Network Analysis of the Multimodal Freight Transportation System in New York City

Project Number: 15 – 2.1b
Year: 2015

FINAL REPORT
June 2018

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ABSTRACT
The research is aimed at examining the multimodal freight transportation network in the New York metropolitan region to identify critical links, nodes and terminals that affect last-mile deliveries. Two types of analysis were conducted to gain a big picture of the region's freight transportation network. First, three categories of network measures were generated for the highway network that carries the majority of last-mile deliveries. They are the descriptive measures that demonstrate the basic characteristics of the highway network, the network structure measures that quantify the connectivity of nodes and links, and the accessibility indices that measure the ease to access freight demand, services and activities. Second, 71 multimodal freight terminals were selected and evaluated in terms of their accessibility to major multimodal freight demand generators such as warehousing establishments. As found, the most important highways nodes that are critical in terms of connectivity and accessibility are those in and around Manhattan, particularly the bridges and tunnels connecting Manhattan to neighboring areas. Major multimodal freight demand generators, such as warehousing establishments, have better accessibility to railroad and marine port terminals than air and truck terminals in general. The network measures and findings in the research can be used to understand the inventory of the freight network in the system and to conduct freight travel demand forecasting analysis.

INTRODUCTION
The efficiency and effectiveness of transportation networks plays a vital role in moving people and circulating goods. A well connected network improves freight mobility and helps economic development while poorly designed ones cause traffic delays, increased shipping costs and safety concerns. Therefore, studying connectivity, accessibility and performance of transportation networks is often considered a critical component of freight travel demand analysis.

The research is aimed at examining the multimodal freight transportation network in the New York metropolitan region to identify critical links, nodes and bottlenecks that affect last-mile deliveries. More specifically, the objectives of the research are to: understand and document the inventory of the multimodal freight transportation network in the region; measure the performance of the network from the supply side; and identify critical nodes, links and terminals that affect last-mile deliveries.

Two types of analysis were conducted to gain a big picture of the region's freight transportation network. First, three categories of numeric measures were developed for the highway network that carries the majority of last-mile deliveries. They are the descriptive measures that demonstrate the basic characteristics of the highway network, the network structure measures that quantify the connectivity of nodes and links, and the accessibility indices that measure the ease to access freight demand, services and activities. Second, 71 multimodal freight terminals were selected and evaluated in terms of their accessibility to major multimodal freight demand generators such as warehousing establishments.

LITERATURE REVIEW

Black (2003) in his book *Transportation: A Geographical Analysis* mentioned several categories of transportation network measures such as network structure, network accessibility, network cost and flows in network. These measures represent the majority of research efforts in transportation network analysis. Among them, network structure and network accessibility focus on the supply side, representing how locations and links in a network are arranged and connected. They can be measured through graph theory and network topology analysis. The other measures, such as network cost and flows in network, emphasize transportation cost and flows as the outcomes of demand and supply interactions. The measurement of them often requires extensive data input or a whole package of travel demand forecasting analysis in order to understand flow or cost generation patterns in the past or future. This research focuses on the supply side of freight transportation networks, and thus is intended to generate the network structure and accessibility related measures.

The foundation of network structure measurement is connectivity. It was initially introduced by Berge (1962) as *cyclomatic number*. Later on, Garrison and Marble (1965) proposed a connectivity measure called alpha index, which is a ratio of the existing number of circuits in a network graph to the maximum number of independent circuits to connect nodes in a system. They also proposed other two other indices, called gamma index and beta index. These indices have been widely used in network analysis from then on.

Besides connectivity, identifying dominant (or called essential, critical and so on) nodes in a graph also gains popularity. Different approaches have been proposed since Berge (1962) claimed it as a problem of leader. The methodology is as below in general. In order to find dominant nodes, a graph is first mathematically represented by a connection matrix in which the topological distance of a link is set as 1 if it is directly connected or 0 otherwise. Based on the connection matrix, the connectivity score of each node is then determined through an iterative procedure by using standard matrix powering. The original connection matrix was powered to its diameter and the actual graph distances for new connections from each intermediate matrix were successively incorporated into the final distance matrix. The resulting connection matrix is summed across rows to get the valued index for each node, denoting the summed shortest graph distances needed to connect that node to all other nodes in a network (see Black, 2003, pp. 80-83; or Wheeler and O'Kelly, 1999 for detailed explanations of the matrix powering and iterative procedures).

Network accessibility measures the advantage of a node relative to other nodes of a network. Specifically, it quantifies the extent to which the rest of a system has access to a particular node in a network. Hansen (1959) proposed a form of accessibility for land use planning, where the accessibility score of a node is proportional to its attractiveness to the rest of the system and an inverse of travel impedance raised to a certain power. Travel distance, time or cost are often used as impedance variables. The attractiveness of a node is usually a function of demand or opportunity indicators such as population, employment, or travel demand.

Travel distance is used as a very important input for transportation network measurement. Distances in transportation are usually measured in two forms: network distance, the actual distance measured in a network; or Euclidean distance, the airline distance between two nodes. Circuity is the ratio of actual network distance to Euclidean distance (Levinson and El-Geneidy, 2009). Kansky (1963) first proposed degree of circuity for a transportation network as the summation of deviations between network distances and Euclidean distances, normalized by the number of nodes. As to the mean circuity value of a network, Newell (1980) claimed that for a randomly selected set of nodes, the network distance in an urban area is about 1.2 times the Euclidean distance. Levinson (2009) developed a model to explore the effect of network structure on network circuity by using twenty metropolitan areas in the U.S. as case studies. Lee and Vuchic (2005) pointed out that there are actually two types of circuities in network: physical and time. The difference between them is that the physical circuity does not include transfer time and penalty. Time circuity, on the other hand, considers extra time caused by indirectness of routes and transfer, in addition to travel time obtained from shortest paths.

In graph theory, node degree indicates the number of edges (or directed links) incident to a node. The larger the average node degree is, the better connected a network is. And another measure, called algebraic connectivity, has been used in quantifying a graph's connectivity and robustness. It is the second smallest eigenvalue of the *Laplacian* matrix of a graph, and a larger value usually means better connectivity, although the actual value and meaning depend on the size of a network. Bigdeli *et al.* (2009) compared different network topologies in terms of robustness and connectivity by using measures such as algebraic connectivity, network criticality, average node degree, and average node betweenness.

This research analyzes the critical nodes, links, terminals, and overall connectivity of the multimodal freight transportation network in the New York metropolitan region, by incorporating the most important network measures reviewed above.

STUDY AREA

The New York metropolitan region is officially called New York-Newark-Bridgeport, New York-New Jersey-Pennsylvania Metropolitan Statistical Area (MSA) by the U.S. Office of Management and Budget. This area consists of 25 counties with 12 counties in New York State, 12 counties in Northern and Central New Jersey, and one county in northeastern Pennsylvania. This region covers most of the area except three counties: Pike County in Pennsylvania, and Orange County and Dutchess County in New York State. This area has the largest population among the 381 MSAs in the U.S. It is also the undeniable "freight capital" of the eastern U.S. and one of the busiest "freight hubs" in the world. The freight transportation in the region supports millions of jobs, and hundreds million tons of freight are moved daily within and through this region. Among all the sources of freight transportation through this region, trucks carry around 80 percent of all freight commodities. The ground transportation, including both passenger and freight, accounts for 40 percent of the nitrogen oxides emissions from all transportation modes (NYMTC, 2006). A comprehensive summary of the significance and characteristics of the urban freight distribution system in the region can be found in Rodrigue (2005).

Initially, the whole region was selected as the case study. However, during the data collection, we found that very limited demand data were available for counties outside of New York City, such as most of the counties in New Jersey and Pennsylvania. Given the data availability issue, eventually we selected a smaller study area that is concentrated with the majority of last mile activities.   This area is consisted of 7 counties, including Bronx, Kings, New York, Queens, Richmond County in New York state, and Bergen and Hudson County in New Jersey state as shown in *Figure 1*.

