.8361	12197	0.0329284	0.0418743	S Main St
22	40	-82.6120	28.9231	-82.6267	28.9526	16900	0.0327100	0.0446017	N Suncoast Blvd
23	41	-82.6267	28.9526	-82.6352	28.9696	16900	0.0327099	0.0446013	N Suncoast Blvd
24	42	-82.6352	28.9696	-82.6354	28.9700	16900	0.0327098	0.0446008	N Suncoast Blvd

25	43	-82.6354	28.9700	-82.6691	29.0304	8616	0.0327096	0.0446004	N Suncoast Blvd
26	**21**	**-82.1953**	**28.5078**	**-82.1704**	**28.5078**	**16500**	**0.0327087**	**0.0563814**	**Cortez Blvd**
27	**22**	**-82.2381**	**28.5231**	**-82.2358**	**28.5231**	**16820**	**0.0326741**	**0.0511735**	**Cortez Blvd**
28	**23**	**-82.2358**	**28.5231**	**-82.1975**	**28.5078**	**16500**	**0.0326277**	**0.0511253**	**Cortez Blvd**
29	**3225**	**-82.1975**	**28.5078**	**-82.1953**	**28.5078**	**16500**	**0.0326275**	**0.0563814**	**Cortez Blvd**
30	24	-82.3671	28.5428	-82.3031	28.5231	19100	0.0324811	0.0508994	Cortez Blvd
31	45	-82.8232	29.4170	-82.8596	29.4748	3400	0.0320685	0.0440034	S Main St
32	46	-82.8596	29.4748	-82.8600	29.4876	9153	0.0320684	0.0440030	S Main St
33	59	-82.0430	28.8583	-82.0455	28.8476	18144	0.0318837	0.0397539	S Main St
34	60	-82.0455	28.8476	-82.0455	28.8471	14000	0.0318836	0.0397535	S Main St
35	69	-80.5827	27.0963	-80.6773	27.1590	7100	0.0314177	0.0501940	SW Wrfld Blvd
36	70	-80.4824	27.0305	-80.5827	27.0963	10847	0.0313885	0.0501645	SW Wrfld Blvd
37	71	-80.4468	27.0065	-80.4495	27.0085	10900	0.0313709	0.0500852	SW Wrfld Blvd
38	72	-80.4495	27.0085	-80.4824	27.0305	10842	0.0313708	0.0346999	SW Wrfld Blvd
39	**503**	**-82.4037**	**28.5402**	**-82.3691**	**28.5422**	**22132**	**0.0305668**	**0.0043342**	**Cortez Blvd**
40	**504**	**-82.3691**	**28.5422**	**-82.3671**	**28.5428**	**19356**	**0.0305667**	**0.0043338**	**Cortez Blvd**
41	**3247**	**-81.5145**	**27.5956**	**-81.5145**	**27.5955**	**9500**	**0.0302646**	**0.0321860**	**W Main St**
42	**14**	**-82.1953**	**28.5080**	**-82.2359**	**28.5232**	**16500**	**0.0301505**	**0.0577123**	**Cortez Blvd**
43	**3235**	**-82.2359**	**28.5232**	**-82.2382**	**28.5232**	**16900**	**0.0301504**	**0.0577119**	**Cortez Blvd**
44	**15**	**-82.2382**	**28.5232**	**-82.3031**	**28.5233**	**16900**	**0.0301502**	**0.0577119**	**Cortez Blvd**
45	73	-84.2156	30.1906	-84.1836	30.1998	3497	0.0300947	0.0337856	Coastal Hwy
46	74	-84.2465	30.1737	-84.2156	30.1906	3497	0.0300550	0.0337449	Coastal Hwy
47	75	-84.3138	30.1409	-84.2465	30.1737	3500	0.0300154	0.0337042	Coastal Hwy
48	47	-82.4207	28.5525	-82.4208	28.5777	13900	0.0300098	0.0437691	W Jefferson St
49	76	-84.3806	30.1042	-84.3801	30.1050	10011	0.0299837	0.0336729	Coastal Hwy
50	77	-84.3801	30.1050	-84.3138	30.1409	4700	0.0299835	0.0336725	Coastal Hwy

