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EVALUATING FREIGHT INTERMODAL CONNECTORS (FICs) IN TENNESSEE

Final Report

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16. Abstract

Freight Intermodal Connectors (FICs), which are also known as “first mile/last mile roadways”, are roadway segments that link freight logistic hubs or freight-intensive land uses to main freight routes. This project focused on segments, corridors and intersections that connect Tennessee freight trucks to/from the major freeways from/to high-priority facilities such as truck hubs, airport, rail, intercity bus terminals, etc. For efficient intermodal freight movement, these connectors must be in a desired service condition (operational, safety, and environmental) capable of accommodating freight needs. The evaluated FICs in Tennessee to identify deficiencies related to congestion, capacity, safety and emission needs. Crash analysis found that connectors leading to pipeline terminals have high crash rates compared to other type of terminals, while port terminal connectors have the lowest crash rates. Signal density was found to significantly affect the probability of crashes together with the presence of a two-way left turn lane (TWLT), which tends to decrease probability of crashes along these connectors. The presence of shoulders along intermodal connectors was found to help reduce the probability of crashes while the presence of curbs and gutters tends to increase crash frequency. Analysis indicated that most FICs with high crash rates were also operating at a lower traffic operations level of service especially for critical movements towards freight facilities. FIC operational and capacity evaluation was aimed at identifying deficiencies with respect to queueing, delay and level of service (LOS) at critical intersections. It was observed that intersection delays varied randomly without specific pattern related to the type of connector. Reliability measures for fluidity analysis were used to identify bottlenecks and related delay costs for some connector segments. Travel time reliability was used to locate the bottlenecks along freight intermodal connectors (FICs). The study collected GPS second-by-second data, then developed statistical regression models to establish the relationship between reliability performance measures. The study showed that freight connectors to and from pipeline terminals have the highest ranked bottlenecks during evening peak hours while those to bus terminals are at highest during the morning peak hours. Airport and port freight connectors were found to have moderately ranked bottlenecks during evening peak hours. A survey was conducted to evaluate FICs in Tennessee from the stakeholders’ (truck drivers’) perspective. The survey results showed the biggest issues that drivers are currently facing are recurring congestion along the FICs, signage, safety and security, bottlenecks, direct/indirect cost of congestion, on-time delivery, and the absence of safety features such as bike lanes, sidewalks, and pedestrian features. The study used Environmental Protection Agency (EPA) mobile source emissions model Motor Vehicle Emission Simulator (MOVES) to estimate truck emissions along the FIC segments on a second-by-second basis in combination with VISSIM simulation software. The MOVES model estimations were compared/combined with estimates from VISSIM to obtain accurate emission results. The VISSIM/MOVES model was used to determine emissions factors for carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM 2.5), and volatile organic compounds (VOC)along the FICs. TDOT should base the implementation of the study findings on the listed and ranked segments and intersection’s safety, operational, travel reliability and air pollution deficiencies. The implementation should include pavement resurfacing, signage, travel-way widening, intersection reconfigurations and signal re-design to mitigate delays, queuing and improve travel time and LOS. TDOT also can use the developed models for predicting crash frequencies along the FIC segments and microscopic models to estimate CO, NOx, PM 2.5 and VOCs emissions at project levels.

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DEFINITION OF ABBREVIATIONS

FIC	Freight Intermodal Connectors
TWLT	Two-Way Left Turn Lane
LOS	Level of Service
EPA	Environmental Protection Agency
MOVES	Motor Vehicle Emission Simulator
CO	Carbon Monoxide
NOx	Nitrogen Oxides
PM 2.5	Particulate Matter
VOC	Volatile Organic compounds
AADT	Average Annual Daily Traffic
VSP	Vehicle Specific Power
STP	Scaled Tractive Power
FHWA	Federal Highway Administration
DOT	Department of Transportation
MPO	Metropolitan Planning Organization
TDOT	Tennessee Department of Transportation
USDOT	US Department of Transportation
FDOT	Florida Department of Transportation
CMAP	Chicago Metropolitan Agency for Planning
CRS	Condition Rating Survey
IRIS	Illinois DOT's Roadway Information System
ATRI	American Transportation Research Institute
NPMRDS	National Performance Management Research Data Set
NHS	National Highway System
WIM	Weigh in Motion
ATR	Automatic Traffic Recorders
IEA	International Energy Agency
UHC	Unburned Hydrocarbons
HCM	Highway Capacity Manual
TRB	Transportation Research Board
BPR	Bureau of Public Roads
HOV	High Occupancy Vehicle
NHPN	National Highway Planning Network
TRIMS	Tennessee Roadway Information Management System
MVMT	Million vehicle miles of travel
PDO	Property Damage Only
NB	Negative Binomial
RI	Reliability Index
TTI	Travel Time Index
PTI	Planning Time Index
MI	Misery Index
SS	Skew Statistics
BI	Buffer Index

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EXECUTIVE SUMMARY

Freight Intermodal Connectors (FICs), which are also known as "first mile/last mile roadways", are roadway segments that link freight logistic hubs or freight-intensive land uses to main freight routes. They are short mile road or rail tracks that connect intermodal terminals to National Highway Systems (NHS) mainline routes (primarily interstates and arterials). This project evaluated FICs in Tennessee to identify deficiencies related to congestion, capacity, safety, emission and supply chain demand needs. The study focused on "roadway connectors": segments, corridors and intersections that connect Tennessee freight trucks to/from the major freeways from/to high-priority facilities such as truck hubs, airport terminals, freight rail terminals, passenger rail and intercity bus terminals, waterways, warehouses, depots, centers, etc. For efficient intermodal freight movement, these roadway connectors must be in a desired service condition (operational, safety, and environmental) capable of accommodating truck and freight needs.

Safety analysis found that connectors leading to pipeline terminals have high crash rates (almost double) compared to other type of terminals while port terminal connectors have the lowest safety indices. This study established contributing causes of crash frequencies and rates along FICs that included Average Annual Daily Traffic (AADT), lanes, shoulders, access and median types. Signal density was found to strongly and significantly affect the probability of crashes together with the presence of two-way left turn lane (TWLT), which surprisingly tends to decrease probability of crashes along these connectors. The presence of shoulders along intermodal connectors was found to help reduce the probability of crashes while the presence of curbs and gutters tends to increase crash frequency. Analysis indicated that most of FIC connectors with high crash rates were also operating at a lower traffic operations level of service, especially for critical movements towards freight facilities.

- The highest number of crashes was found along Jackson Ave (SR-14) connector to and from Leewood Yards - CSX, a Truck/Rail facility in Memphis to I-40.
- The second and third connector segments with the highest number of crashes are also from facilities in Memphis: Democrat Rd (to Memphis International Airport) and Shelby Dr (to Tennessee Yards - Memphis Burlington) respectively.
- E. Magnolia Ave segment (to Greyhound Bus Terminal) in Knoxville has the highest number of fatal and incapacitating injury crashes combined.
- The top FIC connectors that exceeded critical total crash rates include Armory Ave to and from Radnor Yards in Nashville CSX, Western Ave to and from Pipeline facility in Knoxville, Riverside Blvd to and from President's Island in Memphis, Shelby Dr to and from Tennessee Yards - Memphis Burlington, and East Parkway S to and from Forrest Yards Memphis Norfolk Southern.

FIC operational and capacity evaluation was aimed at identifying deficiencies with respect to queueing especially on the critical intersection movements to and from the freight facilities, delay and level of service (LOS) at critical intersections with factors influencing travel cost/per mile of the connectors. Freight travel time reliability, delay cost per mile and factors influencing it were determined. It was found that:

- Intersection with Shelby Dr to and from Tennessee Yards - Memphis Burlington and Jersey Pike/SR-153, an intersection along pipeline connector in Hamilton County recorded the highest AM delay.
- Winchester Rd, Airways Blvd and Plough Blvd interactions along FICs to and from Memphis International Airport recorded the highest PM delays.
- The intersection with Lincoln Street to and from truck-rail connector segment in Sullivan County and E. Magnolia Ave and North Cherry St segment to and from Greyhound Bus Terminal in Knoxville had the lowest delays.
- It was observed that intersection delays varied randomly for different types of connectors with no specific pattern related to the type of connector.
- Reliability measures for fluidity analysis were used to identify bottlenecks and related delay costs for some connector segments.
- The top three segments with the highest delay costs are Democratic Rd to and from Memphis International Airport followed by Ed Shouse Dr to and from Colonial & Plantation Pipeline in Knoxville and E. Magnolia Ave segment to and from Greyhound Bus Terminal in Knoxville.
- The FIC segment with the lowest delay cost is West 19th St to and from Southern Foundry Supply, a Port Terminal connector in Chattanooga

Travel time reliability, which is a key performance measure used by researchers and public agencies in evaluating traffic operations including those related to truck-freight operations, was used to locate the bottlenecks along freight intermodal connectors. The study collected GPS second-by-second data, then developed statistical regression models to establish the relationship between reliability performance measures. In finding the precise location of the freight bottlenecks and ranking them using total delay, the study showed that freight connectors to and from pipeline terminals have the highest ranked bottlenecks during evening peak hours while those to bus terminals are at highest during the morning peak hours. Airport and port freight connectors were found to have moderately ranked bottlenecks during evening peak hours while the lowest ranked segment bottlenecks were the connectors to bus terminals.

The questionnaire survey was conducted to evaluate FICs in Tennessee from the stakeholders' (truck drivers') perspective. In addition to the 22 designated FICs, other freight intensive connectors were identified in Clarksville, Smyrna, and Portland. The purpose of this survey was to gather information regarding the operation and functionality of the freight transportation infrastructure along FICs in the state of Tennessee. To obtain the survey data, a three-page questionnaire was developed and distributed in person to various freight facilities all over Tennessee. The most important findings from the survey were the following:

- The questionnaire survey showed the biggest issue that the drivers are currently facing is recurring congestion along the FICs.
- Signage, bottlenecks, direct/ indirect cost of congestion, on-time delivery, and infrastructure condition are critical factors for freight efficiency.
- The absence of safety features such as bike lanes, sidewalks, and pedestrian features ought to be addressed.
- The respondents provided the following recommendations and concerns: potholes, bottlenecks, clearer signs and better access points

The study additionally evaluated emissions along Tennessee FICs. EPA mobile source emissions model (MOVES) was used to estimate vehicle emissions on a second-by-second basis through microsimulation (VISSIM). Vehicle specific power (VSP) and scaled tractive power (STP) calculated from the second-by-second data was used as input in MOVES. Attention was given to carbon monoxide (CO), nitrogen oxide (NOx), particulate matter (PM 2.5), and volatile organic compound (VOC) emissions. The emission estimates obtained using MOVES were evaluated, and microscopic transportation emission models were established with the use of nonlinear least-squares estimations. FIC segments were ranked based on emission with the following key findings:

- Connectors to Memphis International Airport followed by those to Colonial & Plantation Pipeline Co, Tennessee Yards-Memphis Burlington, Johnston Yards-Memphis Illinois Central, Leewood Yards-Memphis CSX, respectively, generated the highest amount of emission.
- The FICS to and from Tennessee Yards-Memphis Burlington, Memphis International Airport and President's Island-Memphis generated the highest amount of NOx emission.
- The FICS connectors to Tennessee Yards-Memphis Burlington, President's Island-Memphis, Johnston Yards-Memphis Illinois Central, and Memphis International Airport generated the highest amount of PM2.5 emission.

This study benefits TDOT as it provided technical analysis and summary of freight related deficiencies that exist along freight intermodal connectors. The study identified and summarized potential deficiencies to TDOT warranting improvement needs which eventually will improve FICs' capacity, congestion, air pollution and safety. TDOT is expected to use the study for justification of projects such as pavement resurfacing, signage, travel-way widening, intersection reconfigurations and signal re-design for mitigating delays, queuing and for improving travel time and level of service along the FIC connectors. TDOT will also benefit from the study findings by using the developed safety performance functions (SPFs) for predicting and evaluating crash frequencies along the FIC segments and models for estimate CO, NOx, PM 2.5 and VOCs emissions.

1. PROJECT OVERVIEW

1.1. Study Overview

Intermodal freight logistic hubs attract significant amount of trucks which deliver and pick up goods, containers and services through public roadway segments. Freight Intermodal Connectors (FICs), also known as "first mile/last mile roadways", are roadway segments that link freight logistic hubs or freight-intensive land uses to main freight routes. These intermodal connectors are public, short-mileage road or rail track that connect intermodal terminals to National Highway Systems (NHS) mainline routes (primarily interstates and arterials) [1]. For efficient intermodal freight movement, these connectors must be in a desired service condition (operational, safety, and environmental) capable of accommodating truck and freight needs. If FICs have little capacity, they cause traffic congestion that in turn increase travel time, energy consumption, and air pollution. On the other hand, if FICs have too much capacity, their utilization can be too low to justify monetary investment on them. Hence, FICs need to match environmental, operational and safety needs. This study evaluates FICs in Tennessee to identify deficiencies related to safety, economic risk, capacity, environmental and supply chain demand needs. The study focuses on "Tennessee Intermodal Connectors" : segments, corridors and intersections that connect freight trucks to/from the major freeways from/to high-priority facilities such as truck hubs, airport terminals, freight rail terminals, passenger rail and intercity bus terminals, waterways, warehouses, depots, etc.

1.2. Study Objectives and Scope

Table 1.1 lists NHS Intermodal Connectors in Tennessee that are evaluated through this study [2]. The study provides technical analysis and summary of freight-related deficiencies that exist along roadway segments connecting freight, especially trucks to known warehouses, depots, hubs and terminals. Analysis is provided of potential deficiencies warranting improvement such as access and connectivity, capacity, congestion, safety, and environmental impacts. The analysis provides diverse recommendations on the improvement priorities. The expected outcomes include a comprehensive literature review, an FIC multimodal inventory, evaluation of traffic operations and capacity deficiencies, evaluation of traffic safety deficiencies, economic risk analysis and environmental impacts (emissions) along the connectors. Each of the connectors is assigned performance scores based on congestion, capacity, safety, and emission deficiencies, then ranked based on the summation of the scores.

Table 1.1: Tennessee Intermodal Connectors

Freight Facility Location	**Facility Type**	**No.**	**Facility Connector Description**	**Miles**
Chattanooga Metropolitan Airport	Airport	1	Shepherd Rd (Airport Connector) Between SR-153 And Airport Rd	0.78
Colonial & Plantation Pipeline Co. - Knox	Truck/Pipeline Terminal	1	Middlebrooks Pike (SR-169), Ed Shouse Dr, Randy Tyree St and Western Ave From Terminal Entrance To I-75	1.33
Colonial Pipeline - Chattanooga	Truck/Pipeline Terminal	1	Jersey Pike from Enterprise Park Dr to SR-153	0.59
CSX Corporation - Kingsport	Truck/Rail Facility	1	Lincoln St. From John B. Dennis Highway (SR-93) To Facility Entrance	0.9
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	1	Southern Ave. From Lamar Ave. (SR-4) To East Parkway (SR-277)	0.92
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	2	East Parkway (SR-277) and Airways Blvd From Lamar Ave. (SR-4) To Southern Ave.	0.7
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	3	Spottswood Ave. and South Parkway E from Airways (SR-277) To Forrest Yard	0.37
Greyhound Bus Terminal - Knoxville	Intercity Bus Terminal	1	N. Cherry St, E. Magnolia Ave. (SR-1), Hall of Fame Dr, Old Magnolia and S. Hall of fame Dr from I-40 To Central St.	2.35
J.I.T. Terminals - Chattanooga	Port Terminal	1	Manufactures Rd from SR-29 To Terminal Entrance	0.65
Johnston Yards - Memphis Illinois Central	Truck/Rail Facility	1	Mallory Ave and S.3rd St. from I-55 to the Rail yard	1.66
Johnston Yards - Memphis Illinois Central	Truck/Rail Facility	2	Mallory Ave, Florida St and New horn lake Rd from I-55 to the rail yard	1.54
Johnston Yards - Memphis Illinois Central	Truck/Rail Facility	3	Mallory Ave. and Riverport Rd Between I-55 And Rail Yard	2.16
Leewood Yards - Memphis CSX	Truck/Rail Facility	1	Jackson Ave. (SR-14) And Chelsea Ave. Between I-40 And Watford St.	2.86
Memphis International Airport	Airport	1	Tchulahoma And Democrat Rd Between Lamar Ave (SR-4) And Airways Blvd	2.54
Memphis International Airport	Airport	2	Airways Blvd, Plough Blvd and Winchester Between I-240 And the Airport Entrance	2.05
Mid-South Terminals	Port Terminal	1	Hudson Rd. To Pineville Rd. To Moccasin Bend Rd to Hamm Rd to SR- 29	2.35
President's Island - Memphis	Port Terminal	1	Mclemore Ave, Riverside Blvd, Jack Carley Causeway, Harbor Ave, Channel Ave, Jetty St Btw I-55 & Port	7.32
Radnor Yards - Nashville CSX	Truck/Rail Facility	1	Armory Ave And Sidco Dr Between I-65 And Harding Place (SR-255)	2.0
Southern Foundry Supply - Chattanooga	Port Terminal	1	West 19th St. From Riverfront Parkway (SR-58) To the Port Entrance	0.32
Tennessee Yards - Memphis Burlington Nor	Truck/Rail Facility	1	Shelby Dr Between Lamar Ave. (SR-4) And the Tennessee Yard	0.63
Tri-Cities Regional Airport - Kingsport	Airport	1	Airport Access Rd (SR-357) From I-81 To Airport Entrance	2.44
Vulcan Materials Company - Chattanooga	Port Terminal	1	River St. From Evans St. To Riverfront Parkway (SR-58)	0.19
Total		**24**		**35.75**

2. LITERATURE REVIEW

2.1. Overview

A comprehensive literature search was undertaken to uncover both ongoing or previously published reports and papers on Freight Intermodal Connectors. The review helped to determine information and practices from other states that are relevant to this study. The reviewed resources include library holdings, databases, and gateway services.

2.2. Role of the Freights Intermodal Connectors

At the national level, by 2001, there were about 1222 miles designated as intermodal connectors (both freight and passenger) serving 253 ports (ocean and river), 99 airports, 203 truck/rail terminals and 61 pipeline/truck terminals [3]. Federal Highway Administration (FHWA), state Department of Transportation (DOT's) and Metropolitan Planning Organization (MPO's) worked together to develop guidelines for identifying national highway system connectors to major intermodal terminals, with the main criteria being the status of intermodal terminal and the level of activity [4] [5]. FIC's are a critical part of national freight system, providing links between major intermodal facilities and mainline NHS routes. For efficient and reliable freight movements to and from intermodal facilities, it is necessary for the connectors to be in good operational and safety conditions. Five key intermodal connector qualities -reliability, transit-time, efficiency, cost and damage- have been identified to be very important in freight movements [1]. The reliability of service is a key factor in freight business as shippers need assurance from carriers that goods are constantly delivered in specified amounts and in good condition and within required date and time. Poor connector conditions may result in delays, congestion, damaged goods and/or create safety and environmental concerns. With the anticipated growth of freight shipment, the connectors become even more significant with respect to reliability [6]. The connectors are also crucial for military deployment and national security as the Department of Defense (DOD) increases its reliance on commercial freight systems, especially between military bases and ports [3]. Connectors in poor condition can jeopardize economic security and military assembling. The idea is to be ready as demand occurs during unplanned crisis, requiring immediate capacity to move personnel and materials [7].

2.3. Accessibility to Intermodal Freight (Tennessee's Major Cities)

Tennessee has strong highway access to both domestic and international markets, where three interstates pass through the state (1-40, I-75, I-24) create one of the highest truck volume and percentage highways in the country [8]. Table 2.1 summarizes the FIC system in Tennessee by facility/terminal and the total length in miles. Similar to the domestic market, Tennessee has good connections to the international market in neighboring countries of Canada and Mexico. This makes Tennessee 6th in nation and 1st in southeast for value of freights and cargo ton per miles transported by trucks. It is approximated that 80% of the manufactured goods in the state are transported by trucks [6]. There is effective truck access between the four major cities within Tennessee [9]. Memphis has an effective intermodal rail access as it is served by all five Class I railroads with direct connection to all major cities in the middle, west and east coasts of the country. With 887 main channels of navigable rivers, Tennessee proves to have strong waterway access with the main navigable rivers being the Cumberland River, Mississippi River and Tennessee River. The Mississippi River provides access to the major international market including the port of New Orleans [8]. Overall, Tennessee has a unique freight profile, given the state's location and regional geography that attract both domestic and international markets.

Table 2.1: Number of Connectors by Terminal Types

Connectors to	Number of Connectors	Number of Segments	Total Connector lengths (miles)
Airport	4	7	7.81
Truck/Pipeline Terminal	2	5	1.92
Truck/Rail Facility	9	15	11.48
Intercity Bus Terminal	2	6	3.21
Port Terminal	5	14	11.33
Total	**22**	**47**	**35.751**

2.4. Deficiencies of Intermodal Freight in Tennessee

While it is beneficial for state economic growth, serious concerns may arise on negative impacts of freights operations if not managed properly. TDOT published a report on freight needs and project identification that used the volume to capacity ratio (V/C) to locate segments with the worst truck bottlenecks in Tennessee. The key observations identified in the study report included [9]:

- Urban areas have higher v/c ratio and higher truck volume.
- The four largest metropolitan areas in Tennessee have significant truck-related bottlenecks.
- Most of the bottleneck locations are near interchanges.

- Severity of the truck related crashes is much greater than non-truck counterparts.
- Top truck-involved crash rates are located in urban areas (Nashville, Memphis, Knoxville and Chattanooga).

The report recommended Tennessee Department of Transportation (TDOT) establish a statewide truck safety program to investigate the cause of truck-related accidents and to come up with potential solutions. This study extends this recommendation to evaluating safety deficiencies along the connectors [10] by:

- Conducting comprehensive crash data analysis.
- Evaluation and identification of injury severity patterns.
- Evaluation and identification of collision patterns.
- Evaluation and identification of crash contributing causes.
- Evaluation and identification of first harmful events.
- Evaluation and identification of crash locations (segment, intersections etc.).
- Evaluation and identification of crashes in relation to time and day of the week.
- Developing connector safety performance functions (SPFs).

2.5. Freight Intermodal Connectors Evaluation from other States

The role and performance of FICs have been documented from other states and jurisdictions. NHS' "Intermodal Connector: A Report to Congress" [5] is one of the earliest studies on intermodal connectors. The study aimed to identify deficiencies associated with safety and operation of NHS connectors in the country and to come up with an effective option for the improvement of NHS connectors and intermodal infrastructure generally. The study found that 12% of the connector's pavement condition was in poor or very poor condition, 51% of the connector's mileage was found in good condition and 37% in fair condition. The study defines "poor pavement condition as having shallow rutting/cracks that result in reduction of speed, very poor pavement condition having extensive problem with potholes that cause considerable reduction of speed. Chicago Metropolitan Agency for Planning (CMAP) conducted an assessment on the pavement condition of freight connectors using Condition Rating Survey (CRS) data by comparing 2006 and 2009 CRS data from Illinois DOT's Roadway Information System (IRIS) database [11]. The CRS data are shared with FHWA which uses it to assess ride quality as a measure of pavement condition at a national level. The ride quality is measured as being either acceptable or not acceptable as shown in Table 2.2.

Table 2.2: CRS Pavement Condition Rating

CRS	General Condition
9.0	Awarded, new or near new
8.0	Excellent
7.0	Good
6.0	Fair
5.0	Marginal
4.0	Poor
3.0	Intolerable
2.0	Crucial
1.0	Critical
0.0	Not collected

In Louisiana, the regional planning commission for Jefferson, New Orleans, Plaquemines, St. Bernard, and St. Tammany parishes conducted baseline assessments on its freights intermodal connectors aiming to identify and address challenges on the freight industry within the region. The assessment was done through a survey that used FHWA’s NHS connector condition and investment inventory form as well as site visits and interviews with key stakeholders [12]. The evaluation found that most of the intermodal facilities were located adjacent to dense surroundings that discouraged the effort of improving the levels of service along the connectors due to mixed residential and commercial land uses. Lack of shoulders and tight turning radii at the intersections were also documented as to the impact of safety and operations of the trucks. Most of assessed intermodal rail/truck connectors showed lack of signals and gates at rail crossings that caused safety concerns [12]. Table 2.3 summarizes the Louisiana intermodal connector’s assessments.

Table 2.3: New Orleans Intermodal Connectors Assessment Findings [12]

Facility name	**Port Of New Orleans-Jourdan Road Terminal**	**BNSF Westwego**	**CSX New Orleans Terminal**	**KCS Metairie Terminal**	**Up Avondale Terminal**	**Louisiana Int. Airport**	**Port Of New Orleans-Downtown Wharves**	**Port Of New Orleans-Mississippi River Terminal Complex**	**Ns New Orleans Terminal**
Type of Connector	Port terminal	Truck/rail facility	Track/rail facility	Truck/rail facility	Track/rail facility	Airport	Port terminal	Port terminal	Truck/rail facility
Lanes	2	2	4	2	2	2 & 4	2	2-4	1
Connector	LA 17P1	LA 11R 1	LA 15R 1&2	LA 12R 1	LA 10R 1	LA 9A 1&2	LA 18P 1	LA 19P 1	LA 14R 1
Surrounding Land Use	industrial	Light industrial	industrial	Industrial, commercial	Industrial, residential	commercial	Mixed use neighborhood	commercial	Residential, commercial
Shoulders	Good	No shoulder	good	No shoulder	No stabilized shoulders	good	No shoulder	good	good
Roadway	Prone to debris and plant overgrowth	Narrow lanes	Debris, poor pavement at LA 15R1	Good pavement condition	Poor pavement condition. Narrow lane	Fair pavement condition.	Presence of river lee, rough surface.	Excellent physical condition	Undivided roadway. Complex geometry
Rail Crossing	No problem	Complex geometry. No gates at rail crossing.	Passive safety devices at rail crossing	Only passive warning devices at rail crossing	Not stated	No problem	Not a problem	No problem	Not stated
Intersection	Not a problem	Complex roundabout Difficult for truck to navigates	No signs	Intersection located near to the gate and rail closing.	Not a problem	Tight turning radii. No turning lanes.	Turning radii problem	Not stated	Complex geometry, difficult to navigate. Tight radii.
Traffic Operational	Low volume, closed to maritime	Delays at rail crossing.	Low traffic volume & Low congestion	Delays during peak hours.	Not a problem	Delays at intersection	Congestion due to dense surroundings	Congestion problem	Delays at intersection
Remarks	Good	roundabout under construction	fair	The connector is extremely short.	Poor road surface condition with severe deterioration	5-ton weight restriction. Complex geometry	Dense surrounding limit roadway and shoulders	Serve both freights & passenger	Serves freights

2.6. Safety and Operational of Intermodal Freight Connectors

To evaluate FICs, data such as traffic characteristics (volume, speed and travel time), traffic crashes, and roadway geometry are needed. The process commonly starts by reviewing available roadway data, aerial photographs and field inventory on physical conditions of the connectors related to traffic operation and safety. The evaluation may also involve review of relevant data stored in databases maintained by the state's department of transportations. Stakeholder interviews are another way of obtaining necessary information and details for specific connectors [13]. In his research titled "Using Truck GPS Data for Freight Performance Analysis in the Twin Cities Area" [14], Chen-Fu highlighted various tools and methods for traffic data collection including data from various databases monitored by state DOTs, FHWA, USDOT, and American Transportation Research Institute (ATRI). The ATRI is incorporated with FHWA and the trucking industry to continuously collect GPS data on key national corridors. Traffic data can also be obtained from NPMRDS (National Performance Management Research Data Set) that includes probe vehicle-based travel time data (for both passenger and freight vehicles) on all National Highway System (NHS) facilities. The study highlights that "Intelligent Transportation Systems" can be utilized for data collection whereby automated devices that continuously record traffic operations are used. These include Weigh in Motion (WIM) sensors and Automatic Traffic Recorders (ATRs) installed along desired roadway segments that records individual vehicle data such as number of axles, speed, vehicle class, and weight [14]. In its report to the Congress, USDOT pointed out the following issues associated with intermodal freight connectors: inadequate shoulder width or strength to facilitate parking of trucks while waiting to enter the terminal or during breakdown and tight turning radii that make it difficult for trucks to negotiate an intersection. Other issues pointed out include inadequate travel lane width to accommodate trucks that causes operational problems and safety concerns for adjacent land users. Overall the study found intermodal freight connectors to be in poor condition when compared with both non-interstate highways and interstates highways [5]. Florida Department of Transportation (FDOT) conducted a study, "Strategic Intermodal System Connectors Technical Analysis of Issue and Opportunities", that used Synchro-Pro software for the intersection capacity analysis, based on lane configuration, traffic volume and signal phasing. The study found some turning movements and overall intersections were operating under non-desirable level of service grades (E & F), then suggested improvements alternatives such as lane configurations, increasing cycle lengths and changing the minimum splits. Other suggestions included access improvements, improving the capacity of connectors through additional general purpose lanes, turning lanes, pavement conditions and/or drainages [15].