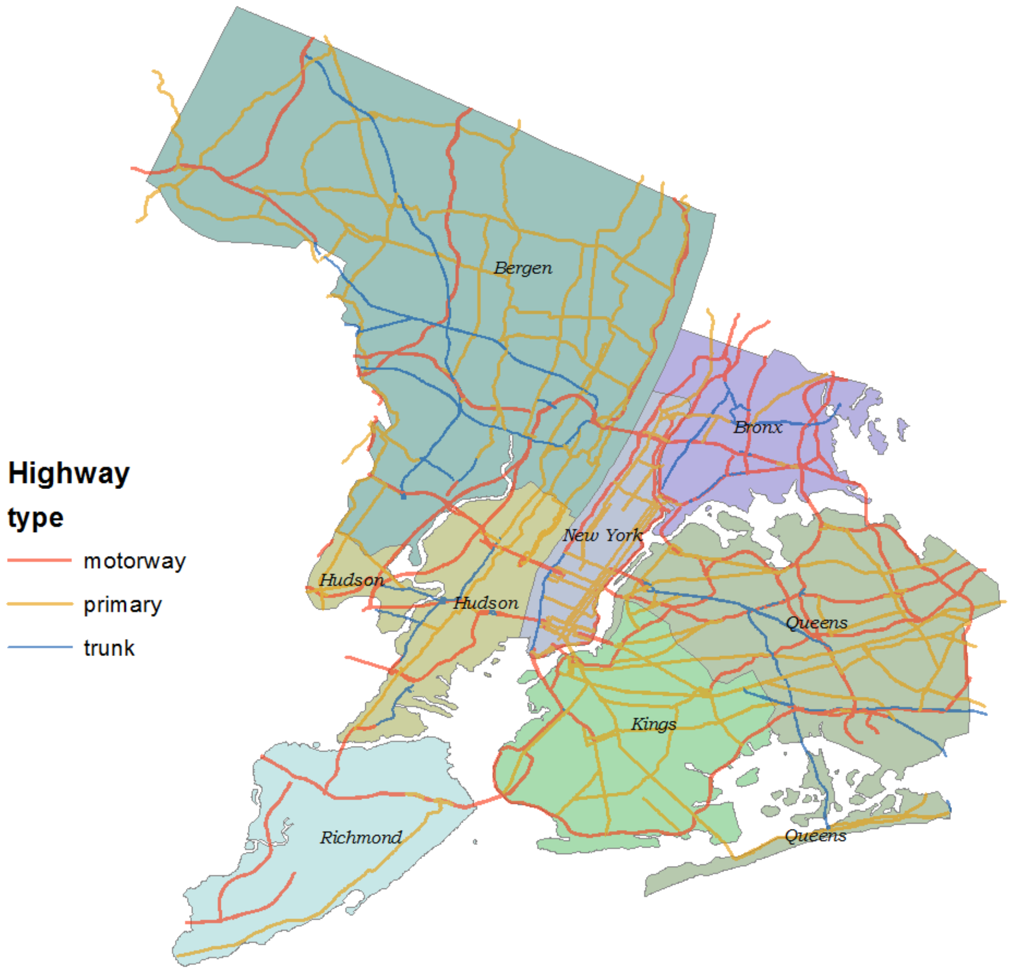

Figure 1 Study area and the highway network

DATA DESCRIPTION

Three types of data are gained and used for network analysis, including the transportation network data representing the *supply* side, the traffic analysis zone (TAZ) based travel demand data and the warehousing establishment data representing the *demand* side, and the freight terminal data representing major multimodal freight *terminals*.

Transportation Network Data (Supply)

The transportation networks (see *Figure 1*) were obtained from the U.S. Census (2010), including highways in the region in year 2010. More specifically, the highway network selected includes interstate, state and regional highways. Some examples are Interstate Highways I-278, I-478, I-678, I-495, I-695 on the New York side, and I-95, I-78 on both New Jersey and New York sides. These highways represent the main inventory of the multimodal freight network and carry the majority of the freight demand in the region.

The highway network data is extracted from Open Street Map. Based on the definitions provided by them, *motorway* means fast, divided restricted access highway, normally with two or more lanes plus emergency hard shoulders. Following that, *trunk* means interstate highways and some state highways. The third category, *primary*, means major highways linking large towns or arterial roads. The three types of highways are marked by different colors as shown in *Figure 1*.

Most of the highway links have two opposite directional lines with different segments connected by different lines. Many very short and disconnected highway segments were found in the raw data, which made it almost impossible to conduct network analysis. A great amount of time and effort was spent in correcting errors (e.g., wrong labels and wrong directions) and merging disconnected highway segments. After the data processing, more than 5,400 links on the original map were merged to less than 1,000 links. In addition, there are 508 actual intersecting highway nodes that connect at least two different highway segments. As another input, we assume the speed limit of *motorway* links is 65 miles per hour, given that most of them are interstate highways. The speed limits of *trunk* and *primary* links are assumed 55 miles per hour, and 45 miles per hour, respectively, according to the average speed limits used in the region.

Freight Demand Data (Demand)

Two types of freight demand related data were collected to generate network accessibility measures. The first one is the traffic analysis zone (TAZ) generation data that contains the number of daily trips produced from each TAZ in the study area. The data was obtained from the New York Best Practice Model maintained by NYMTC. The daily trip intensity, calculated as the number of daily trip production divided by the area size of a TAZ, is presented in *Figure 2*. As can be seen, New York County and Kings County generated the largest amount of daily trips in terms of intensity.

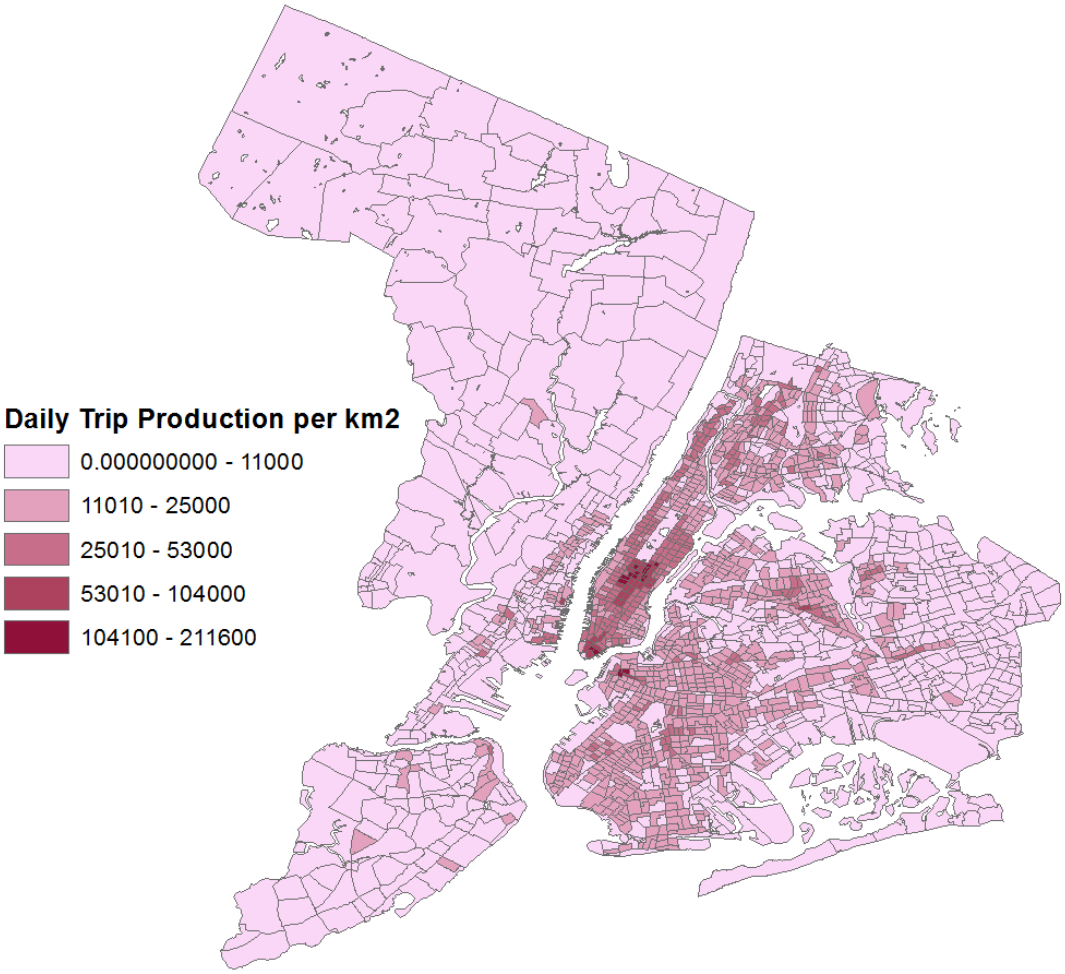

Figure 2 Daily trip production intensity by traffic analysis zone (TAZ)