***Unweighted road-bridge network is considered as the base network for comparison**

Weighted Analysis

As weighted analysis is not applicable for Closeness Centrality (node property) network parameter, hence Weighted Edge Betweenness Centrality values (link property) are calculated for Florida road-bridge network. Similar to Miami-Dade County network, noteworthy changes in bridge ranking due to traffic is also observed and reported in Table 6, where the increase in bridge ranking due to traffic is marked in green and the decrease in red. For example, bridges ranking 10, 19, 42, and 44 in unweighted network got improved to 6, 11, 14, and 15 after considering traffic as weight. Besides, some other bridges ranked as 2, 5, 6, 29, 41, and 43 experienced a huge decrease in ranking due to traffic in weighted network analysis. These results and changes in bridge ranking clearly shows the impact of traffic volume on the road-bridge network along with the network connectivity.

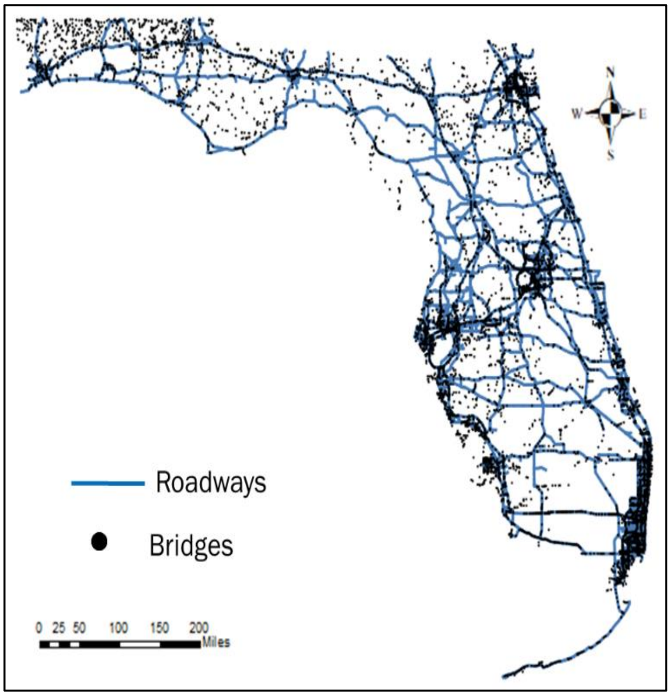


Figure 13 Florida Road-bridge Network

5.5. SCALING EFFECTS

As Miami Beach and Miami-Dade County are a subset of Florida network, hence all the bridge points and bridge segments of Miami Beach and Miami-Dade County are found in the Florida network analysis, but with different centrality values. This happens because of the scaling effect of the networks. The same bridge shows different centrality value for different scale of the network. The smaller the network size, the higher the centrality values of bridges. In Table 7, network scaling effect is shown for the node property (Closeness Centrality) along with the respective bridge rankings of these networks, which clearly depicts higher centrality values for Miami Beach and Miami-Dade County network than the Florida network for the same bridge location.

Table 7 Scaling Effects Based on Node Property (Unweighted Closeness Centrality) of Network

Longitude	Latitude	Bridge Rank (Florida)	Bridge Rank (Miami-Dade)	Bridge Rank (Miami Beach)	Closeness Centrality (Florida)	Closeness Centrality (Miami-Dade)	Closeness Centrality (Miami Beach)	Roads/Bridges
-80.1220	25.9299	1199	37	1	0.004509	0.009720	0.020644	Collins Ave
-80.1204	25.9538	1252	45	2	0.004460	0.009349	0.019895	Collins Ave
-80.1469	25.9552	1279	56	3	0.004435	0.009043	0.019278	Biscayne Blvd
-80.1202	25.9556	1284	49	4	0.004432	0.009227	0.019172	S Ocean Dr
-80.1207	25.9501	1262	42	5	0.004453	0.009429	0.019137	Collins Ave
-80.1540	25.9260	1144	54	6	0.004563	0.009087	0.019049	Biscayne Blvd
-80.1539	25.9262	1288	51	7	0.004428	0.009170	0.018985	Biscayne Blvd
-80.1469	25.9601	1306	55	8	0.004414	0.009056	0.018747	Biscayne Blvd
-80.1537	25.9260	1172	58	9	0.004534	0.008971	0.018609	Biscayne Blvd
-80.1469	25.9550	1316	61	10	0.004408	0.008915	0.018579	Biscayne Blvd
-80.1193	25.9860	1319	53	11	0.004405	0.009108	0.018501	S Ocean Dr
-80.1423	25.9856	1317	64	12	0.004407	0.008830	0.018413	Federal Hwy
-80.1564	25.9168	1173	59	13	0.004534	0.008958	0.018380	Biscayne Blvd
-80.1847	25.8501	1404	36	14	0.004312	0.009857	0.018343	Biscayne Blvd
-80.1841	25.8334	1427	34	15	0.004281	0.010089	0.018297	Biscayne Blvd
-80.1841	25.8333	1435	32	16	0.004266	0.010192	0.018170	Biscayne Blvd
-80.1535	25.9266	1207	63	17	0.004505	0.008844	0.017965	Biscayne Blvd
-80.1468	25.9497	1348	65	18	0.004380	0.008790	0.017937	Biscayne Blvd
-80.1508	25.9347	1220	67	19	0.004492	0.008729	0.017911	Biscayne Blvd
-80.1849	25.8562	1424	39	20	0.004286	0.009706	0.017737	Biscayne Blvd