2.7. Freight Transport Emissions

Statistics from International Energy Agency (IEA) show that the freight transportation sector is the largest and fastest growing sector of oil consumption which contributes to greenhouse gas emissions [16]. The transportation sector in the US uses 27% of energy nationally and is a major contributor to air pollution. Mobile sources (highway and non-road vehicles) are responsible for emitting different pollutants and air toxics such as Unburned Hydrocarbons (UHCs), Volatile Organic Compounds (VOCs), Carbon Monoxide (CO), and particulate matters (PM) [17]. Efforts in estimating the emissions from vehicles have become a moving research area due to the catastrophic effects of emissions to the environment such as global warming and extreme weather which harm the ecosystem and human security. Different methods have been proposed to be used in emissions estimations that range from macroscopic to integration methods, where traffic simulation models approximate emissions. Recently there has been a rapid evolution of microscopic models for estimating vehicle emissions based on second-by-second activities. Transportation agencies and researchers have a long history of implementing techniques to calculate transportation-related emissions. Traditional methods for creating emission inventories utilize annual average estimates [18]. Simulation programs that have been widely used for emission estimations, examples of which are shown in Table 2.4. In traditional studies linking traffic microsimulation with emissions models, second-by-second speed and acceleration data are used to calculate vehicle emissions. The traffic simulation models are generally developed to represent traffic flows, then validated and calibrated by flow parameters such as headway, speed and queue length [19]. Recently intensive research efforts for vehicle emissions models came with a parameter for fuel consumption and emission estimation known as Vehicle Specific Power (VSP). The VSP parameter has become effective due to its direct physical interpretation and strong statistical relationship with vehicle emissions. To evaluate transportation effects from the emission impacts, two ways are commonly used: 1) estimating the speeds from transportation or traffic models and 2) converting average speeds into emission estimates based on environmental models such as MOBILE [20].

Table 2.4: Microsimulation Software and Emission Models

Micro simulation software	Emission Software
AIMSUN	VERSIT+MICRO
INTEGRATION	VT-MICRO
PARAMICS	CMEM
VISSIM	VERSIT
TRANSIMS	PHEM
CORSIM	MOVES
SYCHRO/SIMTRAFFIC	VeTESS
	TREMOVE
	COPERT(EEA)
	ModEM

Vehicle emissions are classified into two categories; exhaust emissions and evaporative emissions. Exhaust emissions are non-combustible gaseous waste products that are produced during the engine combustion process. These emissions are further categorized into sub categories such as start-up emissions and running emissions. The start-up emissions are caused when a catalytic convertor is not hot enough to be fully effective, and the air/fuel mixture needs to be fuel-rich to ensure the engine will start [17]. Hot emissions are produced from the exhaust when a vehicle's engine and emission control system are at their full operational temperatures, while cold start emissions are produced when the temperatures of the engine and emission control systems are between ambient temperature and their full operational temperature [21]. Evaporative emissions are mainly due to the presence of Volatile Organic Compounds (VOCs) that escapes from a fuel system and occur as a result of the diurnal variation in ambient temperature and the temperature changes of the vehicle fuel system during operating cycles. There are three ways in which evaporative emissions occur. Diurnal evaporation is caused by an increase in ambient air temperature which vaporizes fuel inside the vehicle tanks, regardless of whether they are running out or not. Running losses are a result of the vehicle engine vaporizing fuel [17]. Hot soak emissions are gaseous vapors generated immediately following a shutdown of an engine due to vaporization of the fuel remaining in the carburetor float bowl as it is warmed by the residual heat of the engine [22].

Vehicle emission models play an important role in estimating the emissions to the environment interfering with the air quality. Different types of models have been developed depending on the mode of operation. Emission models can be classified into three categories: 1) Regression Based Models, 2) Load Based Models and 3) Emission Maps. Regression based models employ mathematical functions of instantaneous vehicle speed and acceleration as independent variables [23]. Regression models overcome limitations of emissions maps models such as sparseness and flexibility, but they have a disadvantage of lacking physical interpretation and also can overfit the calibration data as they typically use a large number of variables. Load models use a series of modules to simulate the physical phenomena that generate emission estimates. The primary variable of these models is the fuel consumption rate, which represents the engine power demand (or engine load). Emission maps are emission models that have matrices of average emission rates for various combinations of speeds and acceleration in the driving cycle used (acceleration, deceleration, idle, cruising etc.) [24].

2.8. Motor Vehicle Emission Simulator (MOVES)

The MOVES model was developed by the US Environmental Protection Agency (EPA). The software was designed to be used to estimate inventories and projection through 2050 the at the county level for road transport energy consumption and aims to provide a robust environment in which mobile source emissions may be accurately evaluated at micro, meso and macro scales for all vehicles and all pollutant species of interest [21]. The purpose of MOVES is to provide an accurate estimate of emissions from cars, trucks, and non-highway mobile sources under a wide range of user-defined conditions [25]. MOVES uses the second-by-second database of emission rates within which the individual bins (cells) are based on the calculated Vehicle Specific Power (VSP). VSP is the power demand placed on a vehicle when the vehicle operates in various modes and at various speeds [26]. In modeling project-level emissions in MOVES, vehicle trajectory data obtained from the simulation models are processed for input into the MOVES emission model. There are three ways it can be used to model the emissions on a facility: average speed, link schedule and operating mode distribution. For the average speed for project level analysis, MOVES uses default assumptions of vehicle activity patterns, defined by different combinations of vehicle activities (acceleration, deceleration, cruise, idle e.tc) depending on the speed [27]. Studies have combined MOVES and VISSIM emission outputs for further analysis and interpretation of the results through the following approaches [17]:

- Using the VISSIM micro simulation VSP trajectory data as a source of input for MOVES emission model. This approach has the potential to improve the quality of source activity input to MOVES project scale analysis, as well as making the process of generating activity input simpler for the user.
- Using the emissions and vehicle data contained in the MOVES default database to improve VISSIM microsimulation emission module input in order to more accurately represent the vehicle fleet operating in US.

2.9. Optimization of Freight Transportation

Utilizing available options for roadway corridors as possible intermodal connector alternatives has been explored by various researchers through optimization. The overall goal of the optimization has been profit maximization, cost minimization, travel time minimization and reduction of traffic accidents. Furthermore, other factors such as congestion and overall energy cost have also been incorporated into optimization and decision-making process. In one study [28], a GIS-based model was proposed highlighting the cost-distance effect of emissions, congestion and energy. The study model proposed an optimal route based on environmental and energy parameters and provided decision makers with tools for trade-offs across different modal combinations. Intermodal freight transport systems have also been mirrored through supply chain logistics optimization. One of the documented approaches in literature includes the use of mixed integer programming (MIP) where the decision variables are integerized. Arnab Bhattacharya [28] used MIP to make a decision on whether a proposed mode of freight transportation (with rail mode as a default) was the best suitable in terms of total cost of operation by comparing different modes. Additional literature shows factors that affect break-even distance in a freight transportation analysis can serve as a great tool to optimize freight transport. The break-even distance is defined as the distance at which the costs of intermodal transport equal the costs of truck-only transport [29]. Using Monte Carlo Simulation, Nam Seok Kim [30] found that pairing up and altering both geometric and cost factors had notable impact on break even distances, which provide shippers and intermodal operators insights into how to make investments and the right trade-offs.

2.10. FICs Operational and Demand Analysis

Over the years, the evaluation of the operational performance of highways has evolved; this has been as a result of the development and improvements of the Highway Capacity Manual (HCM), a guide for mobility analysis. The first HCM which was published in 1950 was a collaborative effort of the Transportation Research Board (TRB) and the Bureau of Public Roads, predecessor to the Federal Highway Administration. This introduced the concept of capacity as a measure of the ability of a road to accommodate traffic volume. In 1965, the HCM incorporated level of service to relate the quality of traffic service. In 2000, the Safety Evaluation of Freight Intermodal Connectors in Tennessee State had a substantial increase in the breadth and depth of the material as a result of research projects. New material on how to assess the operational performance of various types of roads was then introduced in 2010. The most recent HCM incorporates travel time reliability, HOV lane, work zone and alternative intersection operations [54]. Throughout its history, the HCM has given no special consideration to the operational analysis of freight intermodal connectors (FICs). Freight intermodal connectors are the last mile connection of the freight facility to the national highway system and are comprised of segments and intersections [55, 56]. There have been plenty of studies and research related to safety and operations along the freight routes and segments. For instance, Chimba et al [57] analyzed the safety aspect of truck-intensive corridors. These analyses were based on crash frequency and crash rates using statistical software to establish the collective causes of the crashes along FICs using related traffic and geometric properties. Different researchers have been developing the truck-specific operational performance measures for different purposes [58]. Overall literature shows that analysis of intermodal connectors have used different methodologies including statistical analysis as well as surveys, multi-modal analysis, interviewing key stakeholders and engineering judgment to draw conclusions *[57-60]*. Ko et al [61] developed a method to determine the LOS of trucks different from procedures in HCM. They established that truck LOS should be analyzed differently for different roadway functional classes. For two-lane roadways, the LOS was determined as the dependent of the percent time being followed, percent time following and travel lane. They consider shoulder width and pavement conditions to be factors influencing LOS. Ma et al [62] utilized GPS data from approximately 2500 trucks in Puget Sound, Washington, to develop an algorithm that allows a Google Map-based online system to calculate the precise position and distance traveled by the freight truck. Public agencies can use this algorithm to track routes of freight trucks and compute the travel time and reliability of different routes to give insights in their investment decisions. In Illinois, Hafeez et al *[63]* performed a study to determine the performance of truck-rail intermodal connectors using data from National Performance Management Research Dataset (NPMRDS), National Highway Planning Network and Illinois DOT using Postegre SQL and Post GIS extensions to analyze the impacts of AADT, functional class, number of lanes, length and speed limits.

3. DATA GATHERING

3.1. Crash, Traffic and Geometry Data

Most of the study data were gathered through the review of crash data, traffic characteristics and roadway geometry data, mainly from the Tennessee Roadway Information Management System (eTRIMS) database and traffic history open website [31] both maintained by Tennessee Department of Transportation (TDOT). Other connector-related information was gathered through site visits and review. Initially, a list of Tennessee's intermodal freight connectors was obtained from Federal Highway Administration (FHWA) website [2]. The state of Tennessee has five intermodal facilities and terminals comprised of 23 intermodal connectors in five counties, Table 3.1. However, one connector to Greyhound Bus Terminals in Memphis was not verified during a site visit, hence was dropped, leaving 22 verifiable connectors for analysis (Table 3.1). It should be noted that some of these 22 verified connectors are connected by multiple short roadway segments with varying lengths, traffic characteristics and cross-sectional geometric features. The AADT along the connected segment connectors was therefore taken as the average while the number of crashes and segment lengths were summed. As shown in Table 3.1, most of the connectors are in Shelby County (Memphis area) and Hamilton County (Chattanooga area) which has 10 and 7 connectors respectively. Additional information such as surrounding land uses, and roadway geometrics were gathered through eTRIMS and Google Earth.

Table 3.1: Number of Connectors by County

County	Connector to/from					Total
	Airport	Truck/Pipeline Terminal	Truck/Rail Facility	Intercity Bus Terminal	Port Terminal	
Shelby	2	0	7	0	1	10
Davidson	0	0	1	0	0	1
Knox	0	1	0	1	0	2
Sullivan	1	0	1	0	0	2
Hamilton	1	1	0	1	4	7
Total	**4**	**2**	**9**	**2**	**5**	**22**

Source: TDOT and FHWA [2]

3.2. Crash Data

Three years of crash data (2012-2014) along each of the connectors was downloaded from the eTRIMS database. Each crash is embedded with attributes such as county name, roadway ID, the roadway log mile where the crash occurred, injury severity (type of crash), total killed and injured, first harmful event, roadway location, pavement condition, manner of collision, year of crash, time of crash, lighting condition, weather condition, relation to junction, and urban or rural classification among others. The attributes such as log mile, county and roadway ID were used to merge each crash with information such as traffic volume and roadway geometry.

3.3. Traffic Characteristics and Geometric Data

The average annual daily traffic over three years (2012 to 2014) was gathered through eTRIMS and TDOT traffic history website [31]. Initially, the 2015 traffic data was downloaded from the eTRIMS database, and then the same AADT stations were used to download corresponding volumes for 2012-2014 on the same stations. Some of the connectors do not have AADT stations; hence the most nearby AADT stations were used. Included in the traffic data are AADT, percentage of passenger cars and trucks (single and multi-units), peak hour volume percentage, and directional splits. Geometric data for each connector was also downloaded from the eTRIMS database that provide information such as terrain, land use, number of lanes, travel way width, posted speed limit, illumination, access control class, one-way or two-way street information, and roadside features (shoulder width, drainage composition etc.). Maintenance features in eTRIMS provided median type and width, among others, for each connector. Other downloaded data included elevations, the vertical alignment that provided longitudinal grades while horizontal alignment data provided the degree of the horizontal curve. Google Earth was used for the verification of the eTRIMS downloaded geometric data as well as for gathering the information not found in eTRIMS.

3.4. Field Visit and Review

Initial field visits and review of the identified FICs were conducted between December and February 2017. The field review aimed at seeking input regarding the study's focus and specific areas of concern related to these FICs. The field review included windshield survey of the facilities looking for obvious signs of deficiencies like tire marks on curbs, indications of storage length queue being exceeded, and delay at intersections. The initial visits identified the locations and possible intersections for data traffic collection. Conditions of the connectors in relation to geometric and physical features, railroad crossing, and pavement condition were also evaluated during field review.

4.0. SAFETY ANALYSIS

4.1. Safety Analysis Overview

Safety analysis was conducted to identify related deficiencies along the connectors. The 2012 to 2104 crash data was obtained from the TDOT eTRIMS database. The number of crashes for all roadway segments tabulated is shown in Table 4.1 with the highest number of crashes being along Jackson Ave (SR-14) in

Memphis. Jackson Ave and Chelsea Ave roadway segments connect Lee Wood Yards a truck/rail facility from I-40. The second and third connector segments with highest number of crashes are also from facilities in Memphis, which are Democrat Rd and Shelby Dr respectively. However, E. Magnolia Ave segment in Knoxville has the highest number of fatal and incapacitating injury crashes combined.

4.2. Ranking Connector Segment by Actual Crash Rates

As the connectors vary in length and average annual daily traffic (AADT), crash rate per million vehicle miles of travel (MVMT) is used to compare and rank the connectors as shown in equation 4.1:

$$\text{Annual Crash Rate} = \frac{\text{Five Years Number of Crashes} * 1{,}000{,}000}{365 * \text{AADT} * \text{Connector Length (miles)} * \text{Five Years}} \qquad 4.1$$

The annual crash rates were calculated for total crashes including Property Damage Only (PDO) and for fatal and injury crashes combined (Table 4.2, Figure 4.1 and Figure 4.2). Table 4.2 summarizes and ranks the connector's segments based on the crash rates. Table 4.2 provides crash rates based on whether they are ramp-related or non-ramp-related. In some connectors, high crash frequency has been attributed mainly by off ramp or on-ramp crashes. The connectors with the highest ramp-related crash rates are Amory Ave (a rail facility in Nashville), Western Ave (a pipeline facility in Knox), Jersey Pike (a pipeline facility in Hamilton), Manufactures Rd (a Port facility in Hamilton), and Mclemore Ave (a Port facility in Shelby). Considering total crash rate, Armory Ave, which is a 0.17-mile segment located in Davidson County, has the highest crash rate of 16.44/MVMT followed by Western Ave, a 0.174 mile segment of NHS Pipeline connector in Knox County, with a crash rate of 14.32/MVMT. Several segments did not experience any crashes for the analysis period including Hall of Fame Dr in Knox, Pier St in Shelby and Hudson Rd, River St and West 19th St in Chattanooga. Figure 4.1 and Figure 4.2 graphically ranks the connectors by crash rates based on total crashes and fatal and injury crashes respectively.

Table 4.1: Ranking the Segment by Number of Crashes

Connector Segment	Length	AADT	Fatal	Incap.	Non Incap	PDO	Total Crashes
Jackson Ave-Rail-Shelby	1.55	24343	0	2	83	179	264
Democrat Rd-Airport-Shelby	2.45	14595	0	3	46	143	192
Shelby Dr-Rail-Shelby	0.63	25365	1	1	33	130	165
Plough Blvd-Airport-Shelby	1.78	34315	1	0	34	116	151
East Parkway S -Airways Blvd-Rail-Shelby	0.7	21848	2	0	45	92	139
Western Ave-Pipeline-Knox	0.174	42871	0	1	12	104	117
E. Magnolia Ave-Intercity Bus terminal-Knox	1.532	11443	0	10	24	64	98
Tchulahoma-Airport-Shelby	0.63	20218	0	1	17	54	72
N. Cherry St-Intercity bus terminal-Knox	0.49	13984	0	3	12	45	60
Jersey Pike-Pipeline-Hamilton	0.59	11102	0	0	17	41	58
Middlebrook Pike-Pipeline-Knox	0.507	23665	1	2	10	42	55
Manufactures Rd-Port-Hamilton	0.15	12504	0	1	5	48	54
S. 3rd St-Rail-Shelby	0.53	27448	0	1	16	36	53
Mallory Ave-Rail-Shelby	1.13	6747	0	1	17	30	48
Sidco Dr (4161) -Rail-Davidson	0.92	10707	0	1	11	34	46
Airways Blvd	0.24	49655	1	0	10	30	41
Chelsea Ave-Rail-Shelby	1.31	5600	0	0	18	23	41
Shepherd Rd-Airport-Hamilton	0.73	12352	0	1	6	28	38
Airport Access Rd-Airport-Sullivan	2.44	8450	1	2	10	24	37
Airport Rd-Hamilton	0.86	5314	0	1	7	27	35
Harbor Ave-Port-Shelby	2.856	7861	0	1	11	23	35
Ed Shouse Dr -Pipeline-Knox	0.53	22954	0	1	3	25	29
Armory Ave(4162)-Rail-Davidson	0.17	7191	0	0	4	18	22
Jack Carley Causeway-Port-Shelby	1.08	12941	0	3	7	12	22
Channel Ave-Port-Shelby	3.02	4865	0	0	5	14	19
Riverport Rd-Rail-Shelby	1.03	8514	0	0	4	14	18
Southern Ave-Rail-Shelby	0.92	8410	0	1	1	14	16
Armory Ave (4888)-Rail-Davidson	0.34	17955	0	0	3	12	15
Winchester Rd.	0.36	25574	0	0	4	11	15
Mclemore Ave-Port-Shelby	0.11	12941	0	0	1	8	9
Pineville Rd-Port-Hamilton	0.99	3621	0	1	1	6	8
Riverside Blvd-Port-Shelby	0.049	12941	0	0	0	8	8
Spottswood Ave-South Pkwy E - Rail-Shelby	0.37	4825	0	1	2	5	8
Lincoln St-Rail-Sullivan	0.9	9022	0	0	1	5	6
Moccasin bend Rd-Port-Hamilton	0.4	1881	0	1	0	3	6
New horn lake Rd-Florida St-Rail-Shelby	0.41	4288	0	0	0	6	6
Sidco Dr (4889) -Rail-Davidson	0.57	9232	0	0	1	5	6
Hamm Rd-Port-Hamilton	0.76	3917	0	0	0	5	5
Randy Tyree St-Pipeline-Knox	0.117	22954	0	0	0	3	3
S. Hall of Fame Dr-Intercity Bus Terminal-Knox	0.085	14151	0	0	0	2	2
Old Magnolia Ave-Intercity bus terminal-Knox	0.243	1742	0	0	0	1	1
Hall of Fame Dr-Intercity bus terminal-Knox	0.002	14151	0	0	0	0	0
Hudson Rd-Port-Hamilton	0.711	3621	0	0	0	0	0
Pier St-port-Shelby	0.2	4865	0	0	0	0	0
River St-Port-Hamilton	0.192	8537	0	0	0	0	0
West 19th St-Port-Hamilton	0.316	6665	0	0	0	0	0

Table 4.2: Ranking the Segment by Actual Crash Rates per MVMT

Connector Segment	**Fatal & Injury crash rate**	**Total crash rate**	**Total Crash rate (No Ramp Related)**	**Total Crash rate (Ramp Related Only)**
Armory Ave (4162)-Rail-Davidson	2.99	16.44	10.46	5.98
Western Ave-Pipeline-Knox	1.59	14.32	8.32	6
Riverside Blvd-Port-Shelby	0	11.52	11.52	0
Shelby Dr-Rail-Shelby	2	9.43	9.43	0
East Parkway S -Airways Blvd-Rail-Shelby	2.81	8.3	8.3	0
Jersey Pike-Pipeline-Hamilton	2.37	8.09	5.86	2.23
N. Cherry St-Intercity bus terminal-Knox	2	8	6	2
Moccasin bend Rd-Port-Hamilton	1.21	7.28	7.28	0
Airport-Hamilton	1.6	6.99	6.99	0
Jackson Ave-Rail-Shelby	2.06	6.39	6.27	0.12
Democrat Rd-Airport-Shelby	1.61	6.29	5.96	0.33
Manufactures Rd-Port-Hamilton	0.67	6.07	4.83	1.24
Mclemore Ave-Port-Shelby	0.64	5.77	3.85	1.92
Mallory Ave-Rail-Shelby	2.16	5.75	5.51	0.24
Tchulahoma-Airport-Shelby	1.29	5.16	5.16	0
E. magnolia Ave-Intercity bus terminal-Knox	1.77	5.11	5.11	0
Chelsea Ave-Rail-Shelby	2.24	5.1	5.1	0
Sidco Dr (4161) -Rail-Davidson	1.11	4.26	4.26	0
Middlebrook Pike-Pipeline-Knox	0.99	4.19	4.19	0
Spottswood Ave-South Pkwy E - Rail-Shelby	1.53	4.09	4.09	0
Shepherd Rd-Airport-Hamilton	0.85	3.6	2.46	1.14
S. 3rd St-Rail-Shelby	1.07	3.33	3.14	0.19
Airways Blvd	0.84	3.14	3.14	0
New horn lake Rd-Florida St-Rail-Shelby	0	3.12	3.12	0
Plough Blvd-Airport-Shelby	0.64	2.77	2.26	0.51
Armory Ave (4888) -Rail-Davidson	0.45	2.24	1.94	0.3
Ed Shouse Dr -Pipeline-Knox	0.3	2.18	2.18	0
Old Magnolia Ave-Intercity bus terminal-Knox	0	2.16	2.16	0
Pineville Rd-Port-Hamilton	0.51	2.04	2.04	0
Southern Ave-Rail-Shelby	0.24	1.89	1.89	0
Riverport Rd-Rail-Shelby	0.42	1.87	1.87	0
Airport Access Rd-Airport-Sullivan	0.58	1.64	1.46	0.18
Hamm Rd-Port-Hamilton	0	1.53	1.53	0
S. Hall of Fame Dr-Intercity Bus Terminal-Knox	0	1.52	1.52	0
Winchester Rd.	0.4	1.49	1.39	0.1
Jack Carley Causeway-Port-Shelby	0.65	1.44	1.44	0
Harbor Ave-Port-Shelby	0.49	1.42	1.42	0
Channel Ave-Port-Shelby	0.31	1.18	1.18	0
Sidco Dr (4889) -Rail-Davidson	0.17	1.04	1.04	0
Randy Tyree St-Pipeline-Knox	0	1.02	1.02	0
Lincoln St-Rail-Sullivan	0.11	0.67	0.67	0
Hall of Fame Dr-Intercity bus terminal-Knox	0	0	0	0
Hudson Rd-Port-Hamilton	0	0	0	0
Pier St-port-Shelby	0	0	0	0
River St-Port-Hamilton	0	0	0	0
West 19th St-Port-Hamilton	0	0	0	0