The second data set is the warehousing establishment data that is mainly used to evaluate the accessibility of major intermodal freight terminals in the region. The warehousing establishments furnish local or long-distance shipping or transfer services, or are engaged in the storage of farm products, furniture and other household goods, or commercial goods of any nature. Their business locations and operation strategies significantly affect the generation, distribution, mode choices and traffic assignment of freight demand. Therefore, they are considered one of the most important demand generators for intermodal freight terminals in the region.

The establishment data were collected by the ReferenceUSA, a company of Infogroup, Inc. (ReferenceUSA, 2014). It records warehousing establishments observed in the U.S. in the year 2010. In addition to addresses and geographical coordinates, the data set provides other information for each establishment, such as establishment name, phone number, key executive name, Standard Industrial Classification (SIC) code, employment size, and sales volume. The coordinates were used to translate the tabular data into the GIS shapefiles for the purpose of spatial analysis.

There are 2,017 warehousing establishments in the data. The statistical breakdowns of the warehousing establishments reveal several interesting findings (see **Table 1**). First, in terms of business type, the vast majority of the warehousing establishments (93.6%) are General Warehousing and Storage. They provide service such as storage of household and commercial products, warehousing of merchandise, public and private goods, and container storage among others. The shares of other subgroups are 4.2% for Special Warehousing and Storage, 2.0% for Refrigerated Warehousing and Storage, and 0.3% for Farm Product Warehousing and Storage. Second, in terms of employment size, the warehousing industry in the study area is dominated by small establishments. Almost 90% of warehouses are small businesses with less than five employees (67.6%) or with greater than five and less than 20 employees (21.7%). In contrast, the medium businesses with greater than 20 and less than 100 employees account for 8.4%. The large ones with greater than 100 employees only account for 2.0%.

Table 1 Breakdown of Warehouses by Employment Size and Sales Volume

Employment Size	**%**	**Annual Sales Volume (thousands of dollars)**	**%**
1-4	67.58	1-499	50.37
5-9	14.28	500-999	24.29
10-19	7.39	1,000-2,499	12.69
20-49	5.85	2,500-4,999	5.06
50-99	2.53	5,000-9,999	3.07
100-249	1.44	10,000-19,999	1.34
250-499	0.55	20,000-49,999	1.19
500-999	0.05	50,000-99,999	0.45
N/A	0.35	100,000-499,999	0.20
		N/A	1.34

Consistent with employment sizes, the majority of establishments have relatively low annual sales volumes that are less than 2.5 million dollars. As shown in **Table 1**, 50.4% of warehouses have sales volume less than $500,000, and 24.3% of warehouses generated annual sales between $500,000 and $1,000,000. The large warehouses that have sales volume greater than 10 million dollars only account for 3.2%.

Intermodal Freight Terminal Data (Terminals)

Intermodal freight terminals are very important freight facilities in the region. After large patches of cargoes arrive at these terminals, they are dispatched and delivered to various destinations in or outside of the region through transportation networks. They are also the major locations of shipment consolidation. In these processes, mode shifts often occur and thus generate intermodal freight activities. A good intermodal freight terminal or hub should be well connected to transportation networks and also be able to handle possible mode shifts efficiently.

In order to examine the importance of intermodal freight terminals, a set of 71 main intermodal terminals in the entire New York metropolitan area is extracted from the National Transportation Atlas Database (NTAD), which is a nationwide geographical database of transportation facilities, transportation networks and associated infrastructure provided by the Bureau of Transportation Statistics. There are 20 air facilities, 2 sea ports, 39 rail facilities, and

10 trucking terminals, representing various mode shift combinations such as air – truck, rail – truck, and truck – port – rail and so on.

NETWORK INDICES

The following table consists of three categories of measures that were computed in the network analysis. The first category contains descriptive measures that show the basic characteristics of a network, such as total highway length, number of links, and highway density. The second category includes network structure measures such as Alpha, Beta and Gamma indices, connectivity measures, and degree of circuity. The third category focuses on network accessibility that represents the accessibility of a highway node from other nodes. Based on the numerical values of accessibility index, the nodes are ranked according to a descending order with the nodes with the highest accessibility ranked as the most accessible while the ones with the lowest score as the least.

Table 2 List of highway network measures

Name	Definition	Unit & value range	Reference
1. Network Descriptive Measures			
Number of links	Total number of links in the highway network	/	Graph Theory
Number of nodes	Total number of nodes in the highway network	/	Graph Theory
Number of circuits	Total number of circuits in the highway network	/	Graph Theory
Total length	The total length of the highway links	Kilometers (km)	Graph Theory
Average link length	Total length divided by the number of links	km	Graph Theory
Roadway density	Total length divided by the total area size of the study area	km/km^2	Graph Theory
2. Network Structure Measures			

Alpha index	The total number of existing circuits divided by the maximum number of independent circuits needed to connect the nodes in the network.	Range between 0 (minimum connectivity) and 1 (maximum connectivity)	Berge, 1962
Beta index	The total number of existing edges divided by the total number of nodes.		Berge, 1962
Gamma index	The total number of existing edges divided by the maximum number of edges needed to connect the nodes in a system.	Range between 0 (minimum connectivity) and 1 (maximum connectivity)	Berge, 1962
Algebraic connectivity	The second smallest eigenvalue of the *Laplacian* matrix of a graph. It is greater than 0 if and only if a graph is connected, and its magnitude reflects how well a network is connected.	The value range of algebraic connectivity depends on number of node and the average node degree.	Fiedler, 1973
Total connectivity for a node (distance based)	Total connectivity was determined using standard matrix powering. An iterative procedure was developed to calculate the valued accessibility in which the original connection matrix was powered to its diameter and the actual route distances for new connections from each intermediate matrix were successively incorporated into the final distance matrix.	The larger the total connectivity value is, the easier it is to access a node.	Berge, 1962
Node degree	The number of edges incident to a node.	The larger the node degree is, the better connected a node is.	Graph Theory
Node betweenness centrality	The number of shortest paths from any nodes to all others that pass through a target node. It indicates the centrality of a node in the network.	A node with a higher betweenness centrality value tends to have a more significant influence on the network efficiency.	Graph Theory

Average shortest path length	The length of a shortest path between any node pairs in a network on average		Graph Theory
Degree of circuity	The extent to which actual network distances of existing edges or paths differ from airline distances (or called Euclidean distance) in a network.	The better connected a network is, the lower its degree of circuity would be.	Kansky, 1963
3. Network Accessibility Measures			
Distance based accessibility index of a node	Accessibility of a node from all other nodes by using network distances as impedance.	The larger the value is, the more accessible a node is.	Bigdeli et al., 2009
Betweenness centrality	The number of shortest paths from any nodes to all others that pass through a target node divided by the total number of shortest paths in the network.	The larger the value is, the more “central” or important a node is.	Bigdeli et al., 2009

NETWORK MEASURES

Three types of network measures were calculated to quantify the highway network inventory from different aspects. They are network descriptive measures that show the basic characteristics of the highway network, network structure measures that indicate connectivity, and accessibility related measures that represent the ease of a highway node to be accessed by the system.