***Miami Beach road-bridge network is considered as the base network for comparison**

Similarly, for the link property (Edge Betweenness Centrality) of the network, scaling effect is also replicated in Table 8 where the centrality values of bridge segments for Florida network is smaller than the Miami Beach and Miami-Dade County network. In both cases, Miami Beach network is considered as the base network for the comparison of centrality values and bridge rankings among three different scales.

Table 8 Scaling Effects Based on Link Property (Unweighted Edge Betweenness Centrality) of Network

Start Long.	Start Lat.	End Long.	End Lat.	Bridge Rank (Florida)	Bridge Rank (Miami-Dade)	Bridge Rank (Miami Beach)	Edge Betweenness Centrality (Florida)	Edge Betweenness Centrality (Miami-Dade)	Edge Betweenness Centrality (Miami Beach)	Roads/Bridges
-80.1220	25.9299	-80.1219	25.9304	258	10	1	0.01022	0.07515	0.08365	Collins Ave
-80.1227	25.8871	-80.1220	25.9299	355	20	2	0.00747	0.07327	0.07132	Collins Ave
-80.1840	25.8327	-80.1841	25.8333	494	19	3	0.00412	0.07330	0.06068	Biscayne Blvd
-80.1841	25.8334	-80.1846	25.8478	491	22	4	0.00418	0.07242	0.06039	Biscayne Blvd
-80.1841	25.8333	-80.1841	25.8334	493	21	5	0.00414	0.07261	0.06026	Biscayne Blvd
-80.1893	25.8124	-80.1891	25.8134	502	18	6	0.00400	0.07403	0.06015	Biscayne Blvd
-80.1891	25.8134	-80.1869	25.8255	503	17	7	0.00400	0.07404	0.06009	Biscayne Blvd
-80.1893	25.7820	-80.1893	25.7839	497	7	8	0.00406	0.07757	0.05974	Biscayne Blvd
-80.1893	25.7839	-80.1891	25.7853	498	6	9	0.00406	0.07757	0.05968	Biscayne Blvd
-80.1891	25.7853	-80.1890	25.7861	499	5	10	0.00406	0.07758	0.05962	Biscayne Blvd
-80.1890	25.7861	-80.1890	25.7861	500	4	11	0.00406	0.07758	0.05956	Biscayne Blvd
-80.1890	25.7861	-80.1891	25.7870	501	3	12	0.00406	0.07759	0.05950	Biscayne Blvd
-80.1894	25.8116	-80.1893	25.8124	520	16	13	0.00390	0.07408	0.05908	Biscayne Blvd
-80.1894	25.8114	-80.1894	25.8116	523	15	14	0.00387	0.07426	0.05891	Biscayne Blvd
-80.1894	25.8107	-80.1894	25.8114	531	14	15	0.00386	0.07444	0.05874	Biscayne Blvd
-80.1894	25.8043	-80.1894	25.8107	533	13	16	0.00384	0.07462	0.05856	Biscayne Blvd
-80.1890	25.7962	-80.1894	25.8043	536	12	17	0.00383	0.07481	0.05838	Biscayne Blvd
-80.1891	25.7896	-80.1890	25.7962	539	11	18	0.00382	0.07500	0.05820	Biscayne Blvd
-80.1891	25.7883	-80.1891	25.7896	540	9	19	0.00381	0.07518	0.05801	Biscayne Blvd
-80.1891	25.7870	-80.1891	25.7883	537	8	20	0.00382	0.07537	0.05781	Biscayne Blvd

***Miami Beach road-bridge network is considered as the base network for comparison**

Following Figure 14 shows all the different scales used for the network analyses to explain the scaling effect in this study.