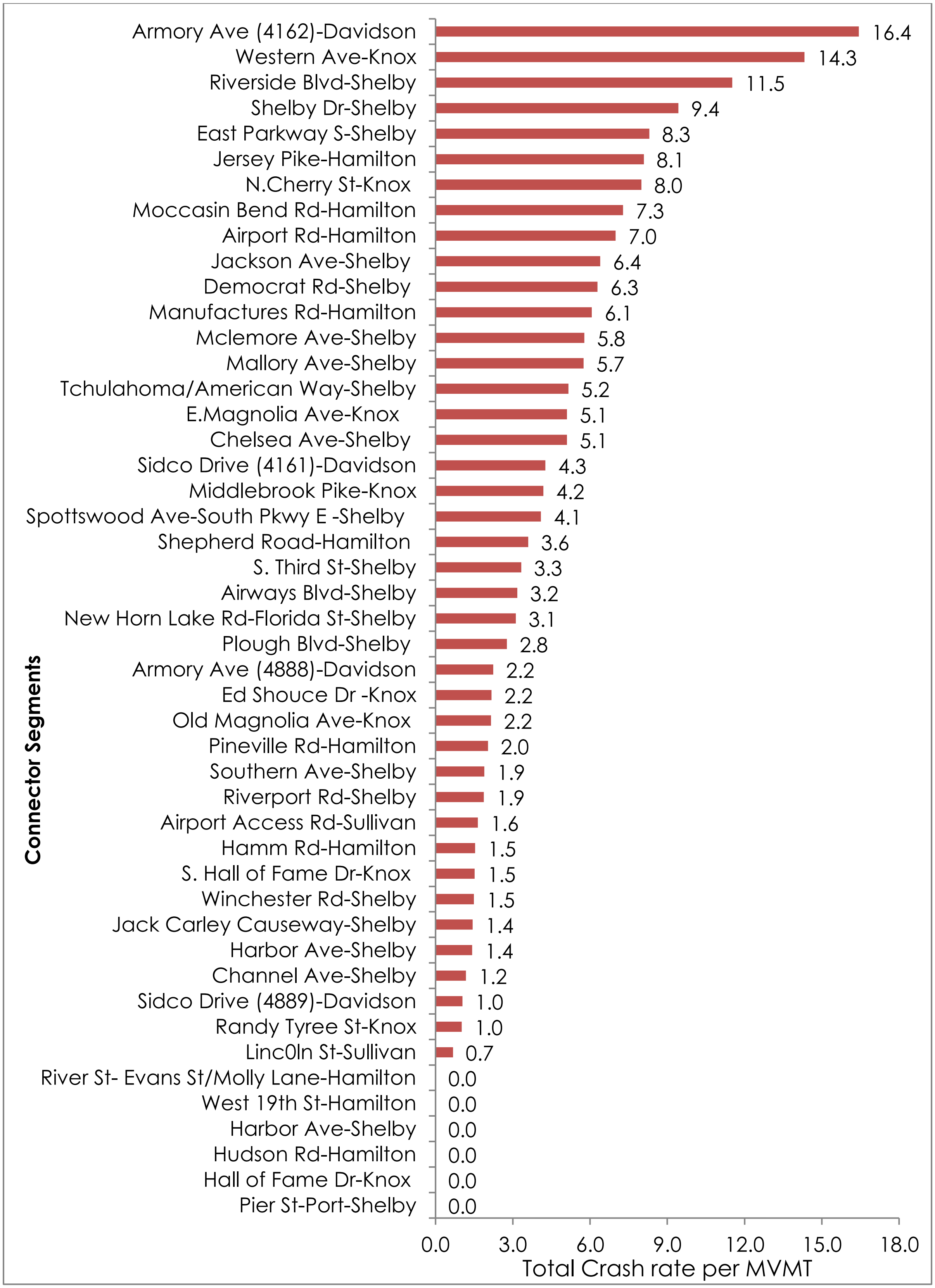


Figure 4.1: Ranking Connector Segments by Total Crash Rates

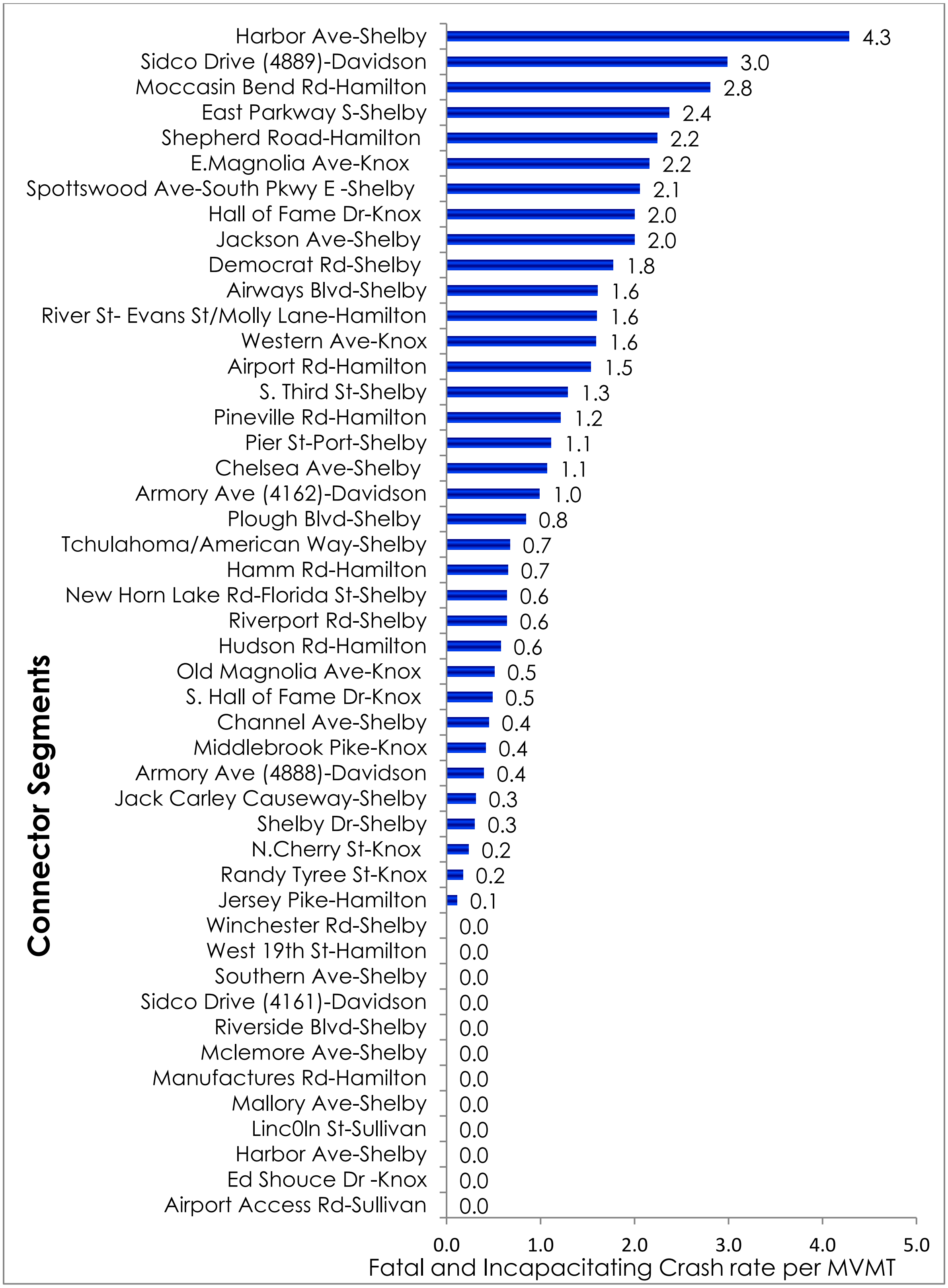


Figure 4.2: Ranking Connector Segments by Fatal and Injury Crash Rates

4.3. Ranking Connector Segment by Critical Crash rate

The critical crash rate criteria are detailed in the Highway Safety Manual (2010 HSM) Chapter 4 section 4.4.2.5. The critical rate method utilizes a statistical test to determine whether the accident rate at a connector segment is significantly higher than TDOT provided average rate for similar type of functional class segment, Table 4.3.

Table 4.3: TDOT State-wide Local Road Segment Crash Rates

Tennessee Department of Transportation										
Statewide Average Crash Rates for Sections and Spots										
Study: 2012 - 2014 HSIP LIST										
Begin Date: 1/1/2012 End Date: 12/31/2014										
Route Type	Rural / Urban	Location Type	Highway Type	Fatal Rate	Incap. Rate	Other Inj. Rate	Pd. Rate	Total Rate	Severe Crash Rate	VMT
FUNCT.	Urban	Section	2 OR 3 LN	0.014	0.102	0.770	2.608	3.493	0.116	13,315
FUNCT.	Urban	Section	2 OR 3 LN W/TL	0.004	0.062	0.624	2.426	3.115	0.066	1,515
FUNCT.	Urban	Section	4 OR MORE UNDIV	0.013	0.075	0.873	3.049	4.010	0.087	2,648
FUNCT.	Urban	Section	4 OR MORE DIV	0.008	0.047	0.563	2.298	2.916	0.055	3,421
FUNCT.	Urban	Section	4 OR MORE W TL	0.013	0.066	0.676	2.452	3.206	0.078	4,441
FUNCT.	Urban	Section	FREEWAY	0.008	0.039	0.523	2.047	2.616	0.047	386

Critical crash rates were calculated using 95% confidence level (i.e. 1.96 constant). The critical crash rate is a threshold value that allows for a relative comparison among segments with similar characteristics. Segments that exceed their respective critical rate can be identified.

$$\textbf{CRITICAL CRASH RATE} = \text{TDOT Average Rate} + 1.96\sqrt{\frac{\text{TDOT Statewide Average Rate}}{(\text{MVMT})}} + \frac{0.5}{\text{MVMT}}$$

$$\text{Where MVMT} = \frac{365 * \text{AADT} * \text{Length} * 3}{1000000}$$

Then connector segments whose actual crash rates exceeded critical crash rate were determined. Fifteen connector segments were found to exceed critical total crash rate and eleven connector segments exceeded critical fatal and injury crash rate. Only one connector's segment (E. Magnolia Avenue) in Knox County exceeded critical fatal and incapacitating crash rate. Table 4.4 and Table 4.5 provides a summary of connector segments that exceeded critical crash rate. Figure 4.3 compares graphically the magnitude of variation between the actual crash rate and critical crash rate for each of the connector segments.

Table 4.4: Connector Segments Exceeding Critical Total Crash rate

Connector Segment	Actual Total Crash Rate	Critical Total Crash Rate
Armory Ave (4162)-Davidson	16.44	6.18
Western Ave-Knox	14.32	4.15
Riverside Blvd-Shelby	11.52	8.61
Shelby Dr-Shelby	9.43	4.07
East Parkway S -Shelby	8.30	4.09
Jersey Pike-Hamilton	8.09	4.93
N. Cherry St-Knox	8.00	4.20
Airport Rd-Hamilton	6.99	4.76
Jackson Ave-Shelby	6.39	3.76
Democrat Rd-Shelby	6.29	3.86
Manufactures Rd-Hamilton	6.07	4.09
Mallory Ave-Shelby	5.75	4.37
Tchulahoma/American Way-Shelby	5.16	4.18
E. Magnolia Ave-Knox	5.11	4.03
Middlebrook Pike-Knox	4.19	3.88

Table 4.5: Connector Segments Exceeding Critical Fatal& Injury Crash rate

Connector Segment	Actual Fatal and Injury Crash Rate	Critical Fatal and Injury Crash Rate
Armory Ave (4162)-Davidson	2.99	2.32
East Parkway S -Shelby	2.81	1.20
Jersey Pike-Hamilton	2.37	1.64
Chelsea Ave-Shelby	2.24	1.70
Mallory Ave-Shelby	2.16	1.31
Jackson Ave-Shelby	2.06	1.03
Shelby Dr-Shelby	2.00	1.19
N. Cherry St-Knox	2.00	1.25
E. Magnolia Ave-Knox	1.77	1.17
Democrat Rd-Shelby	1.61	1.08
Airport Rd-Hamilton	1.60	1.52
Western Ave-Knox	1.59	1.22

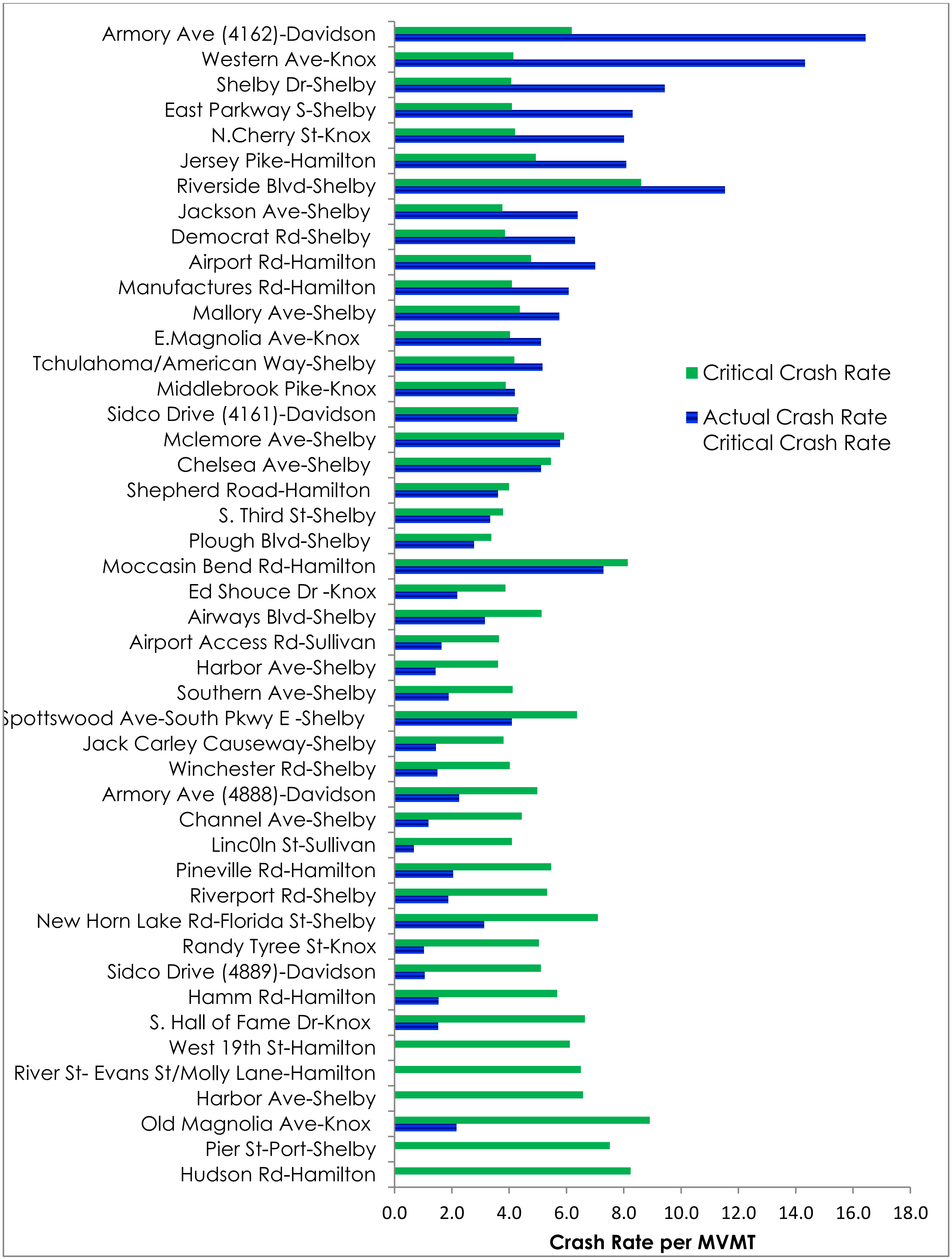


Figure 4.3: Actual vs Critical Total Crash Rates per Connector Segments

4.4. Crash Rates on Airport Connectors

Crash rates along the airport connectors are shown in Figure 4.4. The 2.53-mile connector to Memphis International Airport through American Way and Democrat Rd segments has the highest total crash rate as well as fatal and injury crash rate followed by the 0.78 mile Shepherd Rd connector to Chattanooga Metropolitan Airport.

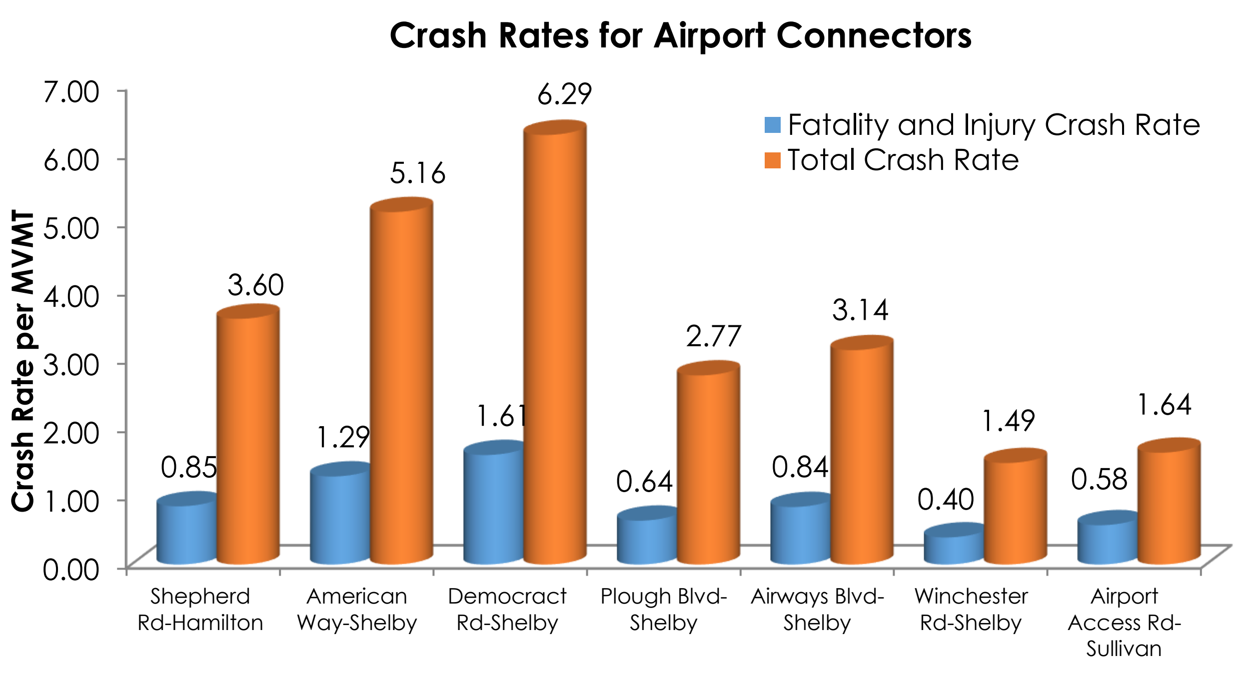


Figure 4.4: Crash Rates on Airport Connectors

4.5. Crash Rates on Intercity Bus Terminal Connectors

Crash rates were also analyzed on the two intercity bus terminals in Chattanooga and Knoxville. The connectors for Nashville and Memphis bus terminals were not verified; hence, it was removed from analysis. Comparing Chattanooga and Knoxville connectors, the 2.35-mile North Cherry St connector segments to Greyhound Bus Terminal in Knoxville has the highest crash rate followed closely by a 0.89 mile connector along Airport Rd to Chattanooga Bus Terminal, shown in Figure 4.5.

4.6. Crash Rates on Truck/Pipeline Facility Connectors

Truck/Pipeline facility connectors in Chattanooga (Colonial Pipeline Facility) and Knoxville (Colonial & Plantation Pipeline Co) were analyzed. As shown in Figure 4.6, the 1.33-mile Western Ave connector segment to Colonial & Plantation Pipeline facility in Knoxville has the highest crash rate under this category with a crash rate of 14.32/MVMT followed by Jersey Pike in Chattanooga. The connector segment connecting Colonial Pipeline in Chattanooga is the highest in fatal and injury crash rate compared to that of the Knoxville facility.

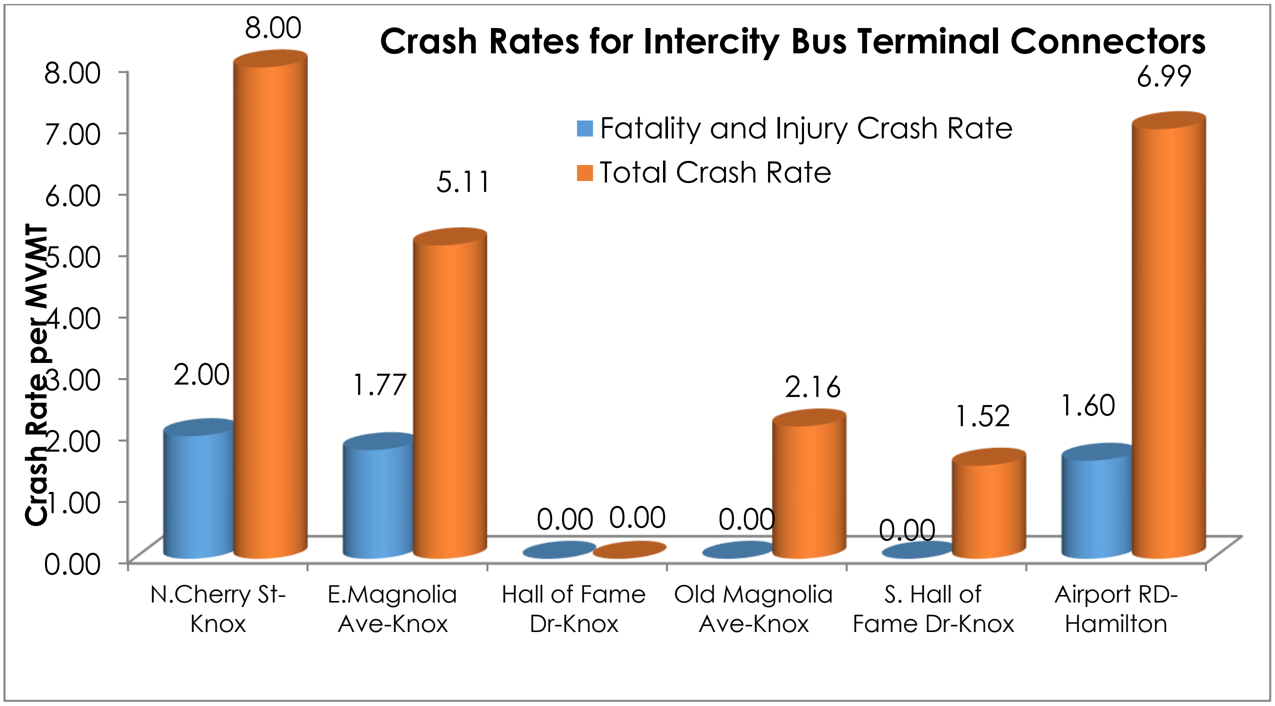


Figure 4.5: Crash Rates on Intercity Bus Terminal Connectors

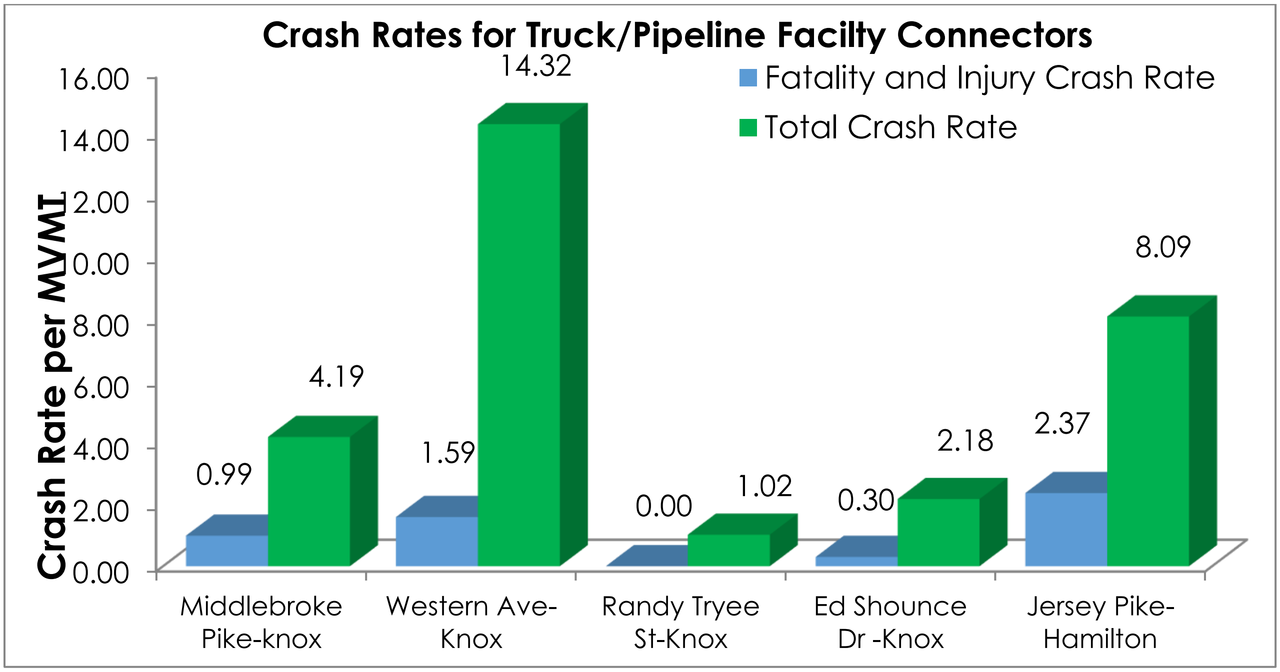


Figure 4.6: Crash Rates on Truck/Pipeline Connectors

4.7. Crash Rates on Port Terminal Connectors

Five Port Terminal connectors, four in Chattanooga and one in Memphis were analyzed. Riverside Blvd, a 0.049-mile connector segment to President's Island in Memphis, has the highest crash rate (11.52/MVMT) compared to others followed by a 0.4-mile connector to Mid-South Terminals, which has a 7.28/MVMT crash rate. Two connectors in Chattanooga (West 19th St and River St-Evans St) had zero crashes, shown in Figure 4.7.

4.8. Crash Rates on Truck/Rail Facility Connectors

There were nine Truck/Rail Facility connectors analyzed, seven in Memphis, and one in Nashville and one Sullivan County. As shown in Figure 4.8, the Amory Ave segment to the Radnor Yards facility in Nashville has the highest total crash rate (16.44/MVMT) among Truck/Rail facilities followed by a 0.63-mile Shelby Dr connector segment to Tennessee Yards-Memphis Burlingtonner (9.43/MVMT). The third highest connector segment under this category is the one leading to Forest Yards-Memphis Norfolk Southern with crash rate of 8.30/MVMT. Lincoln St Connector segment connecting to CSX Corporation in Sullivan has the lowest crash rate of 0.67/MVMT.