Network Descriptive Measures

There are 508 highway intersecting nodes connected by 813 roadway links in the network as shown in *Figure 1*. The size of the study area is 1,577 km^2 with a diameter of 40 km. The road density, calculated as the total length of highway links divided by the area size of the study region, is 1.58 km per km^2. The length of a highway link is 3.06 km on average. Highway density values are also computed for each Traffic Analysis Zone (TAZ) as shown in *Figure 3*. Clearly, New York County and Bronx County, particularly in the lower Manhattan area, have the highest roadway density values.

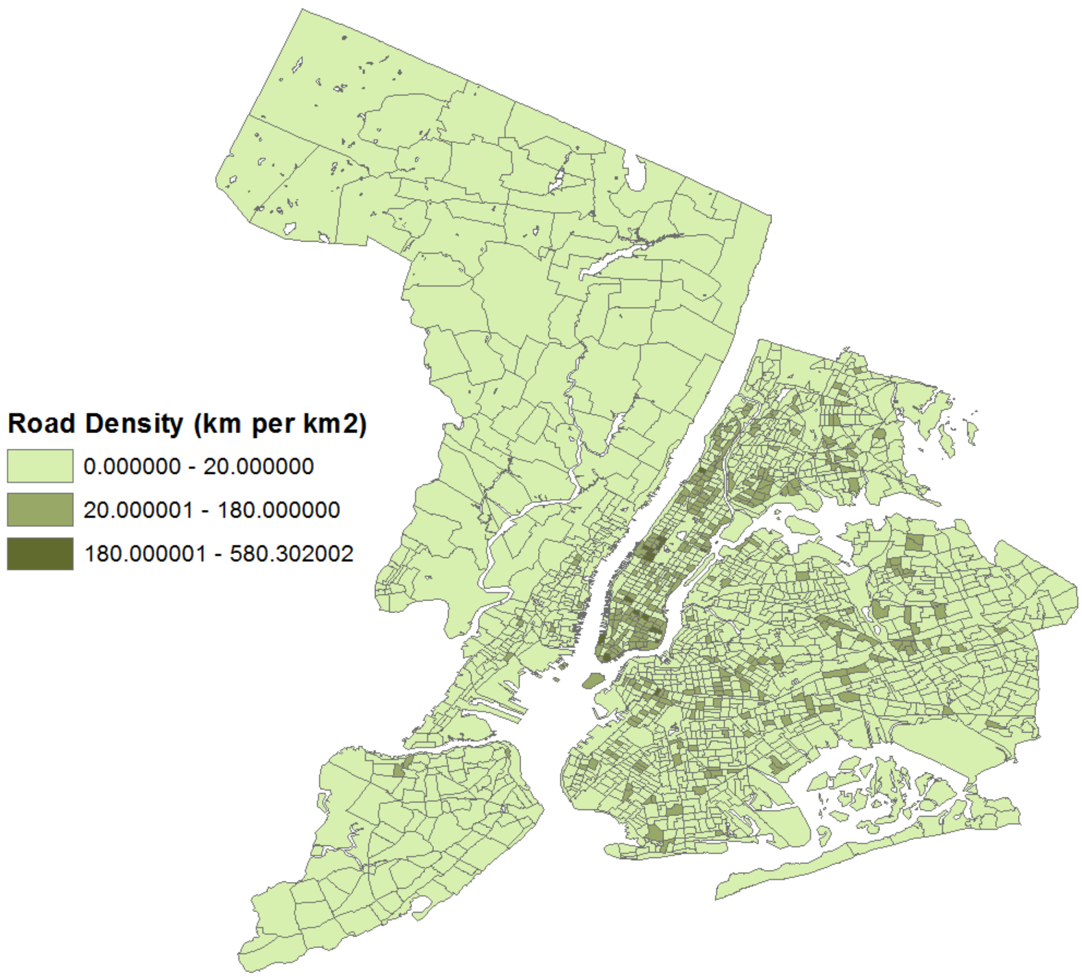

Figure 3 Highway density for each traffic analysis zone (TAZ)

Network Structure Measures

Connectivity Related Measures

For the network, the alpha index is calculated as 0.002, indicating that the existing circuits of the highway network account for 0.2% of the maximum of possible independent circuits needed to connect the nodes. The low value, or more specifically the near 0 value, indicates the relatively poor connectivity of the network. The Gamma index value is consistently low as 0.006, indicating that the number of existing edges in the network is much less than what is needed to form a fully connected network. The beta index is 1.6, meaning that less than 2 edges are directly connected to each highway node on average. The low values of the three indices make sense since we only consider highways for the analysis while neglecting other roadway components such as arterials and local streets. They imply that the connectivity to the high-speed low-interrupted highway network is relatively low. In other words, the existing highway network only provides limited connectivity to freight demand. In order to reach final destinations, the freight demand still needs to rely on arterials and local streets that often experience low travel speeds and long traffic delays in the urban setting.

The Algebraic connectivity of a graph is the second smallest eigenvalue of the *Laplacian* matrix. Here, a *Laplacian* matrix of a network is the difference between the degree matrix and the adjacency matrix. The value of Algebraic connectivity depends on the size of a network. In our case, it was computed as 0.0058. The positive value indicates that the highway network is connected, and the relatively low magnitude (0.0058) indicates that it is not well connected.

For each highway node, total connectivity is calculated by using topological distances between nodes. It was determined using standard matrix powering (Berge, 1962). An iterative procedure was developed to calculate the valued accessibility in which the original connection matrix was powered to its diameter and the actual route distances for new connections from each intermediate matrix were successively incorporated into the final distance matrix. First, the graphical representation of a network was converted to a connection matrix with 1 denoting the presence of link(s) between two nodes and 0 indicating the absence of link. Then, an iterative procedure was used to update or power the initial connection matrix continuously until there was no 0 element in the finally updated matrix. The final connection matrix provides a lot of information: each element of it indicates the number of possible links connecting the corresponding node pair; and the summation of each row, called connectivity score, represents the connectivity of the corresponding origin node. Generally speaking, the larger the connectivity score is for a node, the better this node is connected to other nodes in a network.

All the highway nodes were ranked by the connectivity scores as shown in *Figure 4*. As can be seen, the top 20 nodes with the highest connectivity scores are located in the middle east part of the study area and the upper area of the Manhattan Island, shown as big blue dots. More specifically, most of the well connected nodes with high connectivity scores in Queens County are located where Interstate Highway I-678 meets Long Island Expressway and Grand Central Parkway. And those in Manhattan are located at the boundary highway edges where Bronx County meets New York County. For those nodes that were ranked top 50, most are intersectional points of major interstate highways that either cross other major highways/expressways or connect Manhattan with neighboring areas.