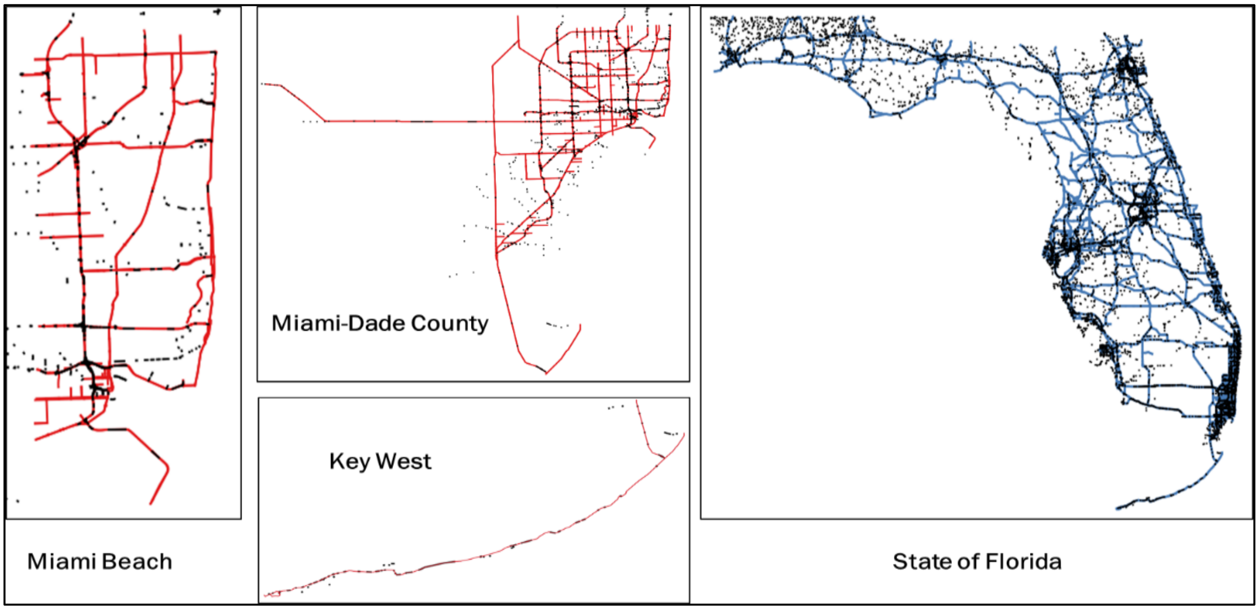


Figure 14 Key West, Miami Beach, Miami-Dade County and Florida Road-bridge Network

6. APPLICATION OF THE PROPOSED METHODOLOGY

6.1. FINDINGS OF THE GUIDE

The main objective of this project is to analyze the road-bridge network from a topographical or global point of view to identify the vulnerable bridges of the road network through network science principles to improve the network resiliency. Hence, the Florida road-bridge network is considered here and analyzed on four different scales. All the network analysis results listed in the previous section are representing the most influential, vulnerable, and central bridges orderly for both weighted and unweighted network. To quantify this phenomena, node level property and link lever property of the network are measured by Closeness Centrality and Edge Betweenness Centrality. Table 3 to Table 8 are representing the ranking of most important bridges of the respective unweighted/weighted networks from high to low. Besides, Table 4 and Table 6 are showing the effect of traffic along with the network connectivity on bridge ranking as well as the changes in priority due to traffic volume which is visualized in Figure 12.