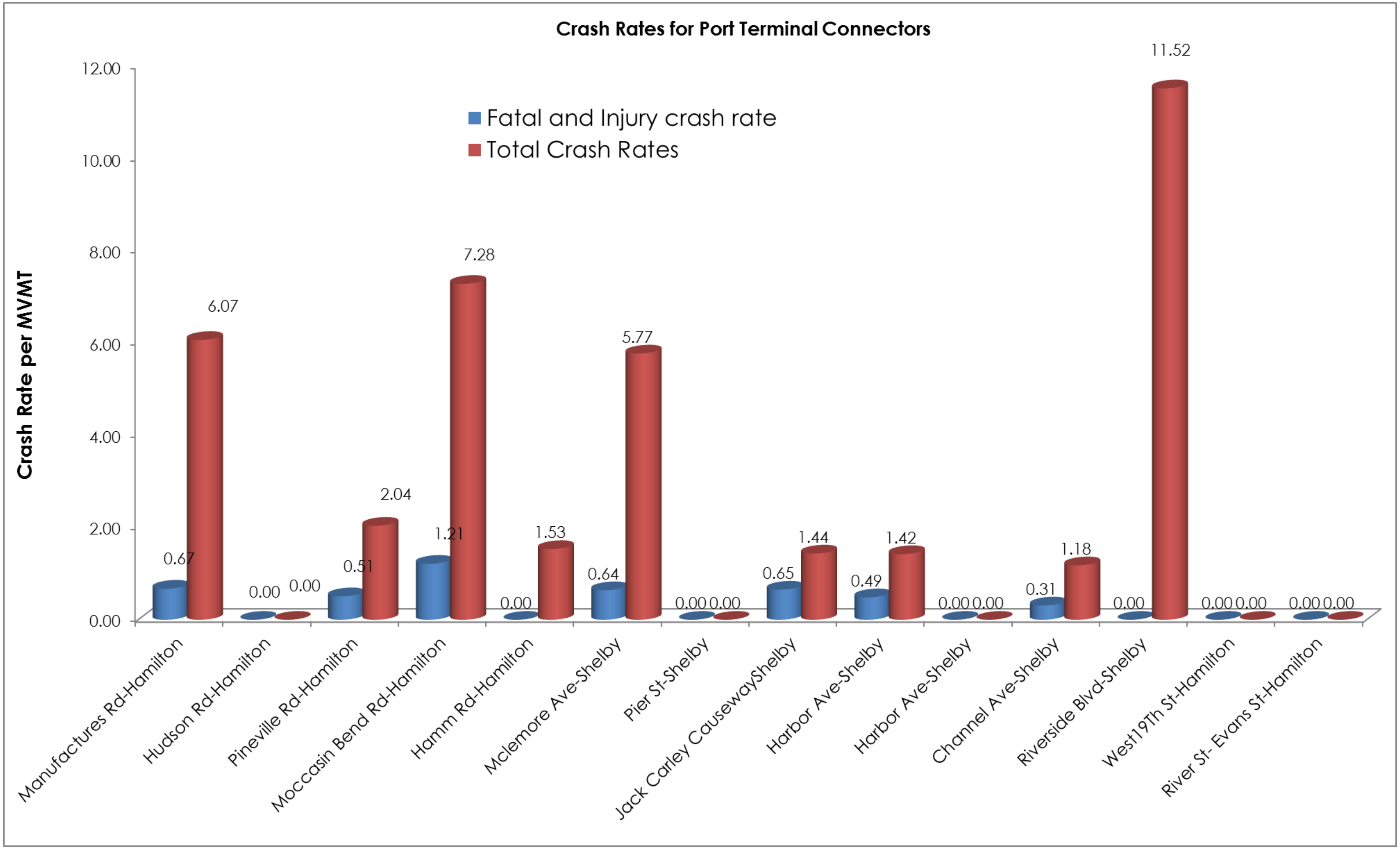


Figure 4.7: Crash Rates on Port Terminal Connectors

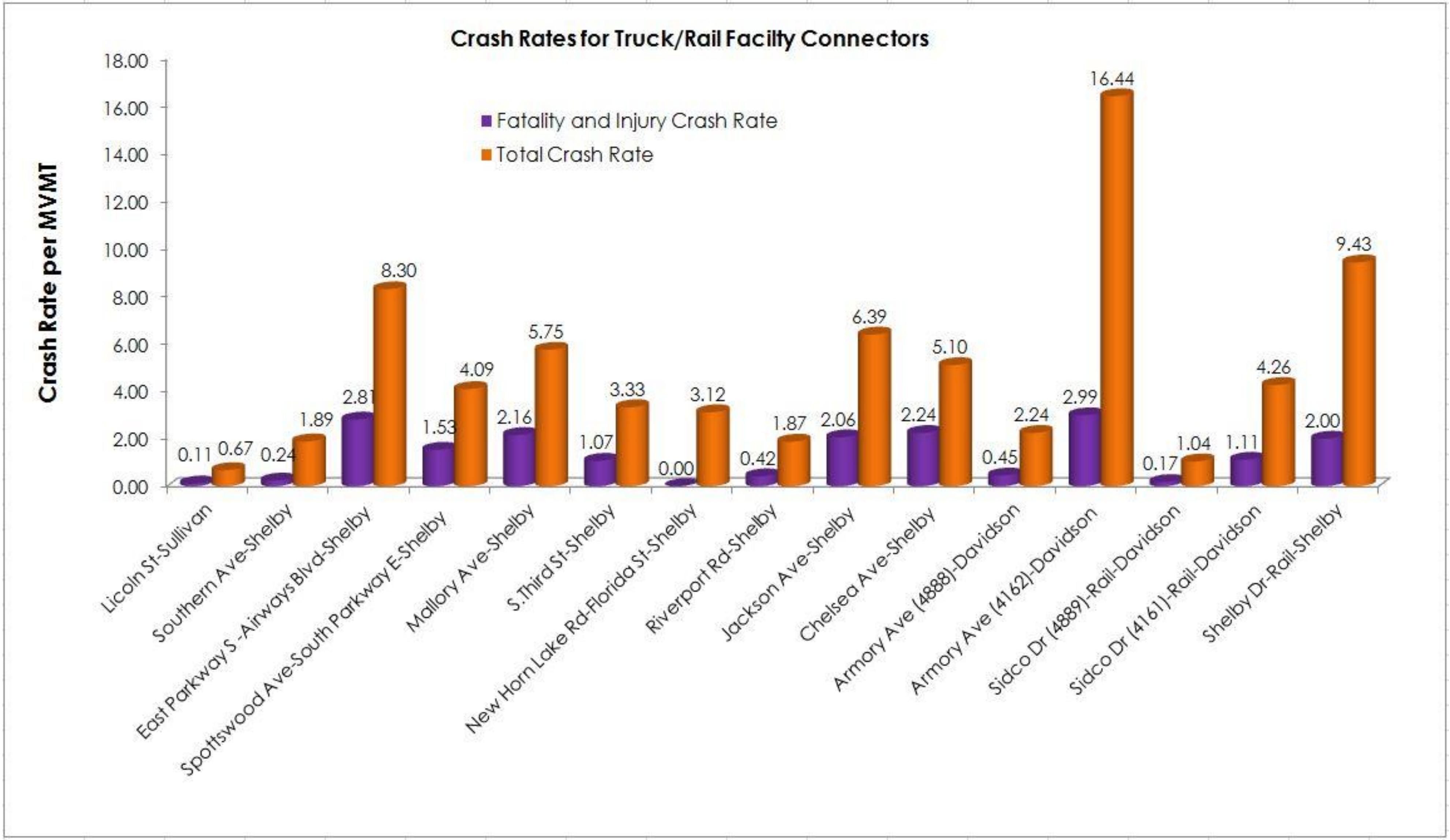


Figure 4.8: Crash Rates on Truck/Rail Connectors

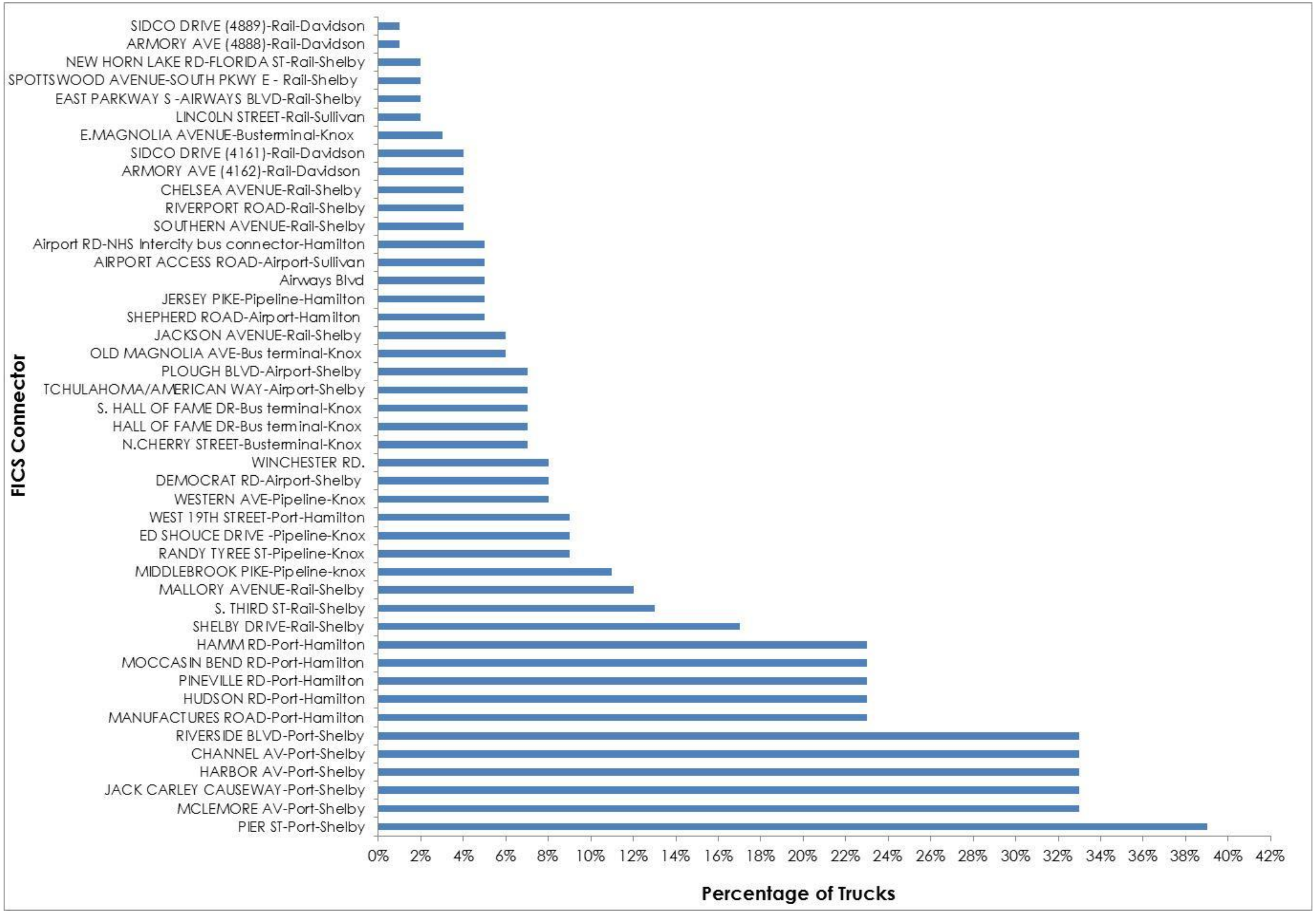


Figure 4.9: Percentage of trucks on different connectors

5.0. SAFETY RISK ANALYSIS

Although transportation provides huge value to people and business communities, risk is an inevitable part of transportation and has two dimensions: likelihood (or probability) and negative consequence. Figure 5.1 shows four different risk categories based on likelihood and consequence [32]. Operations managers need to treat different risk categories differently. The focus is always on risk events that have higher consequence and higher probability. Risk management includes risk identification, assessment, prioritization, planning, implementation, and risk control [33]. The first step is to identify possible risk events, then assess them on consequences and probabilities, prioritize these risk events, then develop risk management and mitigation strategies (including planning, implementation, and risk control) to lower both negative consequences and probabilities.

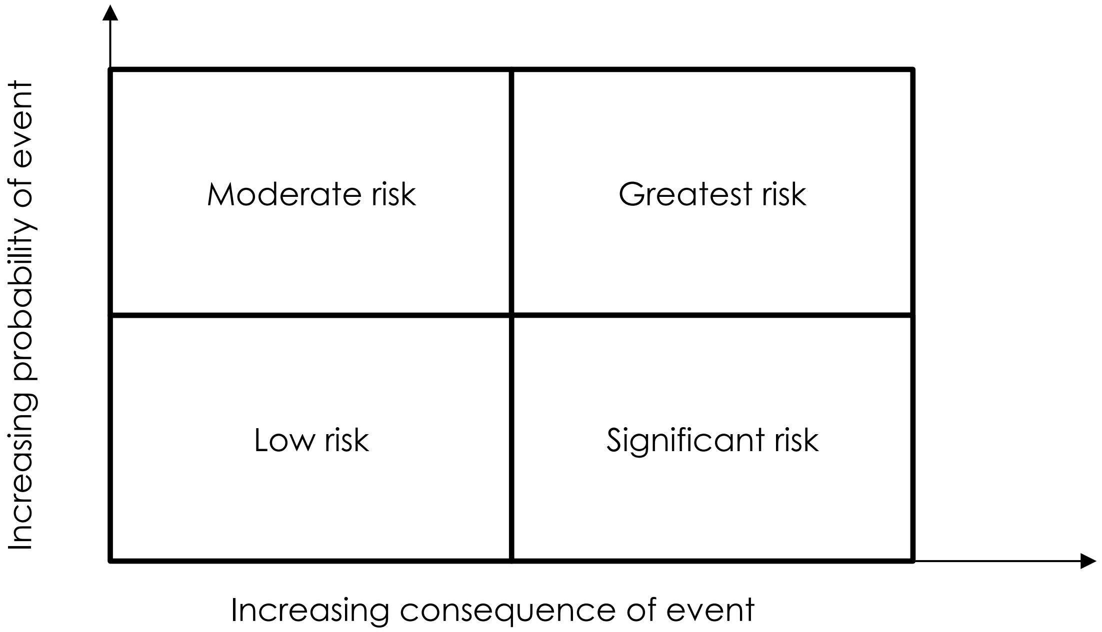


Figure 5.1: Universe of Risk [32]

5.1. Economic and societal impact of motor vehicle crashes

For FICs, motor vehicle crashes are the most important risk that has significant economic and societal impact. Every vehicle crash hurts the individual victims, their families, their employers, and the society in many perspectives. Economic costs typically include property damage (vehicle and transportation system), congestion, and emergency service, medical, legal, insurance, and lost productivity of workplace. Compared to economic impact, societal impact is more indirect and intangible, and obviously more difficult to measure and calculate. For example, how to estimate a person's suffering from broken bones? How about his/her family members' suffering? In order to aggregate these various intangible consequences, societal impact is estimated by dollar values. Most researchers agree that the value of fatal risk reduction falls in the range of $5 to $15 million per life saved [34].

5.2. Risk Cost Estimation

In order to aggregate the economic and societal impact together, a unit cost for each type of event was adopted [34]. "The cost components include productivity losses, property damage, medical costs, rehabilitation costs, congestion costs, legal and court costs, emergency services such as medical, police, and fire services, insurance administration costs, and the costs to employers" [34]. Values for more intangible consequences such as physical pain or lost quality-of-life are also examined in estimates of comprehensive costs, which include both economic cost components and quality-of-life valuations. In other words, comprehensive costs represent the value of the total societal harm that results from traffic crashes [34]. The basis for these estimates is the most recent guidance issued by the U.S. Department of Transportation for valuing risk reduction [34]. Table 5.1 shows the unit cost of crashes by severity as published by USDOT [34]. Unit costs are expressed on a per-person basis for all injury levels; PDO costs are expressed on a per-damaged-vehicle basis.

Table 5.1: Unit cost (consequence) per person/vehicle

Unit cost 2010 dollars police reported	**PDO Crashes**	**Non-Incap. Injury Crashes**	**Incap. Injury Crashes**	**Fatal Crashes**
Economic cost total	6,076	23,742	82,048	1,398,916
Comprehensive cost total	6,076	276,010	1,001,206	9,145,998
Ratio (Comprehensive/Economic)	1	11.63	12.20	6.54

The costs are applied to the frequencies of people killed, injured, number of vehicles damaged, number of crashes by injury severities (i.e., PDO crashes, non-incapacitating injury crashes, incapacitating injury crashes, and fatal crashes) summarized in Table 5.4 and Table 5.5. The reason for listing both Tables 5.4 and 5.5 is because the transportation literature has costs estimated on both the per-person/vehicle basis and the per-crash basis. Both estimates were used to triangulate data and findings. Consequential impacts increase exponentially from PDO crashes to non-incapacitating injury crashes, to incapacitating crashes, and finally to fatal crashes. Understandably, frequencies decrease dramatically as consequential impacts increase radically because of the personal risk on the part of drivers.

5.3. Highway Safety Manual Risk Costs

Another approach is to use cost estimates per crash, including human capital crash cost and comprehensive crash cost. "Human capital crash cost estimates include the monetary losses associated with medical care, emergency services, property damage, and lost productivity. Comprehensive crash costs include the human capital costs in addition to nonmonetary costs related to the reduction in the quality of life in order to capture a more accurate level of burden of injury" [35]. To be consistent in wording, this paper uses economic cost rather than human capital cost in the following sections. Table 5.2 shows its unit cost per crash [35].

Table 5.2: HSM Unit Crash Costs

Unit cost 2001 dollars	PDO (O)	Non-Incap. (Evident) Injury (B)	Incap. (Disabling) Injury (A)	Fatal (K)
Economic cost (Human capital)	6,400	41,900	111,400	1,245,600
Comprehensive cost	7,400	79,000	216,000	4,008,900
Ratio (Comprehensive/Economic)	1.16	1.89	1.94	3.22

5.4. Risk score

The next step is to sum the economic and societal impact together. A risk score is adopted from the literature [32]:

$$\boldsymbol{Risk\ score} = (\boldsymbol{Probability\ of\ the\ occurrence\ of\ an\ event}) * (\boldsymbol{Consequence\ of\ an\ event})$$

The total risk is calculated for each connector:

$$\text{Total risk} = \sum_i p_i c_i$$

Where p_i is frequencies of event *i*, c_i is either economic or comprehensive cost (i.e., consequence) of event *i*, and *i* can be 1 (PDO), 2 (non-incapacitating), 3 (incapacitating), and 4 (fatal). Total risk represents the complete importance of each connector, regardless of how long the connector is and how much traffic is on the connector. When a connector is longer and has more traffic, the crashes are more likely to happen. A normalized measurement is used for each vehicle mile traveled. So, a normalized total risk is calculated as follows:

$$\text{Normalized total risk} = \frac{\sum_i p_i c_i}{365 * AADT * Length * 3}$$

Where each year is 365 days with 3 years, *Length* is the length of a connector, and AADT is the average AADT from 2012 to 2014. The normalized total risk is the economic (or comprehensive) cost per vehicle mile traveled. Note that normalized risk is comparable to trucking operational cost, which is shown in Table 5.3 for years 2008 – 2015 [36].

Table 5.3: Average marginal costs per mile, 2008-2015

Motor Carrier Costs	2008	2009	2010	2011	2012	2013	2014	2015	Average
Vehicle-based									
Fuel Costs	0.633	0.405	0.486	0.590	0.641	0.645	0.583	0.403	0.548
Truck/Trailer Lease or Purchase Payments	0.213	0.257	0.184	0.189	0.174	0.163	0.215	0.230	0.203
Repair & Maintenance	0.103	0.123	0.124	0.152	0.138	0.148	0.158	0.156	0.138
Truck Insurance Premiums	0.055	0.054	0.059	0.067	0.063	0.064	0.071	0.092	0.066
Permits and Licenses	0.016	0.029	0.040	0.038	0.022	0.026	0.019	0.019	0.026
Tires	0.030	0.029	0.035	0.042	0.044	0.041	0.044	0.043	0.039
Tolls	0.024	0.024	0.012	0.017	0.019	0.019	0.023	0.020	0.020
Driver-based									
Driver Wages	0.435	0.403	0.446	0.460	0.417	0.440	0.462	0.499	0.445
Driver Benefits	0.144	0.128	0.162	0.151	0.116	0.129	0.129	0.131	0.136
Total	1.653	1.451	1.548	1.706	1.633	1.676	1.703	1.593	1.620

5.4.1. Risk score results

Table 5.6 and Table 5.7 show the details of economic cost for each connector segment on the per person/vehicle basis. Total economic risk for a connector segment can be significant with an average of \$1.14 million, ranging from 0 to \$6.46 million. A closer look shows two key observations: (1) PDO occurs much more regularly with much smaller impact than other risks; and (2) total risk varies dramatically even for the same type of connectors and for same location connectors. 3,863 vehicles were damaged, while non-incapacitating injuries occurred 694 times, incapacitating injuries took place 46 times, and 7 people were killed. As in the unit cost, Table 5.1 shows each PDO crash on average costs \$6,076 for both economic cost and comprehensive cost, while the other extreme of fatal crash on average costs \$1.40 million for economic cost and \$9.15 million for comprehensive cost per person. For the same type of connectors and for the connectors in the same location (i.e., same county), total risk can be quite different. Using the type of truck/rail as an example, the total risk for economic cost can vary from \$0.23 million for Spottswood Avenue-South PKWY E - rail-Shelby County (Segment ID 10) to \$6.1 million for East Parkway S -Airways BLVD-Rail-Shelby (Segment ID 9); both connectors are in Shelby County.

After factoring the length of each connector and AADT, this second key observation holds. Table 5.7 shows details per number of crashes by severity as a base. There are the same key observations as in Table 5.6. For the same type of connectors and for the connectors in the same area, total risk can be quite different. Using the type of truck/rail as an example, the total risk for economic cost can vary from $0.23 million for Spottswood Avenue-South PKWY E - rail-Shelby County (Segment ID 10) to $5.0 million for East Parkway S -Airways BLVD-Rail-Shelby (Segment ID 9). Normalized economic risk per vehicle mile traveled is on average $0.073, ranging from 0 to $0.30. For comprehensive cost in parentheses, total risk for a connector segment is significant: total comprehensive cost is on average $1.83 million ranging from 0 to $12.3 million. Comprehensive risk per vehicle mile traveled is on average $0.14, ranging from 0 to $0.73.

The last column of normalized risk shows economic cost for one unit of transportation value – per vehicle per mile. This is a cost-benefit ratio. Normalized economic risk per vehicle mile traveled is $0.092 in average, (ranging from 0 to $0.36). Numbers in the parentheses in Table 5.6 and 5.7 show comprehensive costs for each connector segment. Total risk for a connector segment is significant: total economic cost is $6.92 million on average ranging from 0 to $38.5 million. Comprehensive risk per vehicle mile traveled is $0.54 on average, ranging from 0 to $2.30. Fuel cost and driver wage typically are two of the biggest components of operational (variable) cost, on average 0.548 and 0.445 per vehicle mile, respectively [36]. Comprehensive risk per vehicle mile traveled on average is about in the same range as fuel cost or driver wage. In other words, crash risk has a real impact on trucking companies' operating costs.

Table 5.4: Number of People Killed, Injured and Vehicles Damaged

Seg ID	Connector Segment	Total Killed	Incap. Injuries	Non-Incap. Injuries	Vehicle Damaged
1	Shepherd Road-Airport-Hamilton	0	2	10	70
2	Middlebrook Pike-Pipeline-Knox	1	3	15	107
3	Western Ave-Pipeline-Knox	0	1	18	237
4	Randy Tyree St-Pipeline-Knox	0	0	0	10
5	Ed Shouce Drive -Pipeline-Knox	0	1	5	56
6	Jersey Pike-Pipeline-Hamilton	0	0	19	109
7	Lincoln Street-Rail-Sullivan	0	0	1	10
8	Southern Avenue-Rail-Shelby	0	1	1	24
9	East Parkway S -Airways Blvd-Rail-Shelby	2	0	67	283
10	Spottswood Avenue-South Pkwy E - Rail-Shelby	0	1	4	9
11	N. Cherry Street-Bus terminal-Knox	0	5	21	119
12	E. Magnolia Avenue-Bus terminal-Knox	0	11	40	189
13	Hall of Fame Dr-Bus Terminal-Knox	0	0	0	0
14	Old Magnolia Ave-Bus Terminal-Knox	0	0	0	1
15	S. Hall of Fame Dr-Bus Terminal-Knox	0	0	0	3
16	Manufactures Road-Port-Hamilton	0	1	5	104
17	Mallory Avenue-Rail-Shelby	0	1	26	94
18	S. Third St-Rail-Shelby	0	1	24	111
19	New Horn Lake Rd-Florida St-Rail-Shelby	0	0	0	9
20	Riverport Road-Rail-Shelby	0	0	5	27
21	Jackson Avenue-Rail-Shelby	0	2	133	517
22	Chelsea Avenue-Rail-Shelby	0	0	26	68
23	Tchulahoma/American Way-Airport-Shelby	0	1	22	140
24	Democrat Rd-Airport-Shelby	0	4	63	379
25	Plough Blvd-Airport-Shelby	1	0	43	269
26	Airways Blvd	1	0	18	79
27	Winchester Rd.	0	0	5	24
28	Hudson Rd-Port-Hamilton	0	0	0	0
29	Pineville Rd-Port-Hamilton	0	1	1	11
30	Moccasin Bend Rd-Port-Hamilton	0	1	3	10
31	Hamm Rd-Port-Hamilton	0	0	0	8
32	Mclemore Av-Port-Shelby	0	0	2	18
33	Pier St-Port-Shelby	0	0	0	0
34	Jack Carley Causeway-Port-Shelby	0	3	14	37
35	Harbor Av-Port-Shelby	0	1	14	59
36	Harbor Av-Port-Shelby	0	0	0	0
37	Channel Av-Port-Shelby	0	0	5	35
38	Riverside Blvd-Port-Shelby	0	0	0	16
39	Armory Ave (4888)-Rail-Davidson	0	0	5	28
40	Armory Ave (4162)-Rail-Davidson	0	0	4	32
41	Sidco Drive (4889)-Rail-Davidson	0	0	1	11
42	Sidco Drive (4161)-Rail-Davidson	0	1	13	88
43	West 19th Street-Port-Hamilton	0	0	0	0
44	Shelby Drive-Rail-Shelby	1	1	40	337
45	Airport Access Road-Airport-Sullivan	1	2	13	63
46	River Street- Evans St/Molly Lane -Port-Hamilton	0	0	0	0
47	Airport Rd-NHS Intercity Bus Connector-Hamilton	0	1	8	62

Table 5.5: Numbers of Fatal Crashes, Injury Crashes and PDO Crashes

Seg ID	Connector Segment	Fatal Crashes	Incap. Injury Crashes	Non-Incap. Injury Crashes	PDO Crashes
1	Shepherd Road-Airport-Hamilton	0	1	6	31
2	Middlebrook Pike-Pipeline-Knox	1	2	10	42
3	Western Ave-Pipeline-Knox	0	1	12	104
4	Randy Tyree St-Pipeline-Knox	0	0	0	3
5	Ed Shouce Drive -Pipeline-Knox	0	1	3	25
6	Jersey Pike-Pipeline-Hamilton	0	0	17	41
7	Lincoln Street-Rail-Sullivan	0	0	1	5
8	Southern Avenue-Rail-Shelby	0	1	1	14
9	East Parkway S -Airways Blvd-Rail-Shelby	2	0	45	92
10	Spottswood Avenue-South Pkwy E - Rail-Shelby	0	1	2	5
11	N. Cherry Street-Bus terminal-Knox	0	3	12	45
12	E. Magnolia Avenue-Bus terminal-Knox	0	10	24	64
13	Hall of Fame Dr-Bus Terminal-Knox	0	0	0	0
14	Old Magnolia Ave-Bus Terminal-Knox	0	0	0	1
15	S. Hall of Fame Dr-Bus Terminal-Knox	0	0	0	2
16	Manufactures Road-Port-Hamilton	0	1	5	48
17	Mallory Avenue-Rail-Shelby	0	1	17	30
18	S. Third St-Rail-Shelby	0	1	16	36
19	New Horn Lake Rd-Florida St-Rail-Shelby	0	0	0	6
20	Riverport Road-Rail-Shelby	0	0	4	14
21	Jackson Avenue-Rail-Shelby	0	2	83	179
22	Chelsea Avenue-Rail-Shelby	0	0	18	23
23	Tchulahoma/American Way-Airport-Shelby	0	1	17	54
24	Democrat Rd-Airport-Shelby	0	3	46	151
25	Plough Blvd-Airport-Shelby	1	0	34	116
26	Airways Blvd	1	0	10	30
27	Winchester Rd.	0	0	4	11
28	Hudson Rd-Port-Hamilton	0	0	0	0
29	Pineville Rd-Port-Hamilton	0	1	1	6
30	Moccasin Bend Rd-Port-Hamilton	0	1	0	3
31	Hamm Rd-Port-Hamilton	0	0	0	5
32	Mclemore Av-Port-Shelby	0	0	1	8
33	Pier St-Port-Shelby	0	0	0	0
34	Jack Carley Causeway-Port-Shelby	0	3	7	12
35	Harbor Av-Port-Shelby	0	1	11	23
36	Harbor Av-Port-Shelby	0	0	0	0
37	Channel Av-Port-Shelby	0	0	5	14
38	Riverside Blvd-Port-Shelby	0	0	0	8
39	Armory Ave (4888)-Rail-Davidson	0	0	3	12
40	Armory Ave (4162)-Rail-Davidson	0	0	4	18
41	Sidco Drive (4889)-Rail-Davidson	0	0	1	5
42	Sidco Drive (4161)-Rail-Davidson	0	1	11	34
43	West 19th Street-Port-Hamilton	0	0	0	0
44	Shelby Drive-Rail-Shelby	1	1	33	130
45	Airport Access Road-Airport-Sullivan	1	2	10	24
46	River Street- Evans St/Molly Lane -Port-Hamilton	0	0	0	0
47	Airport Rd-NHS Intercity Bus Connector-Hamilton	0	1	7	27