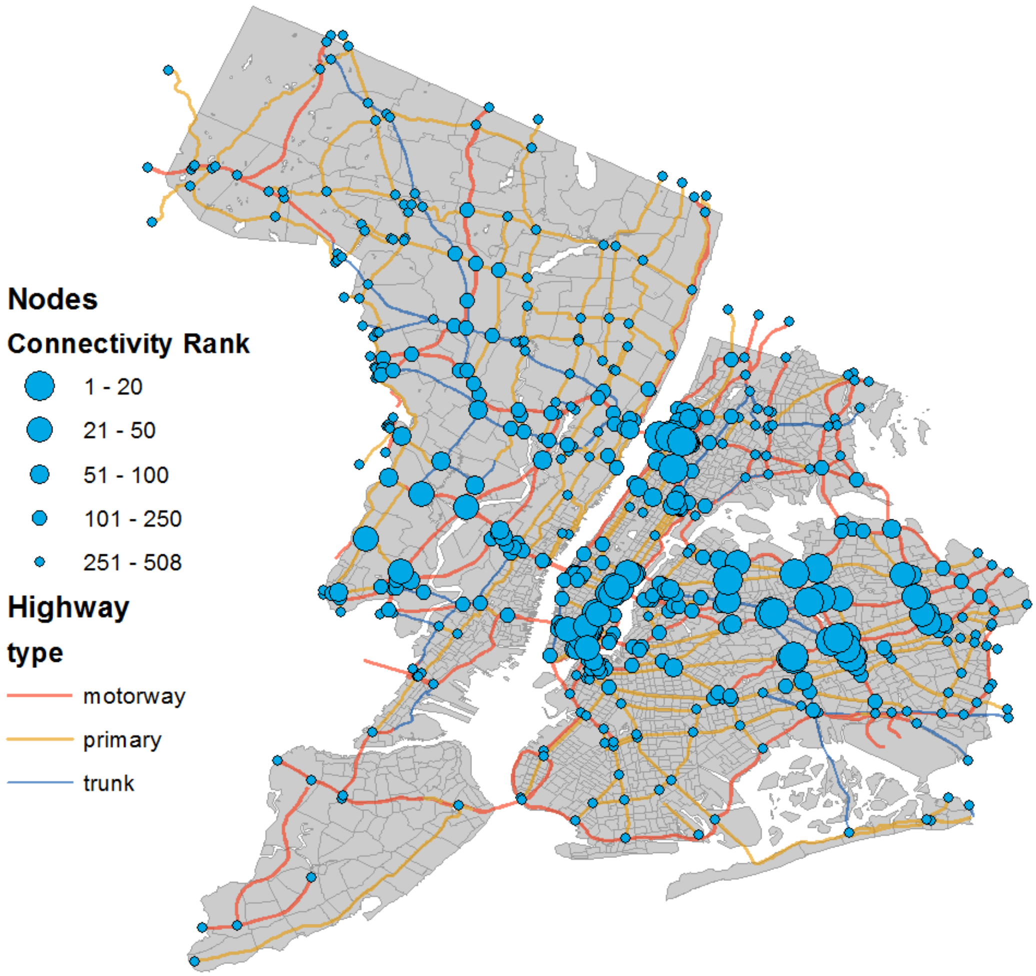

Figure 4 Connectivity ranking of highway nodes (1-the most connected through 508-the least connected)

In graph theory, node degree equals the number of edges (or directed links) incident to a target node. It indicates the number of neighboring nodes that are directly connected to a target node. As shown in *Figure 5*, among all the 508 highway intersecting nodes, 84.2 percent (or 428 nodes) have the degrees of 3 or 4, which means that they have 3 or 4 edges directly connected to them while 2.4 percent (or 12 nodes) have 5 or more directly connected neighbors. The remaining 68 nodes (13.4 percent) are dangle points, meaning that they are end nodes of highway links.

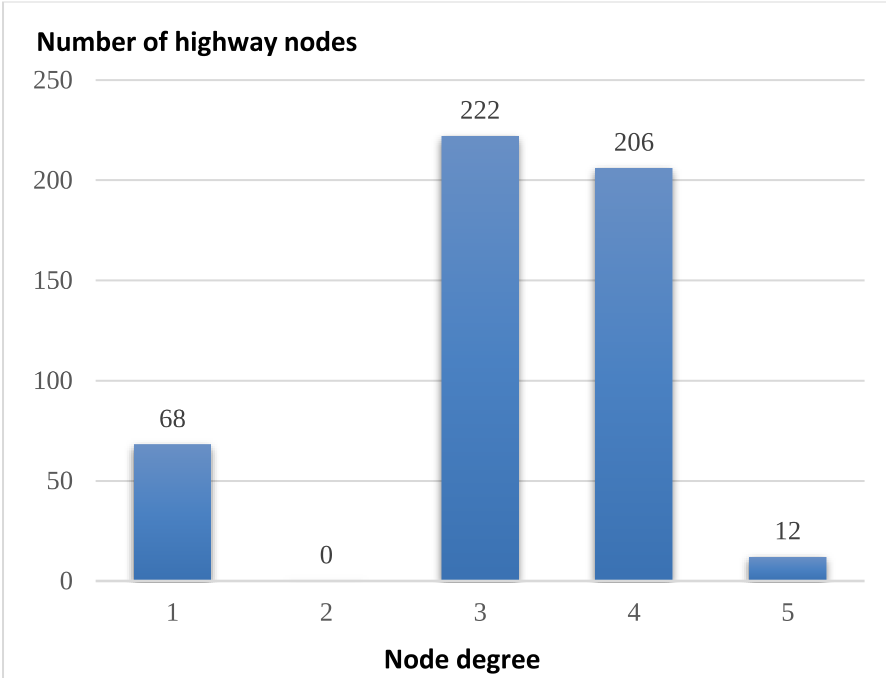

Figure 5 Histogram of highway node degrees

Efficiency Related Measures
Circuity is one common index to measure the efficiency of a transportation network. For a node pair, the simplest form of circuity is the ratio of the actual distance to the airline distance (known as Euclidean distance) between two nodes. As for a highway node, we propose that the degree of circuity for a specific node is the standardized value of absolute differences between network distances and Euclidean distances of all paths originated at that node:

$$\text{Degree of circuity for node } i = \frac{\sum_{j=1}^{n} |E_j - d_j|}{n-1}$$

Where, E_j is the airline distance (or the Euclidean distance) between target node *i* and node *j*; d_j is the actual network distance between target node and node *j*; *n* is the number of nodes that are connected to node *i* directly through edges or indirectly through paths.

For a transportation network as a whole, the circuity index can be calculated as the average circuity value for all node pairs. Regardless of applications, degree of circuity indicates the efficiency of a roadway network in connecting locations. The larger the value is, the longer the actual network distance is than the airline distance, and thus the less efficient a node or a network is.

The degree of circuity for each highway node in the study area was calculated as shown in *Figure 6*. As can be seen, the highway nodes in Manhattan and its neighboring areas tend to have highest efficiency to be connected to the remaining network than other nodes, given that their degrees of circuity are the lowest. The least efficient highway nodes are those "corner" points that are located on the boundaries of the study area and far away from the major demand generators such as Manhattan.