To prioritize (systematic sequencing) the new bridge construction or maintenance work by ABC method, Closeness Centrality values should be considered for specific bridge location (node) analysis, such as road-bridge intersecting point or bridge segment joints. Besides, Edge Betweenness Centrality should be considered while bridge segments are the point of interest for unweighted network. To consider the effect of traffic along with network credentials on bridge segments, ranking of bridges from Table 4 and Table 6 should be taken in consideration.

Normally every two years, the bridges of the United States are inspected for regular maintenance purposes. Sometimes due to time and budget constraints, inspection of all the bridges may not be possible in a timely manner, hence the maintenance work delays. As a result, the bridges which have more impact or influence on the road network remain undermined. This impact means if these bridges are removed from the road network, most of the routes of the network will be affected which will result in increased travel time and vehicle delay, hence deceasing the resiliency of road network. By having the list of influential bridges, Accelerated Bridge Construction (ABC) can approach systematically while performing the maintenance of the existing bridges.

The proposed methodology of identifying central or influential bridges could also be useful for new bridge construction according to ABC decision making guideline. As bridges are a part of road networks, the most influential road segments could also be found by following the similar network analysis. After identifying the central roadway segments which could be connected by bridges, the construction of these new bridges can be prioritized over the other new bridges' construction. By doing so, the bridges which connect most central roadways could reduce the surrounding roadways system travel time, vehicle delay for defined origin destination and the time-cost value of the construction, finally improve the resiliency of the road network.

6.2. SCENARIO ANALYSIS

Scenario 1 (all bridges are functional)

To understand the practical implication and importance of the proposed bridge ranking methodology, a scenario analysis has been conducted with a sample road-bridge network. The network (Figure 15) consists of 9 nodes (origin and destination), 13 links (roadways) and 4 bridges. The direction of the traffic flow is shown with arrows (black and green) in the network. The corresponding values of bridges (e.g., B2= 0.104) are representing the edge betweenness centrality (EBC) values, which are defining the cruciality of the bridges and establishes the bridge ranking. From Figure 15, the most critical bridge of the network according to the EBC value is bridge B2, then B1 followed by B4 and B3. Hence, the bridge ranking is B2, B1, B4, B3 for this network.

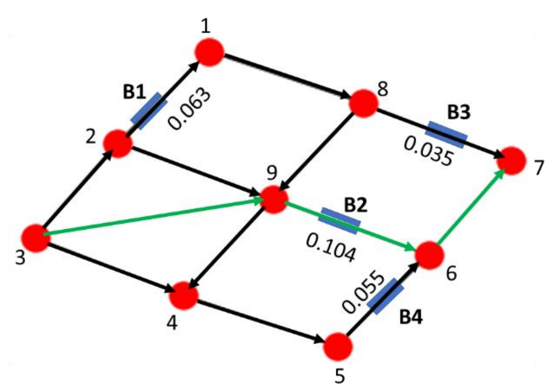


Figure 15 Sample Road-bridge Network for Scenario Analysis (Scenario 1)

To observe the effect of removal of central bridges on the road-bridge network, the origin-destination (OD) pair 3-7 is selected to find out the optimal travel time based on the Bureau of Public Roads (BPR) function [23]. The travel time is calculated by equation 10 according to BPR function as shown in following-

*Travel time = Time (free flow) * (1 + alpha * (volume/capacity) ^ beta)* *(10)*

To calculate the travel time for each link, free flow travel time is assumed 10s, capacity of each roadway is 3600 vehicle per hour (vph), alpha is 0.15 and beta is 4. Table 9 is showing the travel time based on BPR function for each link along with the assumed traffic volume.

Table 9 Travel Time Calculation based on BPR Function (Scenario 1)

from node	to node	Bridge	Free flow travel time (s)	Volume (vph)	Capacity (vph)	Alpha	Beta	Travel time (s)
2	1	B1	10	2439	3600	0.15	4	10.3160
2	9		10	2958	3600	0.15	4	10.6837
1	8		10	2034	3600	0.15	4	10.1528
3	2		10	2438	3600	0.15	4	10.3155
3	4		10	2952	3600	0.15	4	10.6781
3	9		10	2082	3600	0.15	4	10.1678
4	5		10	2132	3600	0.15	4	10.1845
9	4		10	2197	3600	0.15	4	10.2081
5	6	B4	10	2542	3600	0.15	4	10.3728
6	7		10	2044	3600	0.15	4	10.1558
8	7	B3	10	2579	3600	0.15	4	10.3950
8	9		10	2946	3600	0.15	4	10.6726
9	6	B2	10	2687	3600	0.15	4	10.4655

Besides, to identify the shortest path from origin (node 3) to destination (node 7), Djkstra's algorithm [24] is used where the minimum travel time from the origin to destination defines the shortest path. For scenario 1 (Figure 15), shortest path (according to Djkstra's) from 3 to 7 is 3-9-6-7 (denoted by green arrows) and the resultant travel time according to BPR function is 30.7892 s (summation of the individual travel time of links 3-9, 9-6 and 6-7).