Table 5.6: Per Person/Vehicle Injury based Economic cost (comprehensive cost*)

Seg. ID	Connector Segment	Total Killed	Incap. Injured	Non-incap. Injured	Vehicle Damaged**	Total Risk	Normalized Risk
1	Shepherd Road-Airport-Hamilton	0 (0)	164,096 (2,002,412)	237,420 (2,760,100)	425,320	826,836 (5,187,832)	0.0784 (0.4917)
2	Middlebrook Pike-Pipeline-Knox	1,398,916 (9,145,998)	246,144 (3,003,618)	356,130 (4,140,150)	650,132	2,651,322 (16,939,898)	0.2018 (1.2894)
3	Western Ave-Pipeline-Knox	0 (0)	82,048 (1,001,206)	427,356 (4,968,180)	1,440,012	1,949,416 (7,409,398)	0.2387 (0.9071)
4	Randy Tyree St-Pipeline-Knox	0 (0)	0 (0)	0 (0)	60,760	60,760 (60,760)	0.0207 (0.0207)
5	Ed Shouse Drive -Pipeline-Knox	0 (0)	82,048 (1,001,206)	118,710 (1,380,050)	340,256	541,014 (2,721,512)	0.0406 (0.2043)
6	Jersey Pike-Pipeline-Hamilton	0 (0)	0 (0)	451,098 (5,244,190)	662,284	1,113,382 (5,906,474)	0.1552 (0.8235)
7	Lincoln Street-Rail-Sullivan	0 (0)	0 (0)	23,742 (276,010)	60,760	84,502 (336,770)	0.0095 (0.0379)
8	Southern Avenue-Rail-Shelby	0 (0)	82,048 (1,001,206)	23,742 (276,010)	145,824	251,614 (1,423,040)	0.0297 (0.1680)
9	East Parkway S -Airways Blvd-Rail-Shelby	2,797,832 (18,291,996)	0 (0)	1,590,714 (18,492,670)	1,719,508	6,108,054 (38,504,174)	0.3647 (2.2993)
10	Spottswood Avenue-South Pkwy E - Rail-Shelby	0 (0)	82,048 (1,001,206)	94,968 (1,104,040)	54,684	231,700 (2,159,930)	0.1185 (1.1049)
11	N. Cherry Street-Bus terminal-Knox	0 (0)	410,240 (5,006,030)	498,582 (5,796,210)	723,044	1,631,866 (11,525,284)	0.2175 (1.5360)
12	E. Magnolia Avenue-Bus terminal-Knox	0 (0)	902,528 (11,013,266)	949,680 (11,040,400)	1,148,364	3,000,572 (23,202,030)	0.1563 (1.2087)
13	Hall of Fame Dr-Bus Terminal-Knox	0(0)	0(0)	0(0)	0	0(0)	0(0)
14	Old Magnolia Ave-Bus Terminal-Knox	0 (0)	0 (0)	0 (0)	6,076	6,076 (6,076)	0.0131 (0.0131)
15	S. Hall of Fame Dr-Bus Terminal-Knox	0 (0)	0 (0)	0 (0)	18,228	18,228 (18,228)	0.0138 (0.0138)
16	Manufactures Road-Port-Hamilton	0 (0)	82,048 (1,001,206)	118,710 (1,380,050)	631,904	832,662 (3,013,160)	0.0936 (0.3386)

Seg. ID	Connector Segment	Total Killed	Incap. Injured	Non-incap. Injured	Vehicle Damaged**	Total Risk	Normalized Risk
17	Mallory Avenue-Rail-Shelby	0 (0)	82,048 (1,001,206)	617,292 (7,176,260)	571,144	1,270,484 (8,748,610)	0.1522 (1.0479)
18	S. Third St-Rail-Shelby	0 (0)	82,048 (1,001,206)	569,808 (6,624,240)	674,436	1,326,292 (8,299,882)	0.0833 (0.5210)
19	New Horn Lake Rd-Florida St-Rail-Shelby	0 (0)	0 (0)	0 (0)	54,684	54,684 (54,684)	0.0284 (0.0284)
20	Riverport Road-Rail-Shelby	0 (0)	0 (0)	118,710 (1,380,050)	164,052	282,762 (1,544,102)	0.0294 (0.1608)
21	Jackson Avenue-Rail-Shelby	0 (0)	164,096 (2,002,412)	3,157,686 (36,709,330)	3,141,292	6,463,074 (41,853,034)	0.1564 (1.0130)
22	Chelsea Avenue-Rail-Shelby	0 (0)	0 (0)	617,292 (7,176,260)	413,168	1,030,460 (7,589,428)	0.1283 (0.9447)
23	Tchulahoma/American Way-Airport-Shelby	0 (0)	82,048 (1,001,206)	522,324 (6,072,220)	850,640	1,455,012 (7,924,066)	0.1043 (0.5681)
24	Democrat Rd-Airport-Shelby	0 (0)	328,192 (4,004,824)	1,495,746 (17,388,630)	2,302,804	4,126,742 (23,696,258)	0.1352 (0.7763)
25	Plough Blvd-Airport-Shelby	1,398,916 (9,145,998)	0 (0)	1,020,906 (11,868,430)	1,634,444	4,054,266 (22,648,872)	0.0744 (0.4157)
26	Airways Blvd	1,398,916 (9,145,998)	0 (0)	427,356 (4,968,180)	480,004	2,306,276 (14,594,182)	0.1571 (0.9941)
27	Winchester Rd.	0 (0)	0 (0)	118,710 (1,380,050)	145,824	264,534 (1,525,874)	0.0262 (0.1514)
28	Hudson Rd-Port-Hamilton	0(0)	0(0)	0(0)	0	0(0)	0(0)
29	Pineville Rd-Port-Hamilton	0 (0)	82,048 (1,001,206)	23,742 (276,010)	66,836	172,626 (1,344,052)	0.0440 (0.3424)
30	Moccasin Bend Rd-Port-Hamilton	0 (0)	82,048 (1,001,206)	71,226 (828,030)	60,760	214,034 (1,889,996)	0.2598 (2.2944)
31	Hamm Rd-Port-Hamilton	0 (0)	0 (0)	0 (0)	48,608	48,608 (48,608)	0.0149 (0.0149)
32	Mclemore Av-Port-Shelby	0 (0)	0 (0)	47,484 (552,020)	109,368	156,852 (661,388)	0.1006 (0.4243)
33	Pier St-Port-Shelby	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)

Seg. ID	Connector Segment	Total Killed	Incap. Injured	Non-incap. Injured	Vehicle Damaged**	Total Risk	Normalized Risk
34	Jack Carley Causeway-Port-Shelby	0 (0)	246,144 (3,003,618)	332,388 (3,864,140)	224,812	803,344 (7,092,570)	0.0525 (0.4635)
35	Harbor Av-Port-Shelby	0 (0)	82,048 (1,001,206)	332,388 (3,864,140)	358,484	772,920 (5,223,830)	0.0314 (0.2125)
36	Harbor Av-Port-Shelby	0 (0)	0 (0)	0 (0)	0	0 (0)	0 ()
37	Channel Av-Port-Shelby	0 (0)	0 (0)	118,710 (1,380,050)	212,660	331,370 (1,592,710)	0.0206 (0.0990)
38	Riverside Blvd-Port-Shelby	0 (0)	0 (0)	0 (0)	97,216	97,216 (97,126)	0.1400 (0.1400)
39	Armory Ave (4888)-Rail-Davidson	0 (0)	0 (0)	118,710 (1,380,050)	170,128	288,838 (1,550,178)	0.0432 (0.2319)
40	Armory Ave (4162)-Rail-Davidson	0 (0)	0 (0)	94,968 (1,104,040)	194,432	289,400 (1,298,472)	0.2162 (0.9700)
41	Sidco Drive (4889)-Rail-Davidson	0 (0)	0 (0)	23,742 (276,010)	66,836	90,578 (342,846)	0.0157 (0.0595)
42	Sidco Drive (4161)-Rail-Davidson	0 (0)	82,048 (1,001,206)	308,646 (3,588,130)	534,688	925,382 (5,124,024)	0.0858 (0.4750)
43	West 19th Street-Port-Hamilton	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)
44	Shelby Drive-Rail-Shelby	1,398,916 (9,145,998)	82,048 (1,001,206)	949,680 (11,040,400)	2,047,612	4,478,256 (23,235,216)	0.2559 (1.3279)
45	Airport Access Road-Airport-Sullivan	1,398,916 (9,145,998)	164,096 (2,002,412)	308,646 (3,588,130)	382,788	2,254,446 (15,119,328)	0.0999 (0.6697)
46	River Street- Evans St/Molly Lane -Port-Hamilton	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)
47	Airport Rd-NHS Intercity Bus Connector-Hamilton	0 (0)	82,048 (1,001,206)	189,936 (2,208,080)	376,712	648,696 (3,585,998)	0.1296 (0.7166)

The costs are in US Dollars.

* Numbers in parentheses are comprehensive cost.

** For PDO, comprehensive cost is same as economic cost.

Table 5.7: FICs Number of Crashes by Injury based Economic cost (comprehensive cost)*

Seg ID	Connector Segment	Fatal Crashes	Incap. Crashes	Non-incap Crashes	PDO Crashes	Total Risk	Normalized Risk
1	Shepherd Road-Airport-Hamilton	0 (0)	111,400 (216,000)	251,400 (474,000)	198,400 (229,400)	561,200 (919,400)	0.0532 (0.0871)
2	Middlebrook Pike-Pipeline-Knox	1,245,600 (4,008,900)	222,800 (432,000)	419,000 (790,000)	268,800 (310,800)	2,156,200 (5,541,700)	0.1641 (0.4218)
3	Western Ave-Pipeline-Knox	0 (0)	111,400 (216,000)	502,800 (948,000)	665,600 (769,600)	1,279,800 (1,933,600)	0.1567 (0.2367)
4	Randy Tyree St-Pipeline-Knox	0 (0)	0 (0)	0 (0)	19,200 (22,200)	19,200 (22,200)	0.0065 (0.0075)
5	Ed Shouse Drive -Pipeline-Knox	0 (0)	111,400 (216,000)	125,700 (237,000)	160,000 (185,000)	397,100 (638,000)	0.0298 (0.0479)
6	Jersey Pike-Pipeline-Hamilton	0 (0)	0 (0)	712,300 (1,343,000)	262,400 (303,400)	974,700 (1,646,400)	0.1359 (0.2295)
7	Lincoln Street-Rail-Sullivan	0 (0)	0 (0)	41,900 (79,000)	32,000 (37,000)	73,900 (116,000)	0.0083 (0.0130)
8	Southern Avenue-Rail-Shelby	0 (0)	111,400 (216,000)	41,900 (79,000)	89,600 (103,600)	242,900 (398,600)	0.0287 (0.0470)
9	East Parkway S -Airways Blvd-Rail-Shelby	2,491,200 (8,017,800)	0 (0)	1,885,500 (3,555,000)	588,800 (680,800)	4,965,500 (12,253,600)	0.2965 (0.7317)
10	Spottswood Avenue-South Pkwy E - Rail-Shelby	0 (0)	111,400 (216,000)	83,800 (158,000)	32,000 (37,000)	227,200 (411,000)	0.1162 (0.2102)
11	N. Cherry Street-Bus terminal-Knox	0 (0)	334,200 (648,000)	502,800 (948,000)	288,000 (333,000)	1,125,000 (1,929,000)	0.1499 (0.2571)
12	E. Magnolia Avenue-Bus terminal-Knox	0 (0)	1,114,000 (2,160,000)	1,005,600 (1,896,000)	409,600 (473,600)	2,529,200 (4,529,600)	0.1318 (0.2360)
13	Hall of Fame Dr-Bus Terminal-Knox	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
14	Old Magnolia Ave-Bus Terminal-Knox	0 (0)	0 (0)	0 (0)	6,400 (7,400)	6,400 (7,400)	0.0138 (0.0160)
15	S. Hall Of Fame Dr-Bus Terminal-Knox	0 (0)	0 (0)	0 (0)	12,800 (14,800)	12,800 (14,800)	0.0097 (0.0112)
16	Manufactures Road-Port-Hamilton	0 (0)	111,400 (216,000)	209,500 (395,000)	307,200 (355,200)	628,100 (966,200)	0.0706 (0.1086)

Seg ID	Connector Segment	Fatal Crashes	Incap. Crashes	Non-incap Crashes	PDO Crashes	Total Risk	Normalized Risk
17	Mallory Avenue-Rail-Shelby	0 (0)	111,400 (216,000)	712,300 (1,343,000)	192,000 (222,000)	1,015,700 (1,781,000)	0.1217 (0.2133)
18	S. Third St-Rail-Shelby	0 (0)	111,400 (216,000)	670,400 (1,264,000)	230,400 (266,400)	1,012,200 (1,746,400)	0.0635 (0.1096)
19	New Horn Lake Rd-Florida St-Rail-Shelby	0 (0)	0 (0)	0 (0)	38,400 (44,400)	38,400 (44,400)	0.0199 (0.0231)
20	Riverport Road-Rail-Shelby	0 (0)	0 (0)	167,600 (316,000)	89,600 (103,600)	257,200 (419,600)	0.0268 (0.0437)
21	Jackson Avenue-Rail-Shelby	0 (0)	222,800 (432,000)	3,477,700 (6,557,000)	1,145,600 (1,324,600)	4,846,100 (8,313,600)	0.1173 (0.2012)
22	Chelsea Avenue-Rail-Shelby	0 (0)	0 (0)	754,200 (1,422,000)	147,200 (170,200)	901,400 (1,592,200)	0.1122 (0.1982)
23	Tchulahoma/American Way-Airport-Shelby	0 (0)	111,400 (216,000)	712,300 (1,343,000)	345,600 (399,600)	1,169,300 (1,958,600)	0.0838 (0.1404)
24	Democrat Rd-Airport-Shelby	0 (0)	334,200 (648,000)	1,927,400 (3,634,000)	966,400 (1,117,400)	3,228,000 (5,399,400)	0.1057 (0.1769)
25	Plough Blvd-Airport-Shelby	1,245,600 (4,008,900)	0 (0)	1,424,600 (2,686,000)	742,400 (858,400)	3,412,600 (7,553,300)	0.0626 (0.1386)
26	Airways Blvd	1,245,600 (4,008,900)	0 (0)	419,000 (790,000)	192,000 (222,000)	1,856,600 (5,020,900)	0.1265 (0.3420)
27	Winchester Rd.	0 (0)	0 (0)	167,600 (316,000)	70,400 (81,400)	238,000 (397,400)	0.0236 (0.0394)
28	Hudson Rd-Port-Hamilton	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
29	Pineville Rd-Port-Hamilton	0 (0)	111,400 (216,000)	41,900 (79,000)	38,400 (44,400)	191,700 (339,400)	0.0488 (0.0865)
30	Moccasin Bend Rd-Port-Hamilton	0 (0)	111,400 (216,000)	0 (0)	19,200 (22,200)	130,600 (238,200)	0.1585 (0.2892)
31	Hamm Rd-Port-Hamilton	0 (0)	0 (0)	0 (0)	32,000 (37,000)	32,000 (37,000)	0.0098 (0.0114)
32	Mclemore Av-Port-Shelby	0 (0)	0 (0)	41,900 (79,000)	51,200 (59,200)	93,100 (138,200)	0.0597 (0.0887)
33	Pier St-Port-Shelby	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)

Seg ID	Connector Segment	Fatal Crashes	Incap. Crashes	Non-incap Crashes	PDO Crashes	Total Risk	Normalized Risk
34	Jack Carley Causeway-Port-Shelby	0 (0)	334,200 (648,000)	293,300 (553,000)	76,800 (88,800)	704,300 (1,289,800)	0.0460 (0.0843)
35	Harbor Av-Port-Shelby	0 (0)	111,400 (216,000)	460,900 (869,000)	147,200 (170,200)	719,500 (1,255,200)	0.0293 (0.0511)
36	Harbor Av-Port-Shelby	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
37	Channel Av-Port-Shelby	0 (0)	0 (0)	209,500 (395,000)	89,600 (103,600)	299,100 (498,600)	0.0186 (0.0310)
38	Riverside Blvd-Port-Shelby	0 (0)	0 (0)	0 (0)	51,200 (59,200)	51,200 (59,200)	0.0737 (0.0853)
39	Armory Ave (4888)-Rail-Davidson	0 (0)	0 (0)	125,700 (237,000)	76,800 (88,800)	202,500 (325,800)	0.0303 (0.0487)
40	Armory Ave (4162)-Rail-Davidson	0 (0)	0 (0)	167,600 (316,000)	115,200 (133,200)	282,800 (449,200)	0.2113 (0.3356)
41	Sidco Drive (4889)-Rail-Davidson	0 (0)	0 (0)	41,900 (79,000)	32,000 (37,000)	73,900 (116,000)	0.0128 (0.0201)
42	Sidco Drive (4161)-Rail-Davidson	0 (0)	111,400 (216,000)	460,900 (869,000)	217,600 (251,600)	789,900 (1,336,600)	0.0732 (0.1239)
43	West 19th Street-Port-Hamilton	0(0)	0(0)	0(0)	0()	0(0)	0(0)
44	Shelby Drive-Rail-Shelby	1,245,600 (4,008,900)	111,400 (216,000)	1,382,700 (2,607,000)	832,000 (962,000)	3,571,700 (7,793,900)	0.2041 (0.4454)
45	Airport Access Road-Airport-Sullivan	1,245,600 (4,008,900)	222,800 (432,000)	419,000 (790,000)	153,600 (177,600)	2,041,000 (5,408,500)	0.0904 (0.2396)
46	River Street- Evans St/Molly Lane -Port-Hamilton	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
47	Airport Rd-NHS Intercity Bus Connector-Hamilton	0 (0)	111,400 (216,000)	293,300 (553,000)	172,800 (199,800)	577,500 (968,800)	0.1154 (0.1936)

* Numbers in parentheses are comprehensive cost.

5.5. Risk mitigation strategies

Crash data show two key observations: (1) PDO occurs much more regularly with much smaller impact than other risks (i.e., incapacitating injury and fatal); and (2) total risk varies dramatically even for the same type of connectors and for the similar location of connectors. For frequently occurring risk (i.e., PDO and non-incapacitating injury), the risk mitigation strategy is to identify actual causes. Each connector is divided into segments, where crash frequencies are assigned to individual segments by accident locations. The investigation will start with the highest frequencies to identify actual causes (e.g., traffic light, pavement, length and width, speed limit, etc.). The next step is to fix these causes and then to reduce frequencies of PDO and non-incapacitating injury crashes. For rarely occurring risk (i.e., incapacitating injury and fatal), it is very unpredictable but has a significant financial impact. Therefore, the risk mitigation strategy is to transfer the financial liability to a third party should such a rare event (i.e., incapacitating injury and fatal) occur. Individual drivers and trucking companies pool their risk together through a third party, where insurance is the most common method of risk transfer. As risk varies radically even for the same type of connectors in similar locations, this indicates that the most important risk factor is the connector itself. This result echoes the above call to investigate individual connectors to identify actual causes (e.g., traffic light, pavement, length and width, speed limit, etc.). In other words, there must be some particular reasons to cause higher PDO crashes.

5.6. Risk analysis Conclusion

The risk analysis investigated the economic and societal impact of motor vehicle crashes on freight intermodal connectors in Tennessee from 2012 to 2014. Crash data show that (1) PDO and non-incapacitating injury crashes occur much more regularly with a much smaller impact than incapacitating injury and fatal crashes and (2) total risk varies drastically even for same type connectors and for similarly situated connectors. Two risk mitigation strategies are concluded. The first risk mitigation strategy is to identify actual causes for frequently occurring risk (i.e., PDO and non-incapacitating injury) and for connectors with higher frequent risk events. The second mitigation strategy is to transfer the financial liability to a third party for rare but significant risk (i.e., incapacitating injury and fatal) by pooling individual drivers and trucking companies.

6.0. GEOMETRIC AND TRAFFIC FEATURES AFFECTING FICs SAFETY

6.1. Modeling Data Overview

The research evaluated the impact of access density, signal density, percentage of trucks, presence or absence of TWLTL, presence or absence of median and other variables to the safety along the connectors. In addition to these geometric features, the study evaluated the impact of the number of lanes, shoulder width, median width and traffic characteristics (traffic volume and posted speed limits) to the safety of the connectors. Roadway geometry data was therefore obtained from the TRIMS/ETRIMS database which has all roadway information used in this study. Two fields in the database, namely roadway geometrics and roadway characteristics, with different sets of information were used. The roadway geometry gave information concerning the AADT, number of lanes, speed limit, illumination, land use characteristics and the information on the speed limit. The roadway characteristics gave information on median width and shoulder width (both inside and outside width). Traffic volume data was taken from the ETRIMS database as well as from the TDOT website in GIS shapefiles. For some segments, the AADT numbers were not available for certain covered years. In such cases, approximations were made from the AADT in the nearby stations.

6.2. Statistical Model

The study evaluated the impact of number of lanes, shoulder width, median width, traffic volume and posted speed limits to the crash frequency along these connectors. This was achieved by establishing relationships between various roadway characteristics, traffic flow and crash frequency through statistical modeling. Negative Binomial (NB) method was used for this purpose [37] [38]. The Negative Binomial is given by [39][40].

$$p(y_i) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma\left(\frac{1}{\alpha}\right)\Gamma(y_i + 1)}\left(\frac{1}{1 + \alpha\mu_i}\right)^{\frac{1}{\alpha}}\left(\frac{\alpha\mu_i}{1 + \alpha\mu_i}\right)^{y_i}$$

Where $\mu = (yi) = e\ (Xi\ \beta)$

Γ is gamma function

y_i is the number of crashes in a segment i,

μ_i Represents a mean rate of crashes,

α is the over-dispersion parameter

β is the fixed effect coefficient

6.3. Model Explanatory Variables

Based on field surveys along the FICs, literature review and analysis of the gathered data, several explanatory variables were selected to establish a suitable statistical model. Table 6.1 and 6.2 provide a statistical summary of the variables evaluated and their impact to the FICs connectors. The impact of roadway cross-sectional features and traffic characteristics to the crash frequency along the FICs were evaluated through statistical modeling. The primary objective was to evaluate the impact of different variables on crash frequency. The frequency is the number of crashes per segment per year. Only segments longer than 0.1 miles were used in the model.

Table 6.1 Statistical Summary for Continuous Variables

Variable	Mean	Min	Max
AADT	15716	1742	49655
Trucks volume	1536	86	4312
Number of Lanes	4	2	7
Median width (ft)	12.7	0	350
Outside shoulder Width (ft)	3.58	0	16
Signalized Intersection density	0.50	0	3
Access density	7.13	0	67
% Passenger Cars	89	61	99
%Peak hour volume	11	9	14
Directional split	64	51	75

Table 6.2 Statistical Summary for Categorical Variables

Variable	Description	Code for modelling	Segments	%
Posted speed-miles per hour(mph)	<40	0	68	55
	40-55	1	56	45
Terrain	Flat	0	58	31
	Rolling	1	86	69
Median	Presence	1	54	44
	Absence	0	70	56
Outside shoulder	Presence	1	92	74
	Absence	0	32	26
Two-way Left Turn Lane (TWLT)	Presence	1	23	19
	Absence	0	101	81
Ramp	Presence	1	97	78
	Absence	0	27	22
Railroad crossing	Presence	1	100	87
	Absence	0	16	13

6.4. Discussion of the Model results

As expected, not all variables were statistically significant in influencing these crashes to occur; hence the presented results show some significant and non-significant variables on crash frequency along the FICs. The impact and significance of variables retained in the model to crash frequencies are summarized in Table 6.3. Significant variables were found to be AADT, signal density, access density, presence of two-way left turn lane (TWLTL), and presence of outside shoulders. To understand the influence of evaluated variables on FICs crash frequency, the sign and magnitude of respective variable coefficient was observed. The positive coefficient indicates the increase/presence of such variable increases the probability of crash occurrence. The negative sign of a coefficient indicates that increase/presence of such variable will reduce the probability of crash occurrence. In the model presented in Table 6.3, three variables have negative coefficients: number of lanes, presence of two-way left turn lane (TWLTL) and the presence of outside shoulder, meaning an FIC segment with multilane segments, TWLTL medians and in the presence of outer shoulder are relatively safer compared to the opposite geometry. The model also shows several variables with positive coefficient including AADT, signal density, access density and presence of curbs and gutters meaning FIC segments are more hazardous with increase/presence of these variables.