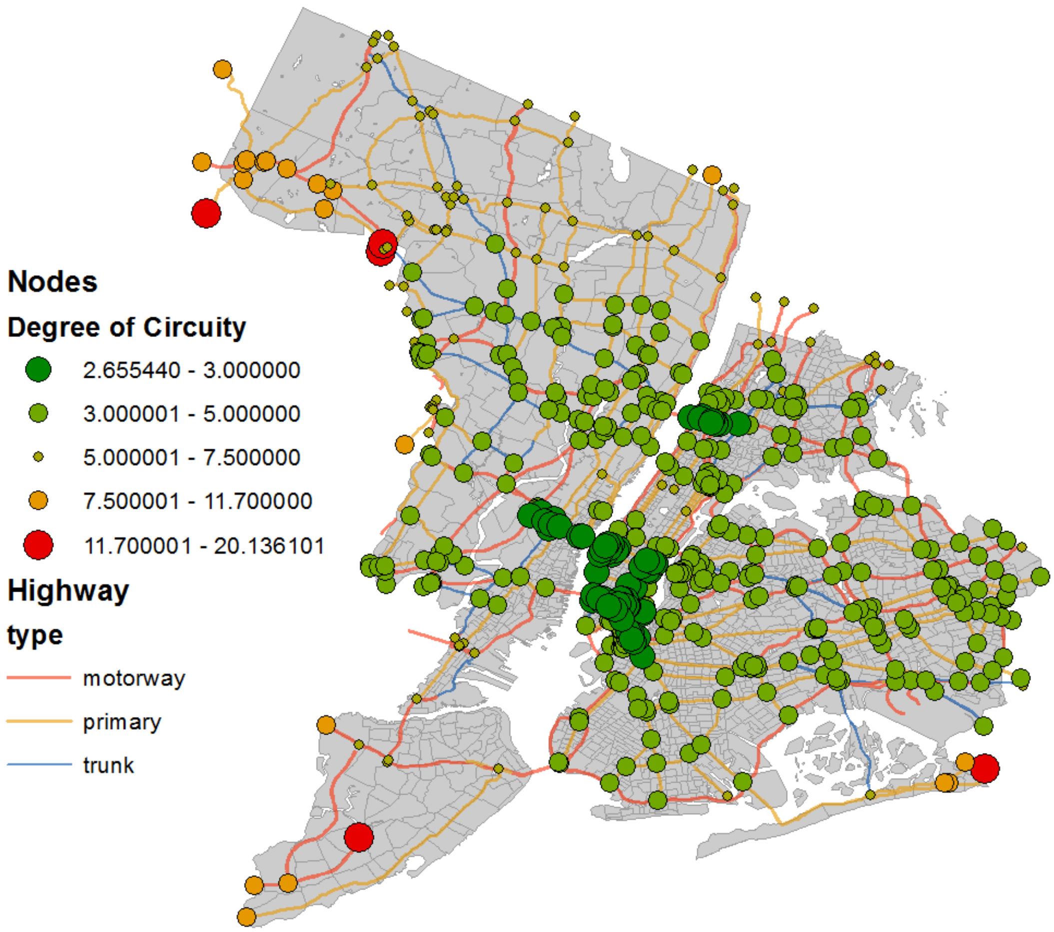

Figure 6 Degree of circuity of each highway node

As for the entire highway network, the degree of circuity, or the average degree of circuity for all node pairs, was found to be 1.23. This is consistent with Newell's findings that transportation networks in urban areas normally have the circuity values of 1.2 on average (Newell, 1980).

Similar to network circuity, average shortest path length (Rodrigue, et al. 2013) is also a measure of network efficiency. The average shortest path length for our study area was found to be 24.6 km given that only highways are used for freight shipments.

Network Accessibility Measures

Accessibility measures the ease of reaching goods, activities and destinations. Given the calculated values by node, it can be used to rank nodes to identify important ones. In the research, we use a distance-based accessibility measure to indicate the importance of a node, in addition to the betweenness centrality index.

A typical method to calculate accessibility for a target node *i* is shown as below:

$$Accessibility_i = \sum_{j=1}^{n} \frac{w_j}{r_{i,j}^x}$$

Where, w_j is the weight of node j; $r_{i,j}^n$ is the impedance between node i and j, which is commonly modeled as a certain power function of network distances or travel times; n is the number of nodes that are attracted to target node i.

In the research, the daily trip productions of TAZs are used as the weights, representing the demand side. The impedance function is structured as the squared network distance between two nodes. Based on the computed accessibility scores, all highway nodes are ranked from 1 for the node with the highest accessibility score to 508 for the node with the least score, as shown in *Figure 7*. One can easily tell from the figure that the most accessible nodes are clustered around bridges and tunnels connecting Manhattan and Long Island, such as Brooklyn Bridge, Manhattan Bridge, Williamsburg Bridge, Queens Midtown Tunnel, and Queensboro Bridge.

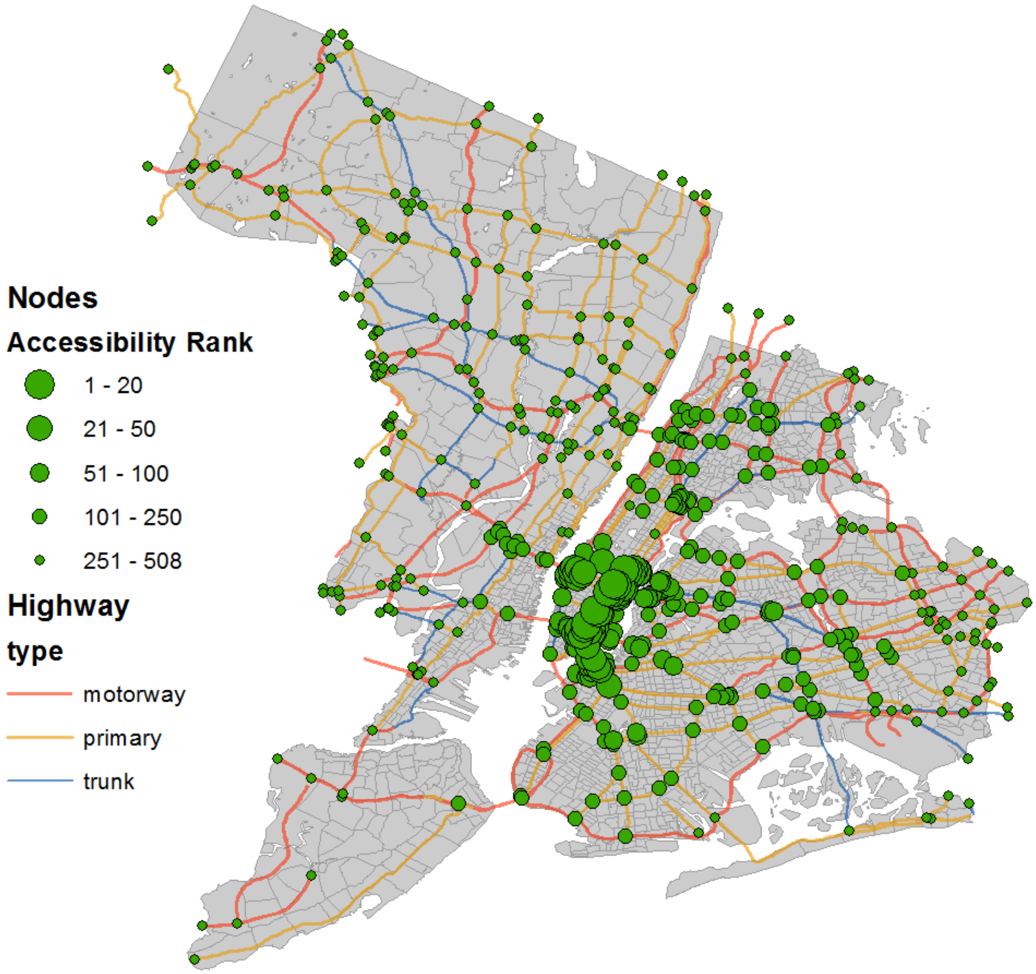

Figure 7 Accessibility ranking of highway nodes (1-the most accessible through 508-the least accessible)

Knowledge of centrality of a node in a network can also be used to explore the accessibility and importance of a node since central locations are often the focal points or share good accessibility. In transportation, facilities that are central could be key infrastructure. Many centrality indices have been developed in graph theory. In this research, the betweenness centrality index of node was used because of the popularity of it and the relationship of it with other similar measures. According to Freeman (1977), betweenness centrality is the number of shortest paths from any nodes to all others that pass through a target node divided by the total number of shortest paths in a network. The larger a value is, the more "central" or important a node would be.