Scenario 2 (less critical bridge is non-functional)

If a less critical bridge (B1) becomes non-functional as shown in Figure 16, the shortest path (according to Djkstra's) for 3-7 OD pair will not change (3-9-6-7) in this case.

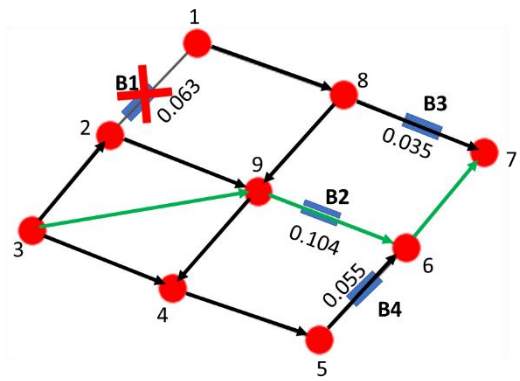


Figure 16 Sample Road-bridge Network for Scenario Analysis (Scenario 2)

But, as the assigned traffic (2439 vph) on link 2-1 will be diverted to other links (e.g., 2-9, 9-4, 4-5 etc.); the travel times for links will change according to BPR function (Table 10). For scenario 2 (Figure 16), shortest path (according to Djkstra's) from 3 to 7 is 3-9-6-7 and the resultant travel time according to BPR function is 31.3074 s. Hence due to the absence of a less critical bridge B1, the travel time increased only 1.683% in compared with scenario 1.

Table 10 Travel Time Calculation based on BPR Function (Scenario 2)

from node	to node	Bridge	Free flow travel time (s)	Volume	Capacity	alpha	beta	Travel time (s)
2	9		10	3364	3600	0.15	4	11.1436
1	8		10	2034	3600	0.15	4	10.1528
3	2		10	2438	3600	0.15	4	10.3155
3	4		10	2952	3600	0.15	4	10.6781
3	9		10	2082	3600	0.15	4	10.1678
4	5		10	2539	3600	0.15	4	10.3711
9	4		10	2603	3600	0.15	4	10.4099
5	6	B4	10	2949	3600	0.15	4	10.6754
6	7		10	2451	3600	0.15	4	10.3222
8	7	B3	10	2579	3600	0.15	4	10.3951
8	9		10	2946	3600	0.15	4	10.6726
9	6	B2	10	3093	3600	0.15	4	10.8173

Scenario 3 (most critical bridge is non-functional)

If the most critical bridge (B2) becomes non-functional as shown in Figure 17, the shortest path (according to Djkstra's) for 3-7 OD pair will change (3-2-1-8-7) in this case.

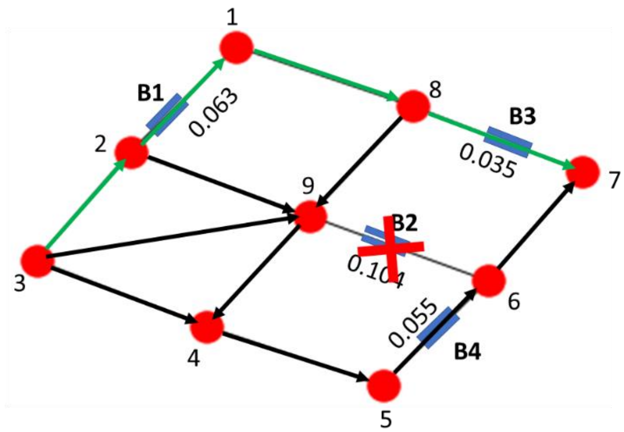


Figure 17 Sample Road-bridge Network for Scenario Analysis (Scenario 3)