Table 6.3 Impacts of Geometric Features and Traffic to Crash Frequency

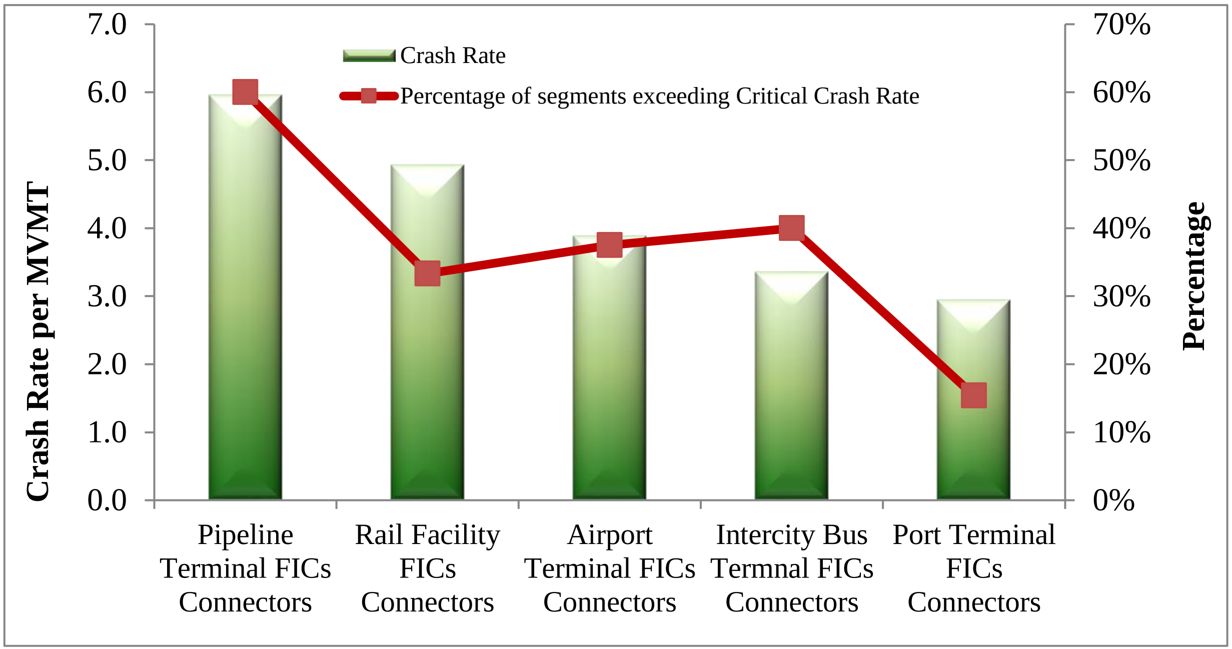
Variables	Coefficient	P-value
AADT*	7.7E-05	4.450
Number of lanes	-0.089	-0.670
Signal Density*	0.291	2.290
Access Density*	0.044	2.670
Presence Ramp	0.335	1.300
Presence of Two-way Left Turn Lane (TWLTL)*	-0.981	-3.890
Presence of Outside Shoulder	-0.467	-1.580
Presence of Curbs and Gutters	0.102	0.370
Constant	1.666	3.840
Length	Offset	

With a positive coefficient, the model suggests that probability of crash occurrence on FICs is influenced by the level of traffic volume (AADT). FIC segments along high volume corridors are more likely to have more crashes compared to low-volume corridors. This result is supported by crash data presented in previous sections which showed congested (higher AADT) FIC segments having higher crash frequency compare to those with low AADT. Connector segments passing through high signal density and access density experience more crashes than those with low signal and access density. That is, an increase in the number of signalized intersections or access points per mile increases the likelihood of crashes along FIC segments. This suggests that FICs routed along segments with few signalized intersections and access roads per mile are safer than those along congested signals and access points. The model shows that connector segments with TWLTL medians are less hazardous compared to other types of medians along FICs. The effect of the number of lanes shows that multilane FICs segments experiences fewer crashes compared to those with fewer lanes. A higher number of lanes can be assumed to give drivers more space to correct mistakes and eventually avoid accidents. However, high traffic volume, higher number of lanes and high signal density most are generally correlated as segments with higher volumes are likely to have more lanes and more signals. Thus, the correlation between more signals and more crashes may require a more sophisticated model, which future studies may need to look at.

6.5. Connectors exceeding critical crash rates

Analysis was also performed on the percentages of the total number of each type of connector exceeding critical crash rates, whereby these percentages only show the relative share of transport facility types shown in Figure 6.1. Within each connector type, pipeline terminal segment connectors had the most crash rates exceeding critical rate (60% of pipeline related connectors exceeded critical crash rate). Examination of the connectors with the highest crash rates and those exceeding critical crash rates found that both operational and geometric challenges may have led to deterioration in safety conditions. The study attempted to establish which type of freight facility connectors were relatively safety hazardous compared to others. No clear distinction of safety trends were established with respect to connectors to and from the airport, pipeline, rail, intercity bus or port terminals (Table 4.2). Figure 6.1 shows the connectors to and from pipeline terminals having the highest averaged crash rates as well as the largest number of segments exceeding critical crash rates compared to other connects. The safest intermodal connectors are shown to be port terminal related rail while airport and intercity terminal connectors have a relatively similar safety index in terms of crash rates. Traffic operations analysis indicated that critical truck movements of most of these hazard-prone connectors were operating at lower level of services especially for critical movements to and from the freight facilities. Turning movements to/from the intermodal connector facilities were analyzed to determine movement delays, see Figure 6.2. These movements were found to have high truck volume as they direct freights from the freeways to the facilities and vice versa. Turning movements to/from the intermodal connector were then compared with intersection delays to understand the variation of delays and to point out turning movements with delays that are higher than the intersection delays. Higher delays on turning movements to/from the facilities suggest an impact of truck volume on intersection performance (LOS).

Figure 6.1 Crash Rates by Connectors Multimodal Type



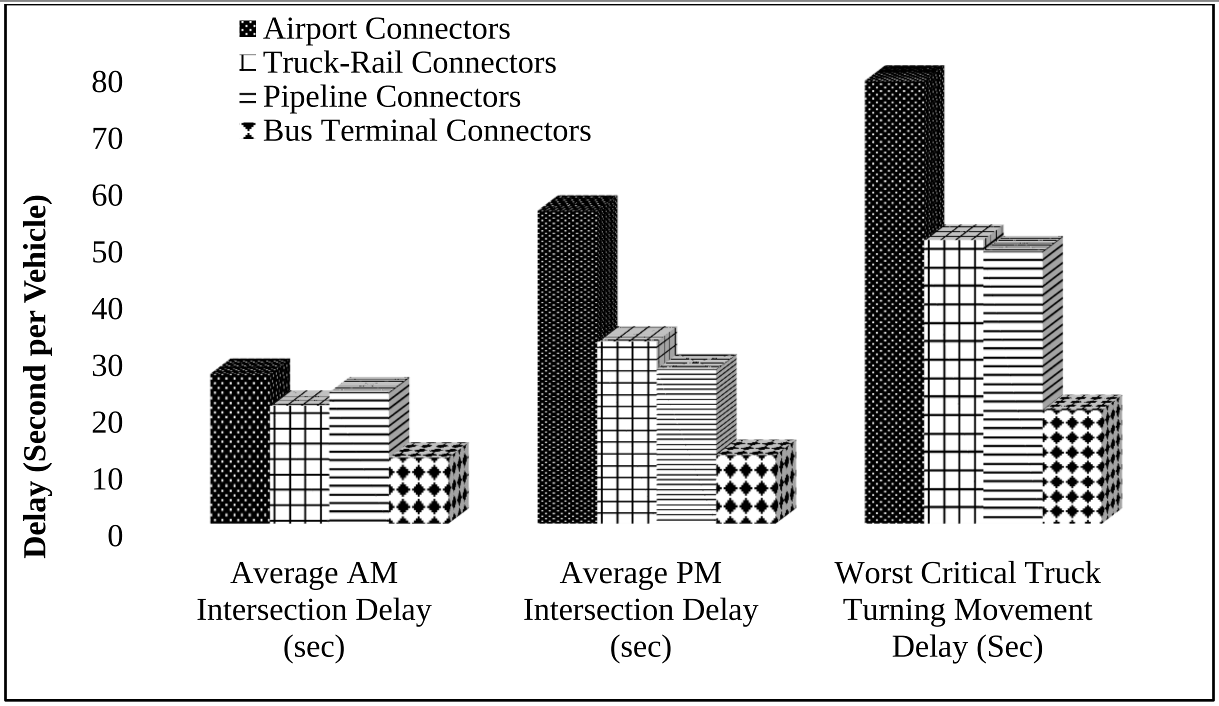


Figure 6.2 Average Intersection Delays along Intermodal Connector

Some of the intersections along these connectors were found to be just a few miles away from the facility's gates causing queues, delays and congestion in general. In terms of geometry, some of these high crash rate connectors were found with narrow lanes, narrow or no shoulder, complex intersection geometry, passive safety devices at railway crossings, etc. These may have contributed to some types of crashes that led some connectors to have higher crash rates than others. Other determined deficiencies seen during the site visit which might be contributing to safety problems on some segments include tight turning radii at the intersections, sight distance restrictions, debris, surrounding land use and lack of relevant signage. Comparing with respect to geographical locations, no significant distinction was established in terms of crash frequency or crash rates among the five counties. However, the shorter connectors experienced higher crash rates compared to longer segments.

6.6. Summary

The study digested the safety in terms of crash frequency, crash rates and statistical significance of attributing traffic and geometric factors. In general, it was found that safety challenges along FICs are mainly resulting from the interaction between freights (trucks) and regular or commuter traffic. It was found that connectors leading to pipeline terminals have high crash rates (almost double) compared to other types of terminals while port terminal connectors have the lowest safety problem indices. The study established correlative contributing causes of crash frequencies and rates along FICs that included AADT, lanes, shoulders, access and median types. Signal density was found to strongly and significantly affect the probability of crashes together with the presence of two-way left turn lane (TWLT) which surprisingly tends to decrease the probability of crashes along these connectors. Presence of shoulders along intermodal connectors was found to help reduce the probability of crashes while presence of curbs and gutters tends to increase crash frequency. Analysis indicated that most of FICs with high crash rates were also operating at lower levels of service, especially for critical movements towards freight facilities due to high truck volumes. It should be noted that some variables considered to be critical for freight trucks were not readily available to be included in this study; hence future studies should incorporate factors such as travel speed, environmental conditions, signal operations, longitudinal slopes, pavement condition, degree of horizontal curves, etc. The analysis did not analyze whether a truck was involved in crashes, therefore, future study should look into this.

7.0. FICs OPERATIONAL AND CAPACITY EVALUATION

7.1. Overview

FICs operational and capacity evaluation was aimed at identifying deficiencies: (1) queue storage lengths being exceeded for the critical movements at the intersection to and from the freight facilities, (2) delay and level of service (LOS) at critical intersections and (3) factors influencing travel cost/per mile of the connectors. Freight travel time reliability was also evaluated.

7.2. Traffic Data

Turning Movement Counts (TMC) were collected at 18 different intersections considered to be critical along the FICs. Data was collected in July 2017 for twelve consecutive hours from 6:00 AM to 6:00 PM for ten days. The corresponding signal timing data for each intersection was requested and obtained from respective county's public works or engineering department. Of all the intersections where data was collected, only one intersection was unsignalized. Figures 7.1and 7.2 show the distribution of traffic volume along the intersections from 6:00 AM to 6:00 PM. As shown, most of the intersection' traffic peaked during PM compared to AM hours. Overall, traffic flow along these FICs was found to be at the highest during regular peak hours (6.00 am to 9.00 am and 4:00 to 7:00 PM). Intersections along FICs in Shelby County recorded the highest traffic volume followed by those in Knox County. The American Way and Lamar Ave intersection connecting to the airport facility recorded the highest volume followed by the East Shelby and Lamar Ave intersection connecting to the truck/pipeline facility, both located in Shelby County. Southern Ave and Copper St in Shelby County recorded the least traffic volume in the area. FICs in Knox County recorded the second highest traffic volumes, with N Cherry St and E Magnolia Ave, the connector to the intercity bus terminal, having the highest traffic volume while E Magnolia and Hall of Fame, also connecting to the Intercity bus terminal, recorded the lowest traffic. In Hamilton County, Jersey Pike and Boany Oaks Dr, an intersection connecting to the truck/pipeline facility, had the highest volume. Airport Rd and SR-2 had the lowest traffic volume of all the intersections. Figure 7.3 shows the percentage of trucks and passenger cars at these intersections during peak hours. Intersections in Shelby County had higher traffic volumes compared to other counties. The intersection of W Mallory Ave and Riverport Rd in Shelby County had the highest percentage of trucks (31%) followed by the intersection of East Shelby and Lamar Ave, which had 24% of trucks. The 12th St and Lincoln St intersection in Sullivan had the lowest percentage of trucks (4%).

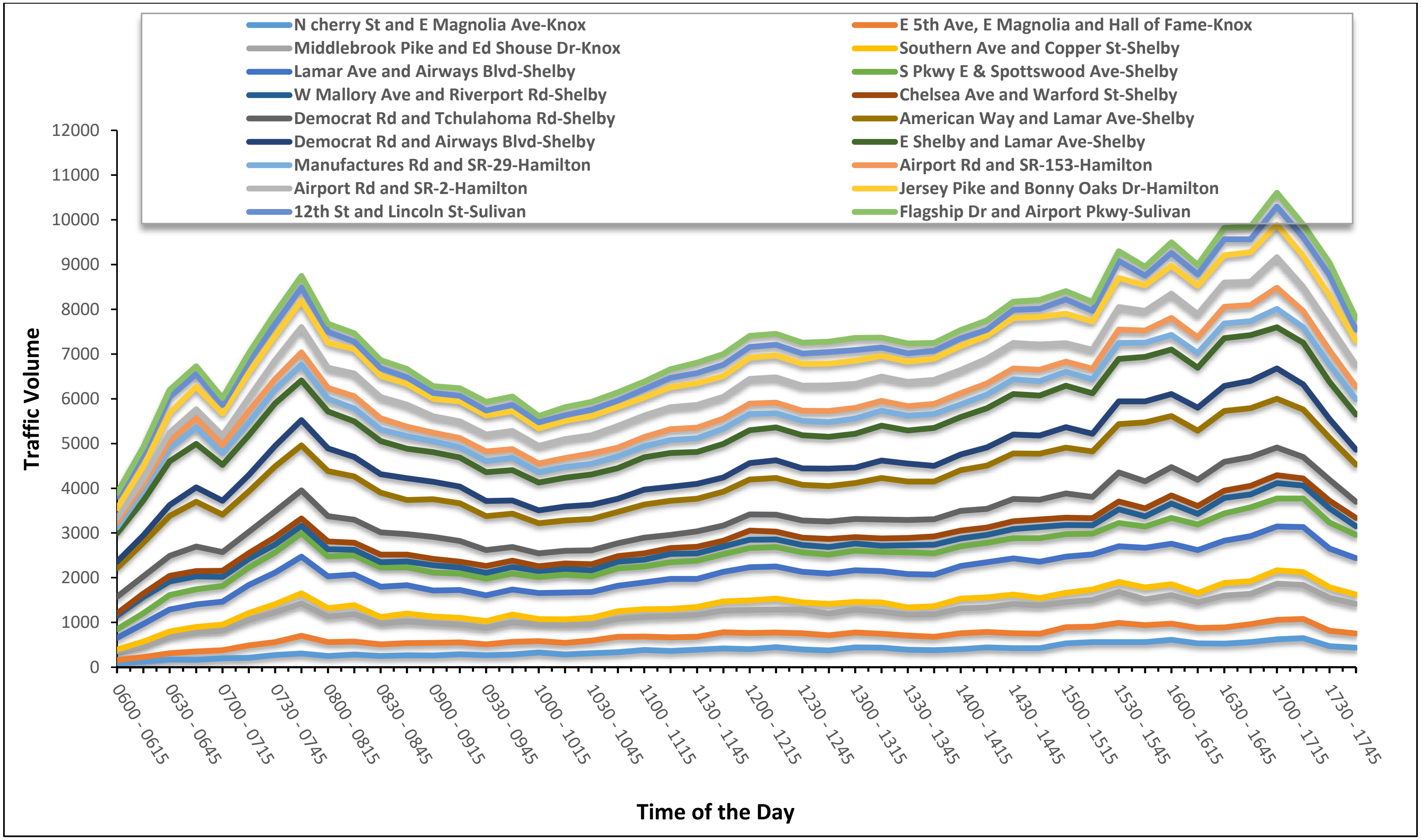


Figure 7.1: Line Distribution of Intersection Volumes by Time of the Day

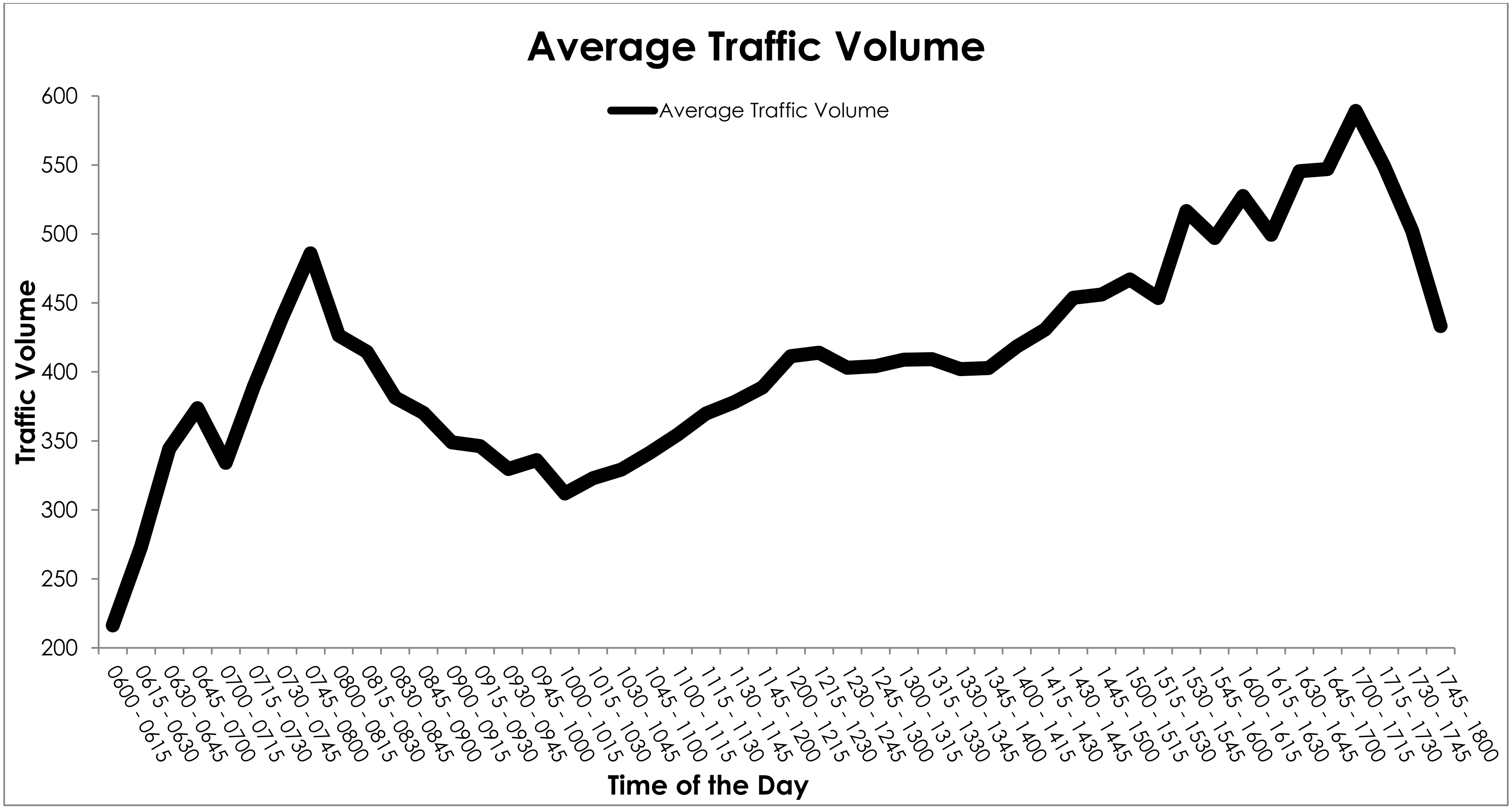


Figure 7.2: Histrogram Distribution of Intersection Volumes by Time of the Day

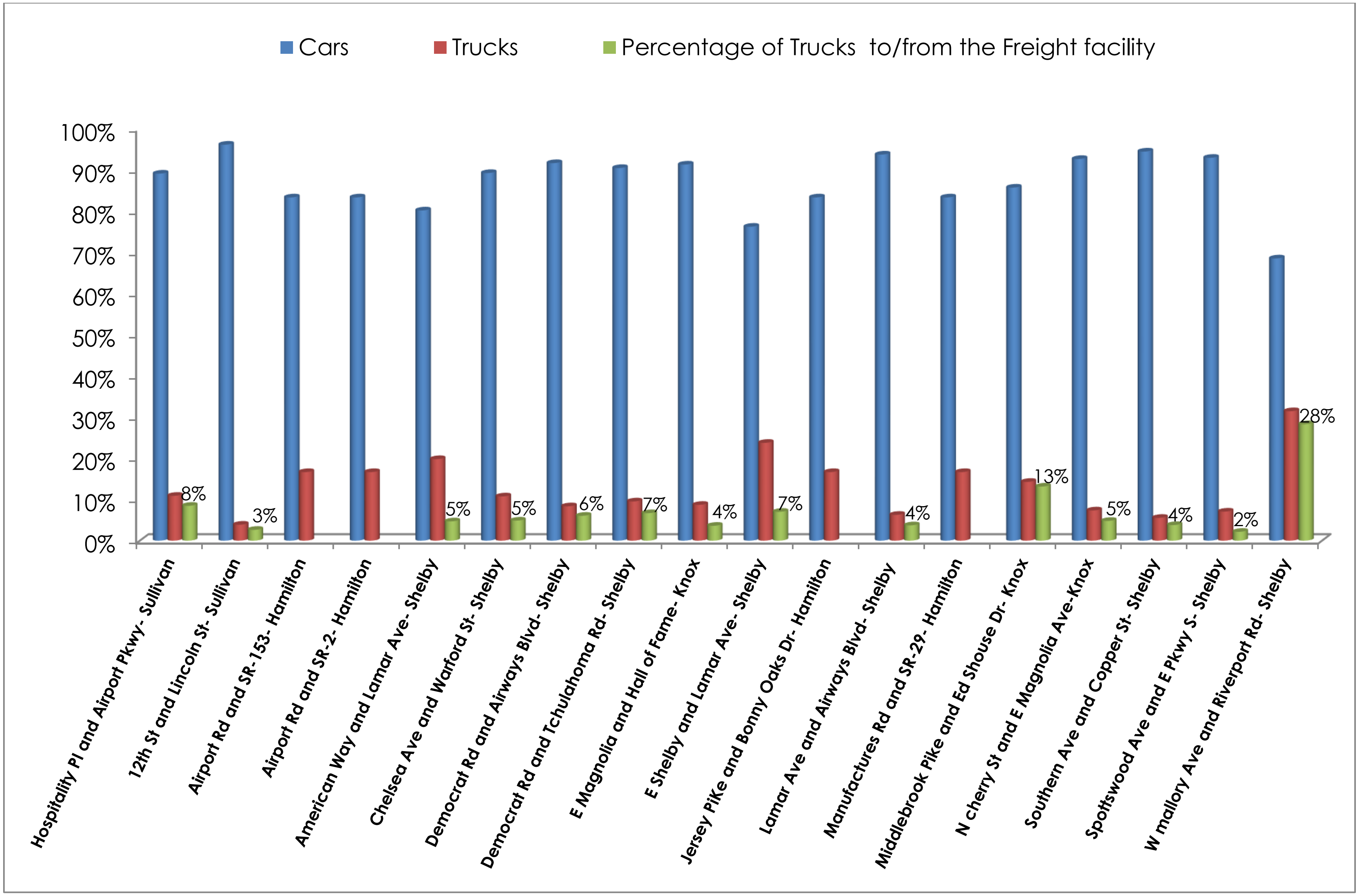


Figure 7.3: Percentages of Trucks relative to Passenger Cars

7.3. Traffic Operations at Critical Intersections

Operational analysis was performed with respect to approaches and critical movements at the intersections to and from the freight facilities. The study developed correlation between truck volume and delays and queues at FIC Intersections, shown in Figure 7.4 and 7.5 respectively. Figures 7.6 shows AM and PM intersection delays. For AM peak hours, intersection delays were found to vary from 10 seconds to 47 seconds, critical movement delays varied from 13 seconds to 69 seconds while critical approach delays varied from 14 to 66 seconds. Jersey Pike/SR-153 Bonny Oaks Dr, an intersection along a pipeline connector in Hamilton County recorded the highest intersection delay (47 seconds) while Lincoln Street, an intersection along truck-rail connector segment in Sullivan County had the lowest delay (10 seconds). It was observed that intersection delays varied randomly for different type of connectors without specific patterns related to the type of intermodal connector. Overall, most of the connectors are operating at lower (unacceptable) level of service during PM peak hours than AM peak hours. PM peak hours' lower level of service on the connectors can be attributed to higher traffic volume. For the PM peak hours, intersection delays varied from 9 seconds to 78 seconds, critical movement delays varied from 16 seconds to 169 seconds while critical approach delays varied from 15 to 158 seconds. Airways Blvd, an airport connector segment in Shelby County recorded the highest delay (78 seconds) while Hall of Fame Dr, the intercity bus connector segment in Knox, had the lowest delay (9 seconds). Also, it was observed that intersection delays vary randomly for different type of connectors, no specific relation was observed between intersection delays and type of intermodal connector. Critical queue lengths are shown in Figure 7.7, whereby the PM critical queue length varied from 55 ft to 713 ft. Tchulahoma/American way, an airport connector segment in Shelby County, had the highest critical queue length (713 ft.) while Chelsea Avenue and Jackson Avenue, rail/truck connector segments in Shelby, had the lowest critical queue lengths of 55 ft.

7.4. Movements to/from the freight facility

Figures 7.8 shows intersection and critical turning movement delays in Chattanooga, Memphis, Knoxville and Sullivan County. These are turning movements to and from the facility characterized by significant truck volume. As shown, in some intersections, critical movement delays are higher (worse) than those of the comparable intersections. For instance, the off-ramp intersections of Manufactures Rd and SR-29 and Airport Connector Rd and SR-153 S/bound have critical movement delays higher than the intersection delays. All three intersections in Knox County where found to have critical movement delays higher than intersection delay.