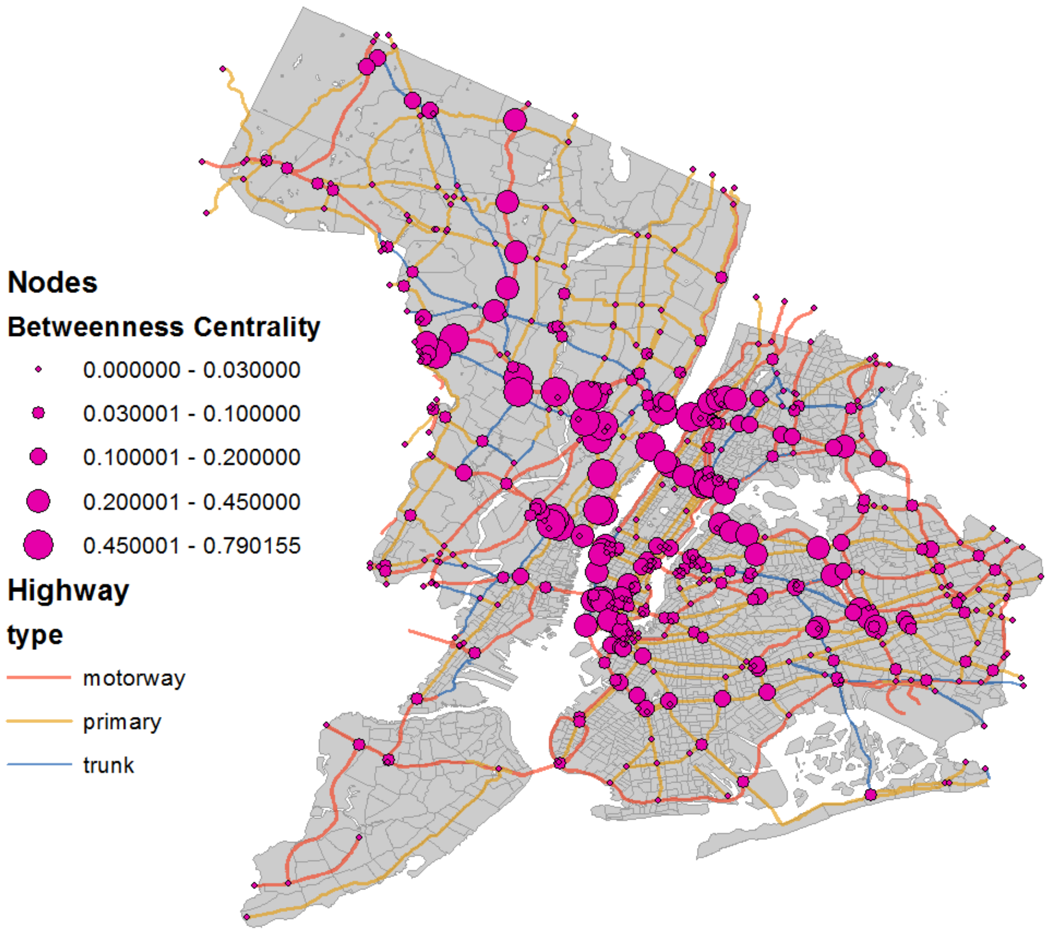

Figure 8 Betweenness centrality of each highway node

The betweenness centrality scores of all nodes in the highway network were calculated as shown in *Figure 8*. Two types of highway nodes show their importance or "central" roles. Highway nodes on the connecting bridges or tunnels between New Jersey and Manhattan or between Manhattan and Long Island appear "central", given the high betweenness centrality scores. In addition, some nodes on the edges of the highway network also seem to be "central". For example, several highway nodes in the middle of New Jersey have high centrality scores as well.

ACCESSIBILITY TO INTERMODAL FREIGHT TERMINALS

Intermodal freight terminals often play a vital role in freight transportation due to the importance of them in generating and distributing freight activities. After commercial goods arrive at these terminals in large patches, they are dispatched and/or delivered to destinations in urban areas. In the process, a mode shift could occur. A good freight terminal or hub should be well connected to transportation networks and also be able to handle possible mode shifts efficiently. 71 intermodal freight terminals were selected, including 20 air facilities, 2 ports, 39 rail facilities, and 10 trucking terminals, representing multiple modal shift combinations such as air – truck, rail – truck, and truck – port – rail.

The accessibilities of warehousing establishments to each freight terminals in order to examine the importance of these terminals. Here, warehousing establishments were used because they are the major generator of intermodal freight demand. The Accessibility Index (AI) is defined as:

$$AI_i = \sum_j \frac{comsiz_j}{d_{ij}} \qquad (4\text{-}1)$$

where,

AI_i is the accessibility index for intermodal terminal i , i =1, 2, …; $comsiz_j$ is the size of warehouse establishment j , indicated by the number of employees, j =1, 2, …; d_{ij} is the network distance between intermodal terminal i and warehouse establishment j .

The calculated accessibility scores of the intermodal freight terminals are shown in **Table 3**, sorted by terminal types. As we can see, railroad and marine port terminals have higher accessibility to warehousing establishments than air and truck terminals in general, with the accessibility scores of 23 and 28 on average, respectively. The top 5 intermodal freight terminals and others are shown spatially in **Figure 9**. First of all, the accessibility index of Yellow Pine Brook New Jersey Terminal is the highest, although it is outside the Manhattan area. The reason is that a few very large warehousing establishments with more than 10,000 employees are located nearby.