Besides, as the assigned traffic (2687 vph) on link 9-6 will be diverted to other links (e.g., 9-4, 4-5 etc.); the travel times for links will also change according to BPR function (Table 11). For scenario 3 (Figure 17), shortest path (according to Djkstra's) from 3 to 7 is 3-2-1-8-7 (denoted by green arrows) and the resultant travel time according to BPR function is 41.1795 s (summation of the individual travel time of links 3-2, 2-1, 1-8 and 8-7). Hence due to the absence of the most critical bridge B2, the travel time increased significantly which is 33.75% in compared with scenario 1. Hence, we should prioritize bridge B2 over B1 as the removal of B2 results in significant higher travel time from 3 to 7.

Table 11 Travel Time Calculation based on BPR Function (Scenario 3)

from node	to node	Bridge	Free flow travel time (s)	Volume	Capacity	alpha	beta	Travel time (s)
2	1	B1	10	2439	3600	0.15	4	10.3161
2	9		10	2958	3600	0.15	4	10.6837
1	8		10	2034	3600	0.15	4	10.1528
3	2		10	2438	3600	0.15	4	10.3155
3	4		10	2952	3600	0.15	4	10.6782
3	9		10	2082	3600	0.15	4	10.1678
4	5		10	2804	3600	0.15	4	10.5521
9	4		10	2869	3600	0.15	4	10.6051
5	6	B4	10	3214	3600	0.15	4	10.9529
6	7		10	2716	3600	0.15	4	10.4859
8	7	B3	10	2579	3600	0.15	4	10.3950
8	9		10	2946	3600	0.15	4	10.6727

7. CONCLUSIONS AND RECOMMENDATIONS

Accelerated Bridge Construction (ABC) is an emerging alternative to traditional construction as ABC minimizes the life-cycle cost, construction time, several discrepancies related to construction methods and results in a better quality of work. This study proposed a framework for identifying network credentials of bridges (i.e., rank of relative importance) by combining traditional Geographic Information System (GIS) modeling with network science theories (centrality of bridges) to improve the road-bridge network resiliency. Resiliency of a system is defined as the ability to withstand external shocks (robustness) and recover from that perturbation to the full functionality (rapidity). For any external shocks, bridges may become inaccessible for neighboring traffic as well as undergo maintenance activities resulting in significant travel delays i.e., increased average travel time of vehicles. Systematic identification of the topological credentials of bridges as part of the road network may contribute to faster recovery of the system optimal travel time.

The outcome of the proposed approach is a list of bridges in the road network based on their centrality values (from most central to least central) that can be adopted at different scales i.e., network size. The study conducted extensive network experiments and demonstrated how such topological credentials can change at different scales as well as when weights are introduced to the topology such as traffic volumes to establish relative importance of bridges more in a global perspective rather than localized ones. This would allow practitioners and other stakeholders performing ABC activities to decide on which bridge should be inspected, maintained, or constructed first based on the position of the bridges in a network setting. Different agencies also engage in solving unprecedented problems observed on local roads or bridges, however, this study provides novel insights on how to go beyond local context and incorporate a broader perspective to avoid cascading effects in such networks. As such, prioritizing maintenance activities or new construction work can be done with a bigger picture into consideration.

The applications of this research can also be extended towards responding any emergency evacuation scenarios by ensuring more efficient route guidance to evacuees and avoid possible gridlocks due to ABC activities. For example, people in Miami Beach, USA tend to take Venetian and MacArthur Causeways as they evacuate inland. Such preferences can be diverted ahead of time if the vulnerability of these bridges is assessed ahead of time to ensure more credible system performance. Besides, the network metrics such as centrality changes based on the scale of the network as shown in Table 7 and Table 8. Hence, deciding an appropriate network scale should be the first step towards identifying the influential bridges in each road network. This study conducted network experiments at four different scales (i.e., Key West (US-1), Miami Beach, Miami-Dade County and Florida). For future studies, a larger road network (entire USA) could be considered which may capture larger scaling effect at the state or multi-state level. This study can also support traffic simulation-based studies to quantify the effects on travel time based on network credentials. Previous studies showed how to prioritize bridges based on mixed-integer programming, however, the network variables introduced in this study can add to such formulations to deduce more efficient solutions.

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