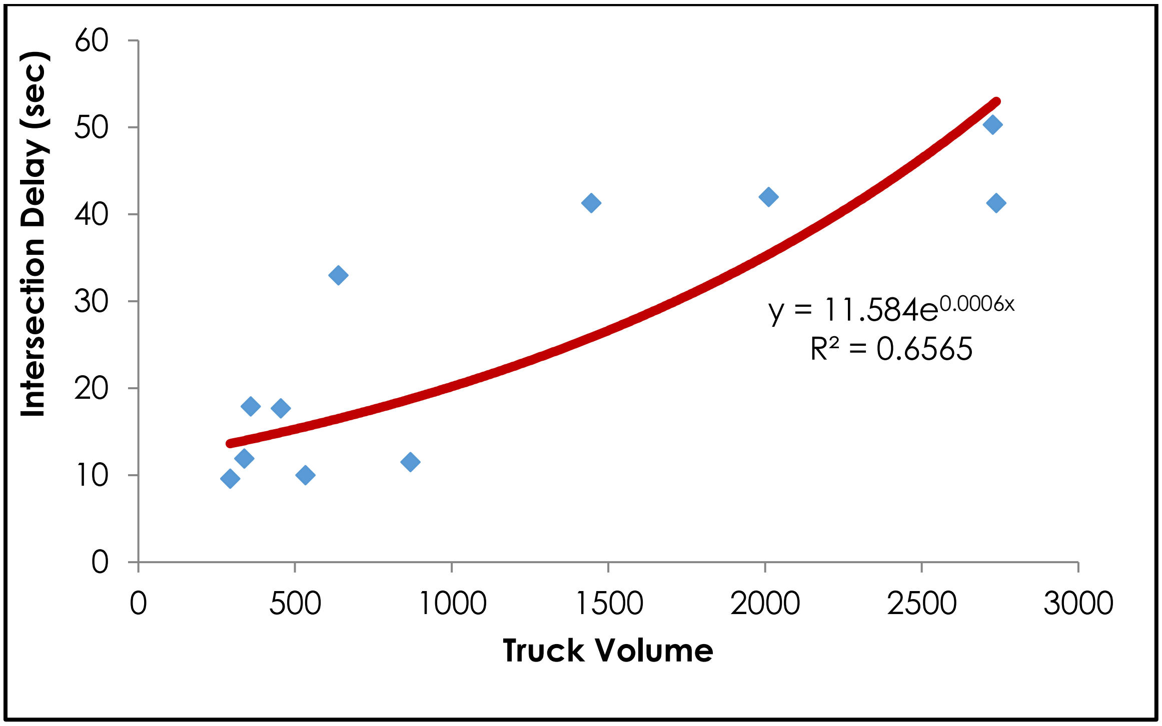


Figure 7.4: Relationship Between Truck Volume and Intersection Delays

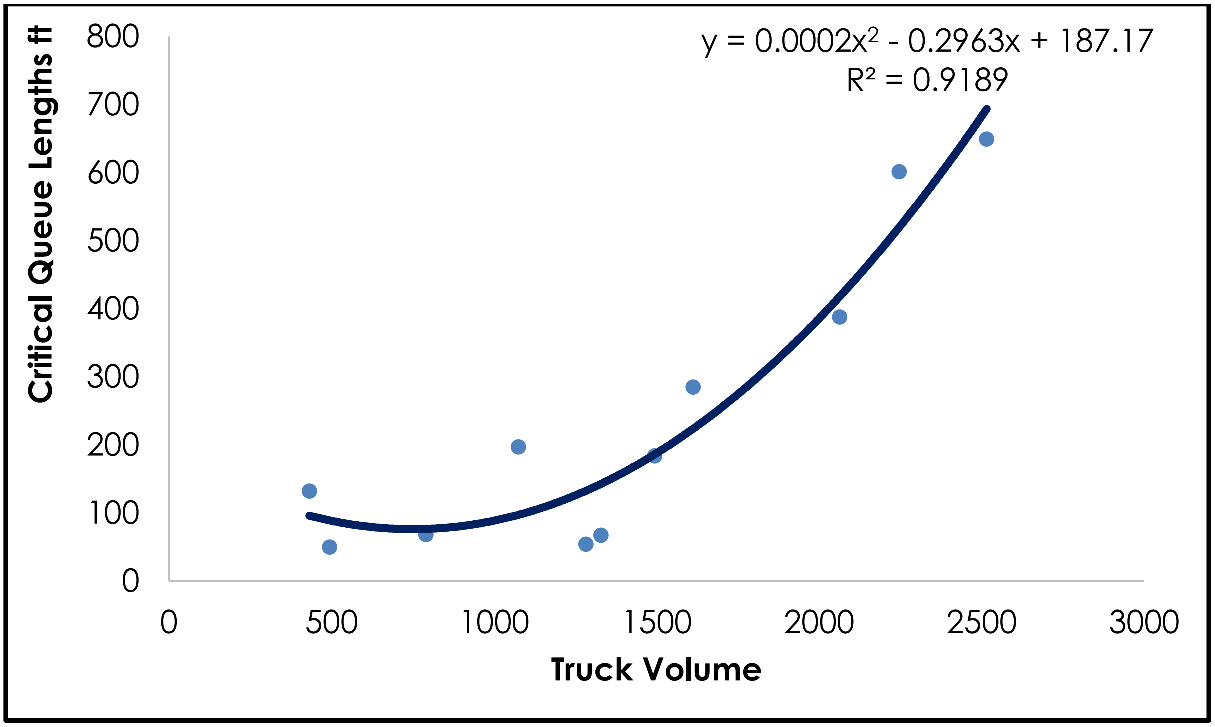


Figure 7.5: Relationship Between Truck Volume and Critical Queue Lengths

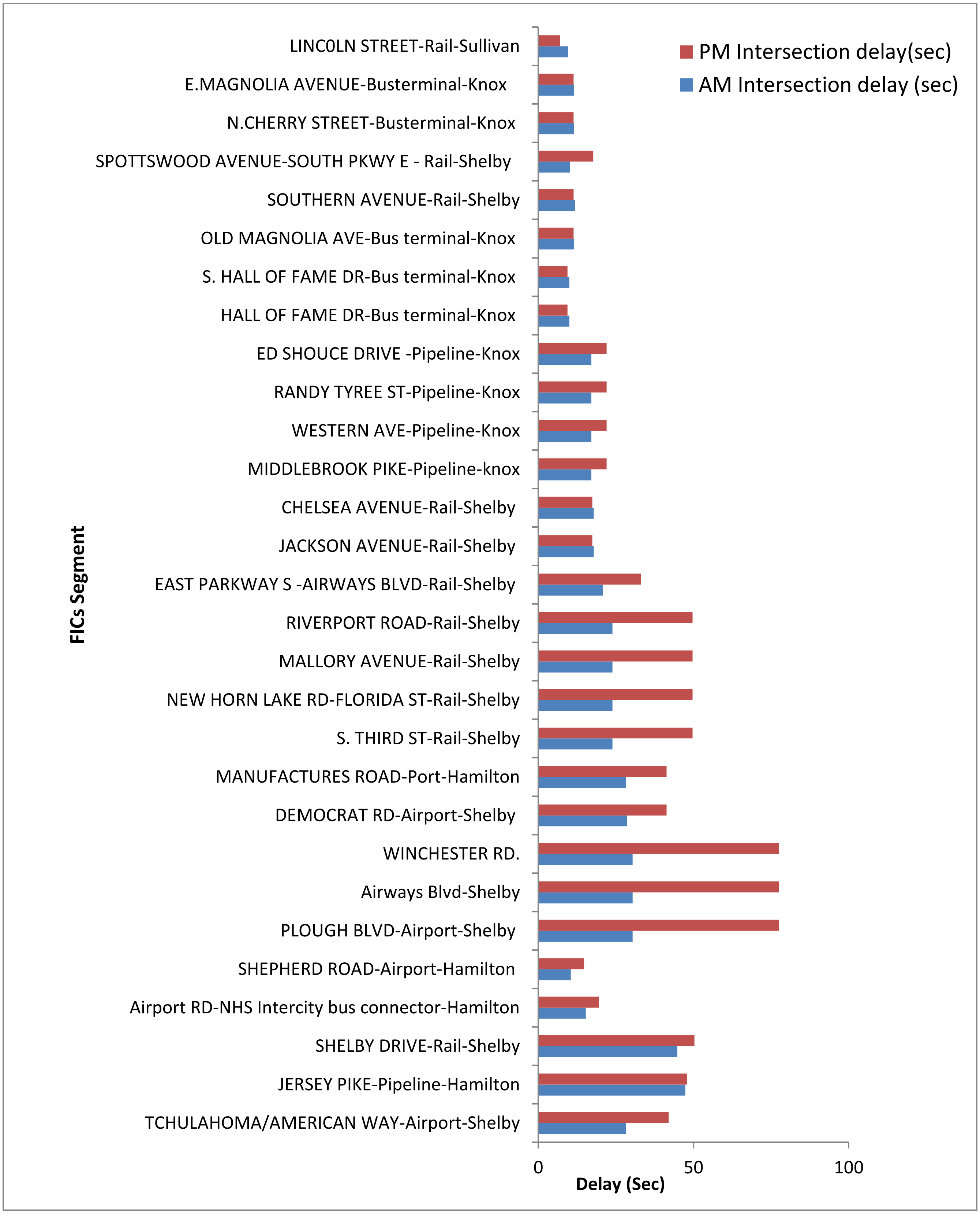


Figure 7.6: FICs AM and PM Delays

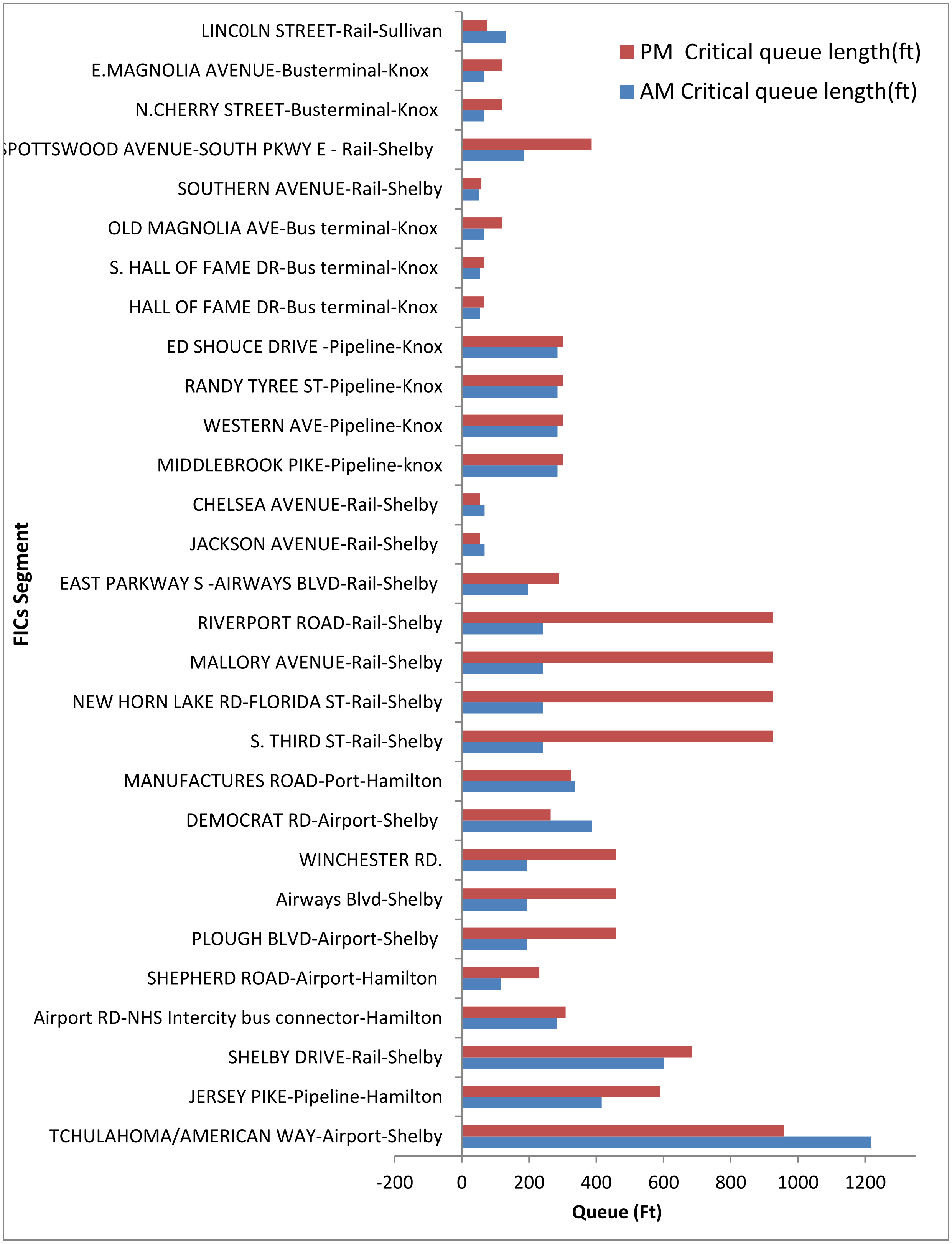


Figure 7.7: FICs AM and PM Critical queue length

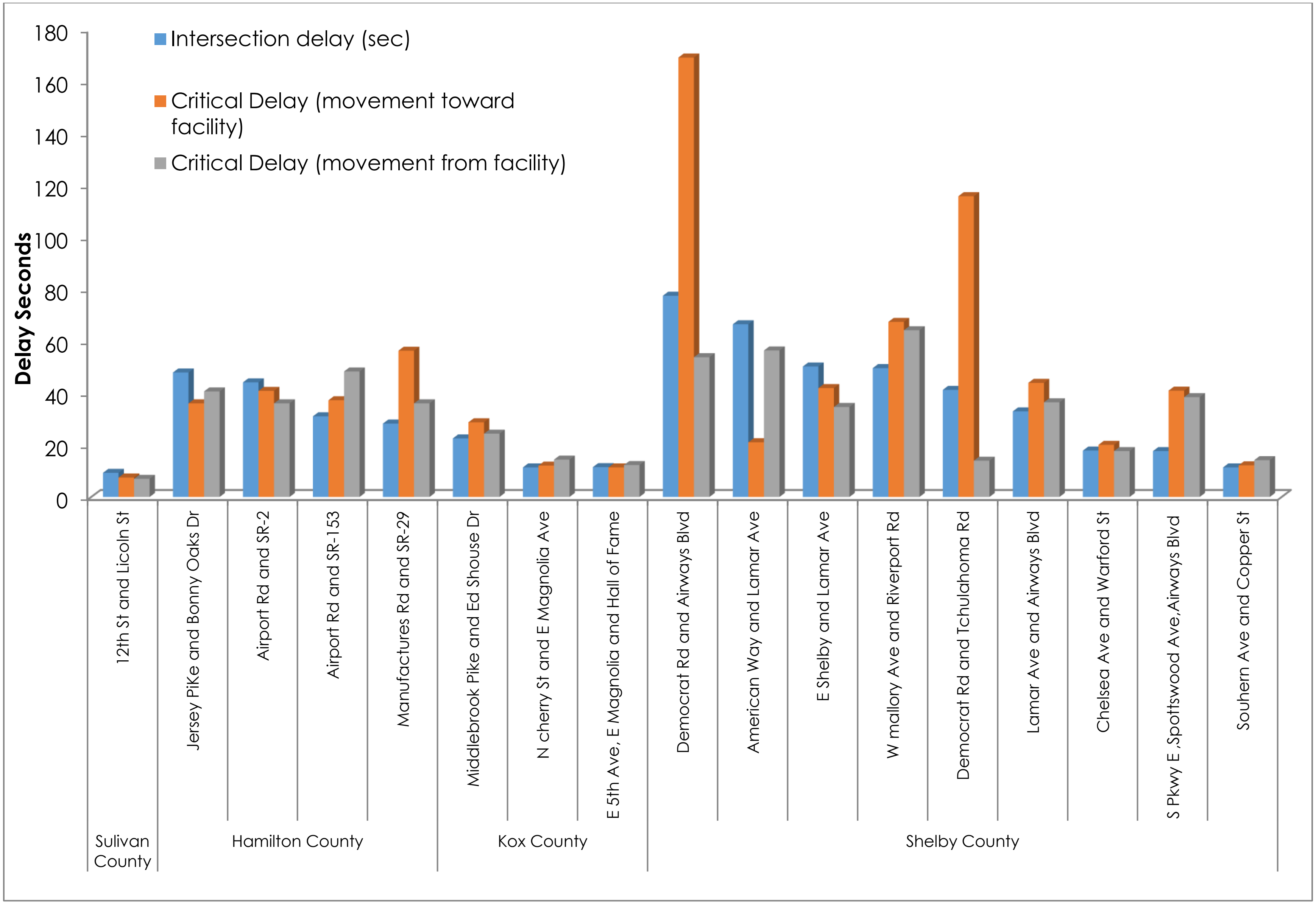


Figure 7.8: Intersection Delays, Critical Delays (Movement to/from the Facilities) by County

7.5. Influence of different performance measures in delay cost per mile

The influence of different intersection and segment operational performance to delay cost per mile was also evaluated. The data distribution was checked by one sample Kolmogorov-Smirnov test for normal distribution. Poisson model (Table 7.1) was therefore applied using the following as the independent variables; intersection level of service, number of lanes, length of the segment, reliability index, average travel time, total delay, intersection delay, queue length and AADT. The results show that, for the intersections with level of service A, B and C, the intersection delay cost per mile length is lower compared to intersection level of service D. The trend of how each intersection level of service influence the delay cost per mile is inconclusive. The low amount of data used for comparison is the most probable cause of this inconclusive trend. Table 7.1 shows that FICs with one lane in each direction have a higher positive coefficient compared to those with two lanes in each direction. The odds ratio is very high which indicates that for each of a two-way two-lane FIC segments, there is a likelihood of higher delay than for a multilane highway. Connector length has a negative coefficient, indicating that as the length of the connector increases the delay cost per unit length decreases. This might be associated with the fact that the acceleration and deceleration phases are not accounting for a large portion of the trip. In this study the connector segments were free from major intersections, meaning the stop start situations were averted in these long connectors. The reliability is the main factor normally considered when determining the route choice for experienced drivers in any route. From the results, the reliability index has a positive coefficient which shows the increase in reliability index of the connector significantly increases the link delay cost per unit mile. The coefficient for average travel time is negative meaning as the average travel time in the connector increases the overall connector delay cost per mile length decreases. The model shows the Annual Average Daily Traffic (AADT) of a connector to be a significant variable in the overall connector delay cost per unit mile. High traffic volume in the connector is shown to increase the connector delay cost per unit mile. This is characterized by the fact that the more vehicles along the connector the less the flexibility of traveling, lane changing, passing maneuver and generally low travel speeds.

TABLE 7.1 Poisson regression model results

Parameter	Coefficient (B)	P-Value	Exp(B)
LOS A	-125.283	0.000	3.9 E-55
LOS B	-70.012	0.000	3.9 E-31
LOS C	-1135.005	0.000	0.000
LOS D (Base)	0[b]		1
Number of lanes 1	463.146	0.000	1.4 E201
Length (mi)	-778.393	0.000	0.000
RI	63.108	0.000	2.6 E27
Average time	-3726.447	0.000	0.000
Total delay	-180.601	0.000	3.7 E-79
Intersection delays	-1.305	0.000	.271
Queue length	-1.608	0.000	.200
AADT	.378	0.000	1.459

8.0. TRAVEL TIME RELIABILITY FLUIDITY ALONG THE FICS

8.1. Overview

Travel time reliability is a key performance measure used by researchers and public agencies in evaluating traffic operational performance. Despite it being a key performance measure, the relationship between different travel time reliability measures remains ambiguous. This chapter shows the relationship between different reliability measures. The study collected GPS second-by-second data, then developed statistical regression models to establish the relationship between reliability performance measures. The developed models show the Reliability Index (RI) has a significant quadratic relation with Travel Time Index (TTI), cubic relation with Planning Time Index (PTI), Misery Index (MI) and Skew Statistics (SS). An evaluation of freight fluidity along FICs was, therefore, conducted with the objective of assessing the travel time reliability and precisely locating bottlenecks. This assessment offered first/ last mile observability, the detailed knowledge of when and where regarding traffic progression and freight movement along the freight intermodal connectors using GPS data. Figure 8.1 shows the general overview of the steps undertaken for the evaluation after GPS data collection.

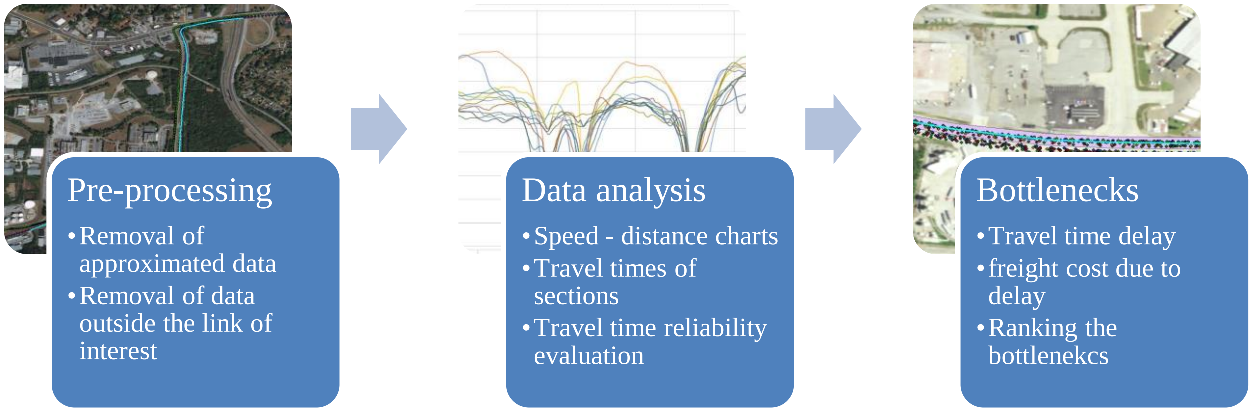


Figure 8.1:Overview of the freight fluidity evaluation

8.2. Data collection and processing

The study used traffic and geometric data from Enhanced Tennessee Roadway Information Management System (eTRIMS), GPS spot speeds and traffic flow data to obtain travel time and computed the following reliability measures: 80th percentile travel time index(reliability index (RI)), Travel Time Index (TTI), Planning Time Index (PTI), Misery Index (MI) and Skew Statistics (SS). The data was collected along 8 different FICs located in 3 different counties, Shelby, Knox and Hamilton as given in Table 8.1. To collect the GPS spot speed and travel time data, the floating car method was utilized using a USB GPS receiver. The driver trailed behind freight vehicles along the intermodal connectors to mimic the speed patterns of freight trucks. At a sampling rate of 1 sec, ArcGIS, a GIS mapping software, was used to directly obtain the real time data (latitude, longitude, heading, spot speed and altitude) in shape files from the USB GPS receiver as the floating car traversed the FICs. The number of runs along each FIC was subject to statistical characterization to determine the adequate sample size that could be used to obtain speed patterns that are representative of the freight trucks along the connectors. Based on the research, the minimum number of sample data that could be used to devise the characteristic of the population was 30. Therefore, 30 runs were performed for each segment.

Table 8.1: FICs assessed for travel time reliability and bottlenecks

FIC	Facility Name	County	Connector Segment	Length
2	Colonial & Plantation Pipeline Co,-Knox	Knox	Middlebrook Pike-Pipeline-Knox	0.507
	Colonial & Plantation Pipeline Co,-Knox	Knox	Western Ave-Pipeline-Knox	0.174
	Colonial & Plantation Pipeline Co,-Knox	Knox	Randy Tyree St-Pipeline-Knox	0.117
	Colonial & Plantation Pipeline Co, Knox	Knox	Ed Shouse Drive -Pipeline-Knox	0.53
7	Greyhound Bus Terminal-Knoxville	Knox	N. Cherry Street-Bus Terminal-Knox	0.49
	Greyhound Bus Termn-Knox	Knox	E. Magnolia Ave-Bus Terminal	1.532
	Greyhound Bus Termn-Knox	Knox	Hall of Fame Dr-Bus Termn-Knox	0.002
	Greyhound Bus Terminal-Knox	Knox	Old Magnolia Ave	0.243
	Greyhound Bus Termn-Knox	Knox	S. Hall of Fame Dr-Bus Termn	0.085
9	Johnston Yards-Memphis Illinois Central	Shelby	Mallory Avenue-Rail-Shelby	1.13
	Johnston Yards-Memphis Illinois Central	Shelby	S. Third St-Rail-Shelby	0.53
10	Johnston Yards-Memphis Illinois Central	Shelby	New Horn Lake Rd-Florida St-Rail-Shelby	0.41
13	Memphis International Airport	Shelby	Tchulahoma/American Way-Airport-Shelby	0.63
	Memphis International Airport	Shelby	Democrat Rd-Airport-Shelby	1.91
14	Memphis Intern. Airport	Shelby	Plough Blvd-Airport-Shelby	1.45
	Memphis Intern. Airport	Shelby	Airways Blvd	0.27
	Memphis Intern. Airport	Shelby	Winchester Rd.	0.36
18	Southern Foundry Supply-Chattanooga	Hamilton	West 19th Street-Port-Hamilton	0.316
21	Vulcan Materials Company-Chattanooga	Hamilton	River Street- Evans St/Molly Lane -Port-Hamilton	0.192

8.3. Analysis of GPS data

Shapefiles for the intermodal connectors were extracted using ArcMap. These shape files underwent various analysis techniques with the objective of removing outliers to give room for accurate analysis. As an initial step, the Thiessen polygon buffer technique was utilized to remove data that fell outside FIC limits as a result of the GPS probe approximating locations and reading during periods of weak signal. A 25-foot-wide buffer from the centerline to each side of the road was generated starting off at the beginning mile marker to the end mile marker of each of the connectors. This technique also involved combining data from the 30 runs of each connector in one layer to discard outliers in batch mode. The processed GPS data was exported to MS Excel for further analysis. An in-depth analysis of the data obtained from the shapefiles involved distance, travel time and travel time reliability computations, identification of bottlenecks and ranking. The GPS coordinates obtained from the GPS data logs were used to compute the distance traveled during data collection and was compared to the distance data obtained from ETRIMS. Equation 8.1 was used for instantaneous distance computation.

$$\mathrm{Dist} = 2\mathrm{R}\sin^{-1}(\sqrt{\sin^2\left(\frac{\mathrm{Lat}_1-\mathrm{Lat}_2}{2}\right) + \mathrm{Cos\ Lat}_1 * \mathrm{Cos\ Lat}_2 * \sin^2\left(\frac{\mathrm{Lo}_1-\mathrm{Lo}_2}{2}\right)} \tag{8.1}$$

Where R = Radius of earth $6.317 * 10^6$ m

$\mathrm{Lat}_{1\text{ or }2}$ = Latitude of the first point or second point

$\mathrm{Lo}_{1\text{ or }2}$ = Longitude of the first and second point

The instantaneous distances were cumulated to give the total distance traveled during data collection for each intermodal connector. The instantaneous speed data recorded using the GPS probe was plotted against cumulative distance to provide speed profiles for the study beds as illustrated with the Johnston Yards connector in Figure 8.2 (where each line individual run). The speed profiles were used to determine the areas where the test vehicle experienced long uninterrupted high speed, speed reductions and stoppage. The graphical representations of speed and cumulative distance also aided in the identification of major intersections where trucks experience speed reductions or stoppage. After identifying the major intersections from the speed profiles, lengths between the major intersections and the beginning of the link were measured using the distance tool in ArcMap, and the data points on the different links were determined. Average travel times and different reliability measures in these links were determined for each travel direction for both AM and PM peak hours.