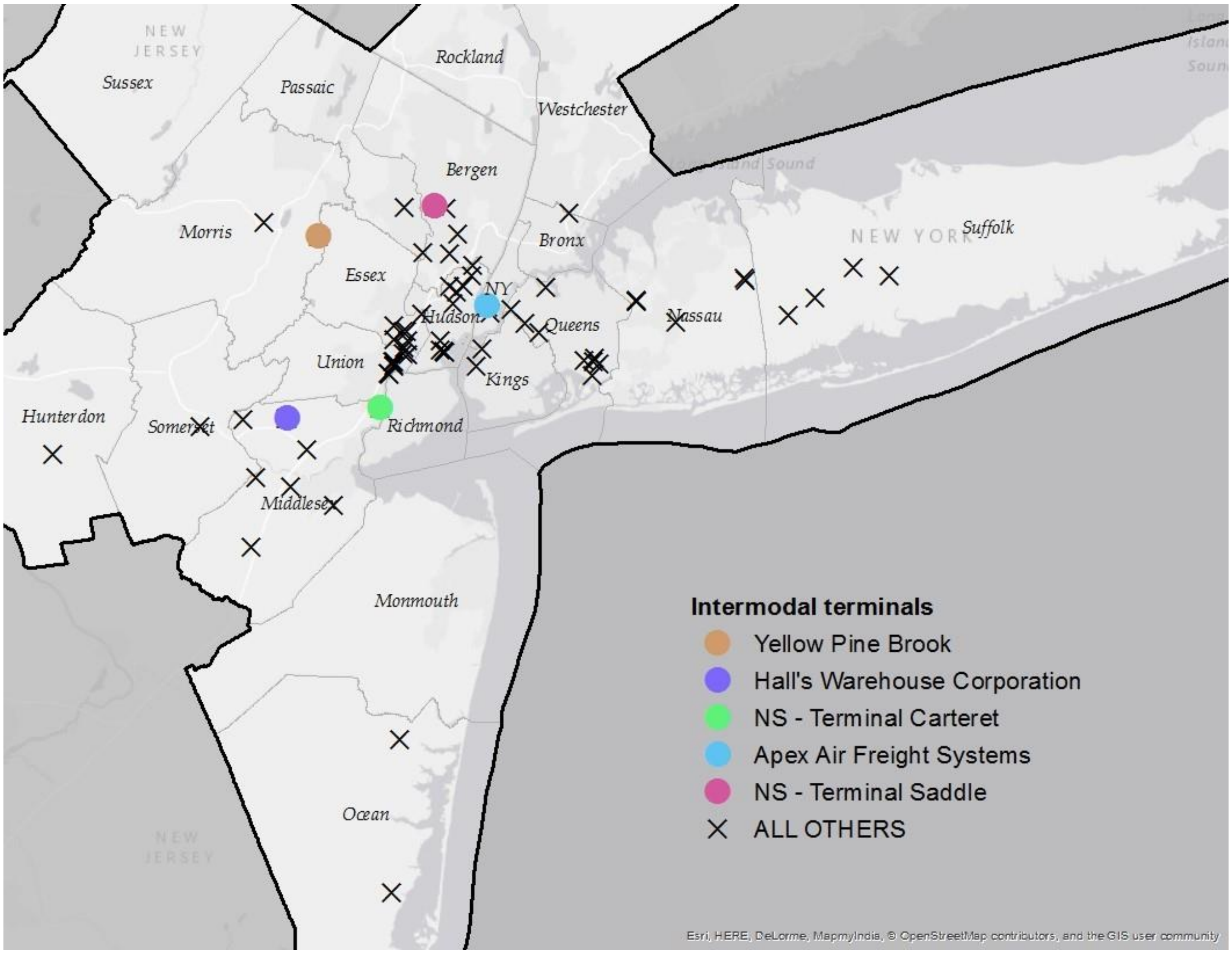

Figure 9 Top 5 intermodal freight terminals

Table 3 Accessibility index of intermodal freight terminals

Name	Type	Mode Type	Accessibility Index	Ranking
Apex Air Freight Systems	Air	Air & Truck	44501.52	4
AJ Worldwide Services	Air	Air & Truck	18770.01	7
Sureway Worldwide	Air	Air & Truck	2911.60	13
Emery Forwarding Springfield Gardens NY	Air	Air & Truck	2412.89	17
Signature Flight Support	Air	Air & Truck	816.31	39
Emery Customs Brokers Newark NJ	Air	Air & Truck	799.94	41
Newark International Airport	Air	Air & Truck	510.72	44
Aramex International	Air	Air & Truck	505.77	45
La Guardia Airport	Air	Air & Truck	387.56	49
Sprint International Express	Air	Air & Truck	366.23	52
Yusen Air and Sea Service (USA)	Air	Air & Truck	324.95	54
Advantage Air Express	Air	Air & Truck	217.33	57
World Trade Business USA	Air	Air & Truck	194.14	59
Associated Global Systems	Air	Air & Truck	180.62	60
Air Cargo Partners	Air	Air & Truck	174.90	61
Virgin Atlantic Cargo	Air	Air & Truck	174.90	62
Service By Air	Air	Air & Truck	165.82	64
Air Sea International Forwarding	Air	Air & Truck	140.99	66
John F. Kennedy International Airport	Air	Air & Truck	134.22	67
Allstates World Cargo	Air	Air & Truck	13.67	71
The Port Authority Of New York and New Jersey	Port	Truck - Port - Rail	2376.62	18
Global Terminal	Port	Truck - Port - Rail	1090.28	29
Hall's Warehouse Corporation	Rail	Rail & Truck	154648.77	2
NS Connecting Line Bulk Transfer Terminal Carteret	Rail	Truck - Port - Rail	45747.44	3
NS Connecting Line Bulk Transfer Terminal Saddle	Rail	Rail & Truck	22716.51	5
NDS North Bergen NJ	Rail	Rail & Truck	20861.15	6
Christian Salvesen	Rail	Rail & Truck	11397.88	8

CSX Intermodal Little Ferry NJ	Rail	Rail & Truck	6781.76	9
NS Connecting Line Bulk Transfer Terminal Jersey City	Rail	Rail & Truck	5227.55	10
National Distribution Centers	Rail	Rail & Truck	3923.09	11
Bass Transportation South Plainfield NJ	Rail	Rail & Truck	3814.02	12
Poinier Street Lumber Transfer and Distribution Center	Rail	Rail & Truck	2692.99	14
NS Connecting Line Bulk Transfer Terminal Brooklyn	Rail	Rail & Truck	2474.61	15
Port Newark Refrigerated Warehouse	Rail	Rail & Truck	2415.55	16
NS Independent Bulk Transfer Terminal New Brunswick	Rail	Rail & Truck	1841.78	19
NS Connecting Line Bulk Transfer Terminal North Bergen	Rail	Rail & Truck	1654.62	20
R Horizon	Rail	Rail & Truck	1452.05	21
Pinter Warehouse	Rail	Rail & Truck	1402.51	22
Port Jersey Logistics Jersey City NJ	Rail	Rail & Truck	1382.97	23
NS Elizabeth, NJ 322 Third	Rail	Rail & Truck	1260.92	25
Tyler Distribution Centers, Inc. P.A. Marine Terminal	Rail	Truck - Port - Rail	1222.91	26
East Coast Warehouse & Distribution	Rail	Rail & Truck	1161.06	27
BGB Transport	Rail	Rail & Truck	1160.70	28
The Abrachem Group Clinton NJ	Rail	Rail & Truck	1080.07	30
Matlack Bulk Intermodal Systems	Rail	Rail & Truck	1050.46	31
CSX Intermodal North Bergen NJ	Rail	Rail & Truck	1029.71	32
NS Croxton NJ	Rail	Rail & Truck	1015.87	33
Construction & Marine Equipment Co., Inc	Rail	Rail & Truck	938.06	35
NS Independent Bulk Transfer Terminal Jersey City	Rail	Rail & Truck	928.62	36
NS Connecting Line Bulk Transfer Terminal Elizabeth	Rail	Rail & Truck	871.69	38
Maher Terminals	Rail	Rail & Truck	792.59	42
Port Of New York and New Jersey	Rail	Truck - Port - Rail	732.07	43
Metroplex Distributors	Rail	Rail & Truck	505.65	46
New York and Atlantic Railroad	Rail	Rail & Truck	460.59	47
New York, Susquehanna and Western	Rail	Rail & Truck	435.44	48
NS Independent Bulk Transfer Terminal Bridgewater	Rail	Rail & Truck	381.70	50

Marschall Warehouse	Rail	Rail & Truck	376.23	51
NS Independent Bulk Transfer Terminal Middlesex NJ	Rail	Rail & Truck	299.45	55
NS Independent Bulk Transfer Terminal Patterson NJ	Rail	Rail & Truck	277.18	56
MHF, Inc.	Rail	Rail & Truck	200.35	58
Bass Transportation Co., Inc. Flemington NJ	Rail	Rail & Truck	22.44	70
Yellow Pine Brook NJ Terminal	Truck	Truck - Port - Rail	937813.52	1
Yellow Queens NY Terminal	Truck	Truck - Port - Rail	1298.00	24
Yellow Carlstadt NJ Terminal	Truck	Truck - Port - Rail	941.01	34
Yellow Edison NJ Terminal	Truck	Truck - Port - Rail	898.69	37
Yellow Elizabeth NJ Terminal	Truck	Truck - Port - Rail	814.63	40
Yellow Mount Vernon NY Terminal	Truck	Truck - Port - Rail	365.34	53
Island Transportation Corp. West Babylon NY	Truck	Rail & Truck	168.97	63
Yellow Long Island NY Terminal	Truck	Truck - Port - Rail	159.05	65
Yellow East Islip NY Terminal	Truck	Truck - Port - Rail	78.33	68
Yellow Lakewood NJ Terminal	Truck	Truck - Port - Rail	57.56	69

CONCLUSIONS

The transportation network in the New York Metropolitan region is one of the busiest networks worldwide where massive freight transportation activities occur daily. Two types of network analysis were conducted for the region in order to understand and document the inventory of freight transportation networks in the region, including: (1) numerical measurement of network structure, connectivity, accessibility and efficiency of the highway network; and (2) identification of critical intermodal freight terminals given their accessibilities to major intermodal freight demand generators such as the warehousing industry.

As found, the highway network in the region provides limited connectivity for freight activities. The network is connected but not well connected, which implies that arterials and local streets are very important supplements for freight to reach final destinations. As for highway intersecting nodes, the most important ones in terms of network connectivity and accessibility are those in and around Manhattan, particularly the bridges and tunnels connecting Manhattan to neighboring areas. 71 major intermodal freight terminals were evaluated in terms of their accessibilities to freight demand generators such as the warehousing industry. As found, major multimodal freight demand generators, such as warehousing establishments, have better accessibility to railroad and marine port terminals than air and truck terminals in general.

ACKNOWLEDGMENT

This research is supported by the Volvo Research and Educational Foundations through the MetroFreight Center of Excellence, METRANS Transportation Center, and University of Southern California. All errors and omissions are the responsibility of the authors.

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