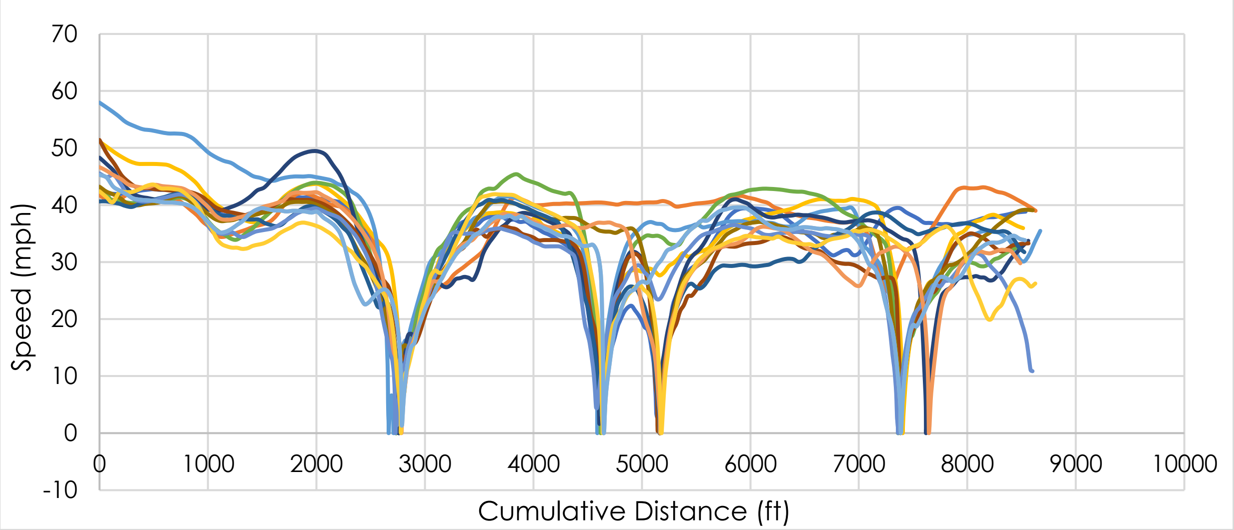


Figure 8.2: Speed Profile for FIC #9. Johnston Yards Memphis Illinois Central

8.4. Time-Based Reliability measures

Figure 8.3 shows how travel time varies, whereby the travel time is minimum when the trucks are traveling at free-flow speed. Buffer time, as seen in Figure 8.3 [51], is the difference between planning time and average travel time. On-time trips are all trips with travel time less than target travel time while failing/late trips are ones with travel time more than target maximum travel time. From the travel time distribution of the trip, time-based reliability measures are derived and proved to be very efficient in operational performance assessment. The following are the commonly used reliability measures and their formulas [52, 53].

- *80th percentile Travel time index/Reliability index (TTI_{80})*: this is sensitive to operational changes and research shows it is the most useful and recommended by HCM 6th edition. It's the ratio of the 80th percentile travel time to the free flow travel time.

  $$Reliability\ Index = t_{80}/t_{ffs} \qquad (8.2)$$

  Where t_{80} = 80th percentile travel time in a link

  t_{ffs} = Link travel time under free flow condition

- *50th percentile Travel time index (TTI_{50})*: This has generally lower values than the reliability index due to the presence of longer travel times in overall travel time distribution. It's the ratio of the 50th percentile to the free flow travel time

  $$50th\ percentile\ Travel\ time\ index = t_{50}/t_{ffs} \qquad (8.3)$$

  Where t_{50} = 50th percentile travel time in a link

- *Buffer Index (BI)*: This is the measure determining how much fractional additional time (time cushion) a traveler should put on top of normal travel time to have 95% chance of on time arrival. It is given as the ratio of the difference between 95th percentile travel time and average travel time.

$$Buffer\ Index = \frac{t_{95} - t_{avg}}{t_{avg}} \qquad (8.4)$$

- *Planning time Index (PTI):* This takes account of the extreme times when travel conditions are in the worst operational performance. At ideal system conditions the PTI equals TTI_{50}. It is given as the ratio of the 95th percentile travel time and the free flow travel time.

$$Planning\ time\ index = t_{95}/t_{ffs} \qquad (8.5)$$

- *Skew statistic (SS)*: This shows how much the travel time varies above the mean compared below the mean. It's given as the ratio of the change in 90th percentile travel time and mean travel time to change in mean travel time and 10th percentile travel time.

$$Skew\ Statistic = \frac{t_{90} - t_{avg}}{t_{avg} - t_{10}} \qquad (8.6)$$

- *Misery Index (MI):* This gives the description of the nearly worst-case condition. It's given as the ration of the 97.5 percentile travel time to the free flow travel time.

$$Misery\ index = t_{97.5}/t_{ffs} \qquad (8.7)$$

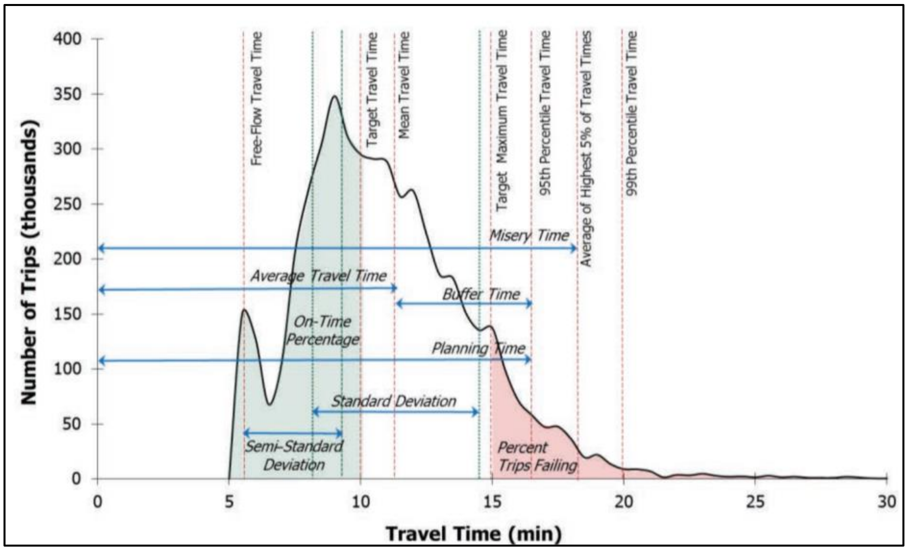


Figure 8.3. Variation of travel time and travel time reliability

8.5. Relationship between Travel Time Measures

Figure 8.3 shows the relationship between different travel time reliability measures. As shown in Figure 8.4, the misery index (MI) has the highest values compared to other reliability measures along the connectors while the buffer index (BI) constantly had the lowest values along the connectors. The skew statistic has the most diverse index measure compared to others while the travel time index (TTI) and planning time index (PTI) have the least diverse indexes.

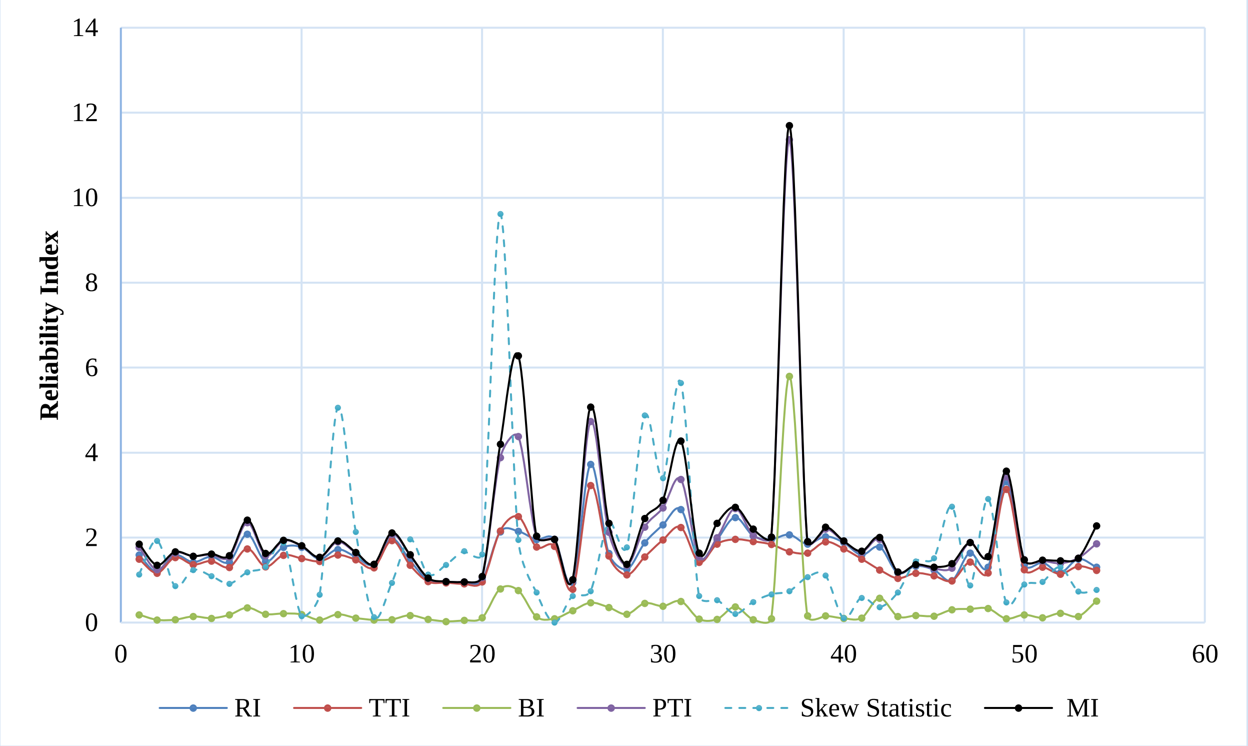


Figure 8.4: The relationship between the reliability indexes

The relationship between various reliability measures were assessed, first by using the Pearson linear correlation to check if different reliability measures have significant relation to each other. The correlation results are shown in Table 8.2. The reliability index (RI) has a significantly strong positive linear correlation with travel time index (TTI), planning time index (PTI) and misery index (MI). However, RI has a weak positive correlation with the buffer index (BI) and skew statistic. Curvilinear regression models were performed to establish the relationship between reliability index (80th percentile travel time index) and other reliability measures while assessing the significance and fitness of the model. The buffer index was found to have no significant relationship with the reliability index. The relationship between the reliability index and other parameters was estimated using curvilinear regression analysis. The regression models showed that reliability index has a quadratic relation with travel time index given by equation (8.8):

$$RI = 0.305TTI^2 - 0.068TTI + 0.964 \tag{8.8}$$

RI was found to have a cubic relation to planning time index, misery index and skew statistics as shown in equations 12-14.

$$RI = -0.003xPTI^3 - 0.016PTI^2 + 0.752PTI + 0.284 \tag{8.9}$$

$$RI = 0.005MI^3 - 0.133MI^2 + 1.112MI + 0.005 \tag{8.10}$$

$$RI = -0.016xSI^3 + 0.23SI^2 - 0.729SI + 2.046 \tag{8.11}$$

From regression models, conversion of the value of other reliability measures to the reliability index (80th percentile travel time index) was possible, and operational performance evaluation can be done.

Table 8.2: Linear correlation results for travel time reliability measures

		RI	**TTI**	**BI**	**PTI**	**Skew Statistic**	**MI**
RI	Pearson Correlation	1					
TTI	Pearson Correlation	.837	1				
	Sig. (2-tailed)	.000					
BI	Pearson Correlation	.138	.142	1			
	Sig. (2-tailed)	.321	.305				
PTI	Pearson Correlation	.484	.478	.863	1		
	Sig. (2-tailed)	.000	.000	.000			
Skew Statistic	Pearson Correlation	.105	.108	.103	.122	1	
	Sig. (2-tailed)	.452	.437	.459	.379		
MI	Pearson Correlation	.490	.488	.859	.984	.128	1
	Sig. (2-tailed)	.000	.000	.000	.000	.356	

8.6. Analysis and Results

To provide a general overview of the state of the studied FICs, travel time and average link speed were tabulated and ranked in Table 8.3. The graphical representations of the travel time and average link speed are also shown in Figure 8.5 and 8.6 respectively. Figure 8.6 shows that trucks took the most time traversing through the intermodal connectors linking to the Memphis International Airport as compared to other studied connectors.

Table 8.3: FIC Travel time and Average link speed data

Connector	Distance (miles)	Speed (mph)	Time (min)
Johnston Yards-Memphis Illinois Central	0.41	26.2	0.96
Southern Foundry Supply-Chattanooga	0.30	18.1	0.98
Vulcan Materials Company-Chattanooga	0.26	14.8	1.04
Memphis International Airport	1.99	53.2	2.24
Colonial & Plantation Pipeline Co-Knox	1.24	28.5	2.63
Greyhound Bus Terminal-Knoxville	1.25	23.7	3.14
Johnston Yards-Memphis Illinois Central	1.97	33.9	3.56
Memphis International Airport	2.26	33.1	4.10

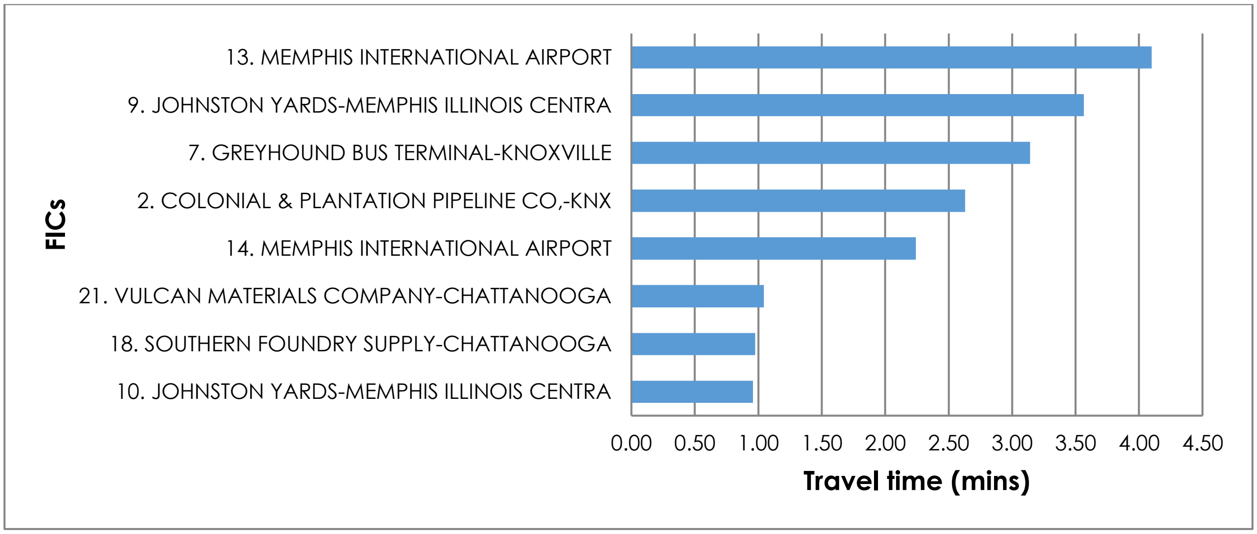


Figure 8.5: Ranking of FIC Travel time

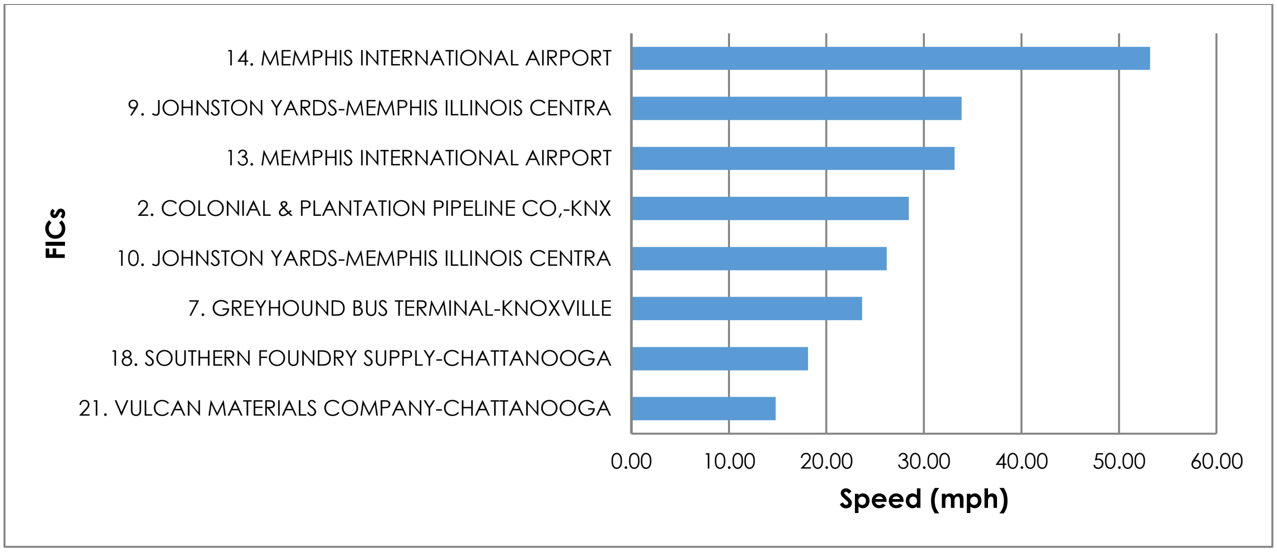


Figure 8.6: Ranking of FIC Average link speed data

Considering that the observed average link speed along this connector was 33.1 mph, the travel time was mainly attributed to the length of the connector. Using speed and the distance travel data, travel time reliability was determined by computing the 80th percentile reliability index (RI). As a first step, the threshold speed of each segment of an intermodal connector link was determined. Using the computed link segment distance, both travel time along the link at ideal conditions and at the 80th percentile were calculated. Reliability index of each FIC segment was then calculated using equation 8.12. The bottlenecks were identified as the road sections where the freight movement experiences reduced efficiency. The bottlenecks were identified along the links where travel times were unreliable using thresholds in Table 8.4. The cumulative freight travel time delay for the unreliable links was determined using equation 8.12 and average cost due to delay was calculated using equation 8.13. The bottlenecks were ranked based on delay cost as shown in Table 8.5 and Figure 8.7.

$$\text{Total Truck Delay} = \text{Average Travel Time} - \text{FFS Travel Time} * V * \%T \qquad (8.12)$$

Where V = Average link volume during peak hour

t%= Percentage truck composition of the link

$$\text{Cost due to Freight Delay} = \text{Total Truck Delay} * \text{Average Delay Cost} \qquad (8.13)$$

Table 8.4: Travel time reliability

Reliability Index	Travel Time Reliability
1 to 1.5	Reliable
1.5 to 2	Moderately reliable
> 2	Unreliable

Table 8.5: List of identified Bottlenecks and related delay costs

FIC Segment	Reliability Index	Average time (min)	Delay per veh (min)	Total delay (hrs)	Delay Cost ($)
2. Western Ave-Pipeline-Knox (PM)	3.72	0.52	0.29	1.39	122.56
7. Old Magnolia Ave-Bus Terminal-Knox (AM)	2.47	0.64	0.31	0.53	46.48
7. Old Magnolia Ave-Bus Terminal-Knox (AM)	2.04	0.73	0.36	0.62	54.34
2. Middlebrook Pike-Pipeline-Knox (Pm)	2.3	0.83	0.57	2.77	243.37
13. Democrat Rd-Airport-Shelby (Pm)	2.08	0.94	0.40	1.03	90.26
18. West 19 Street-Port-Hamilton (Pm)	2.14	1.04	0.56	0.12	10.89
18. West 19 Street-Port-Hamilton (Am)	2.15	1.12	0.67	0.15	13.08
7. N. Cherry Street-Bus Terminal-Knox (AM)	2.07	1.20	0.48	0.83	73.28
2. Ed Shouse Drive-Pipeline-Knox (Pm)	2.67	1.45	0.70	3.41	299.80
13. Democrat Rd-Airport-Shelby (Pm)	2.08	3.26	1.58	4.06	357.10
7. E. Magnolia Avenue-Bus Terminal-Knox (PM)	2.03	3.42	1.62	2.80	246.14
7. E. Magnolia Avenue-Bus Terminal-Knox (AM)	1.96	3.81	1.74	3.00	264.13

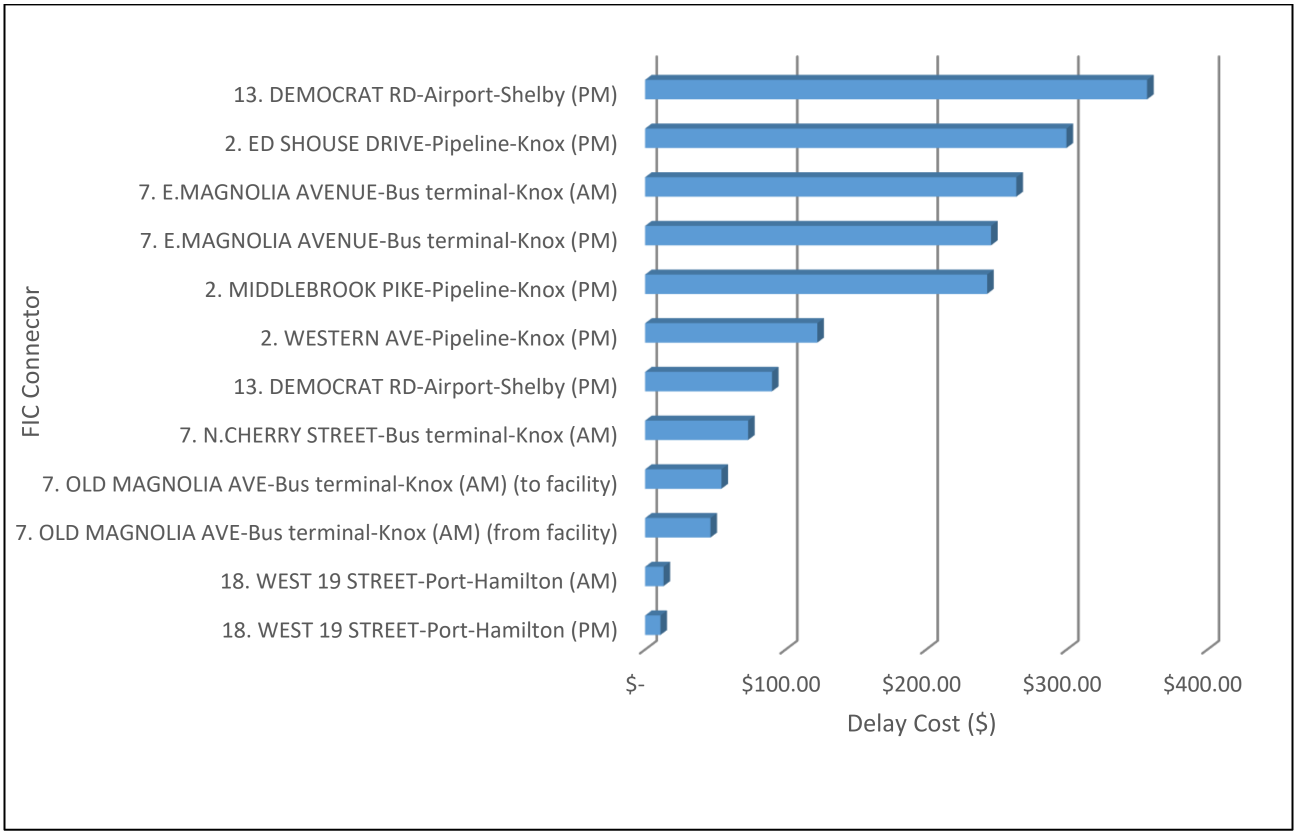


Figure 8.7: Ranking of bottlenecks and hourly loss by freight companies

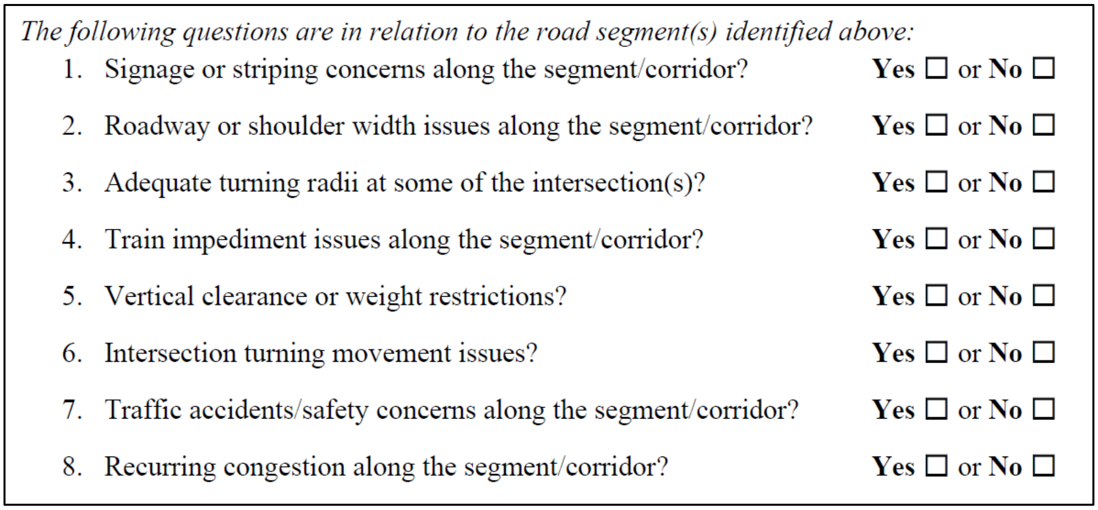
9.0. TRUCK DRIVER SURVEY ANALYSIS

9.1. Overview

The survey was conducted to evaluate Freight Intermodal Connectors (FICs) in Tennessee from the stakeholders' (truck drivers') perspective. In addition to the 22 designated FICs, other freight intensive connectors were identified in Clarksville, Smyrna, and Portland; these were also included in the study, as shown in the questionnaire in the Appendix. The purpose of this survey was to gather information regarding the operation and functionality of the freight transportation infrastructure along FICs in the state of Tennessee. To obtain the survey data, a three-page questionnaire was developed and distributed in-person to various freight facilities all over Tennessee in Memphis, Knoxville, Kingsport, Nashville, Portland, Clarksville, and Chattanooga; 42 freight facilities that utilize the studied FICs were considered for the study. All the target facilities were visited and addressed with the project proposal, and 95% of these freight hubs were willing to facilitate the study.

9.2. Evaluation of Survey Data

The questionnaire was composed of 18 multiple choice questions and four free-response questions, and the results obtained were analyzed in MS Excel and are presented in figures 9.1 to 9.11. The Truck Driver Survey targeted 420 drivers statewide from the 42 freight facilities to assess the studied FICs, and feedback was obtained from 36 drivers. The questionnaire started with questions shown in figure 9.1, to determine issues/ concerns faced by truck drivers. Figure 9.2 shows the responses obtained from the 36 drivers. As reported from the survey, the biggest issue that the drivers are currently facing is recurring congestion along the FICs. Given the size of freight trucks, turning movement at intersections is also another issue of concern as indicated by the 50% of the truck drivers who participated. In addition to the issues related to the FICs, the questionnaire focused on a general basis to determine the importance of various factors on freight transportation efficiency, namely signage, safety and security, bottlenecks, direct/ indirect cost of congestion, on-time delivery, and infrastructure condition, as shown in Figure 9.3.



The following questions are in relation to the road segment(s) identified above:

1. Signage or striping concerns along the segment/corridor? **Yes** ☐ or **No** ☐
2. Roadway or shoulder width issues along the segment/corridor? **Yes** ☐ or **No** ☐
3. Adequate turning radii at some of the intersection(s)? **Yes** ☐ or **No** ☐
4. Train impediment issues along the segment/corridor? **Yes** ☐ or **No** ☐
5. Vertical clearance or weight restrictions? **Yes** ☐ or **No** ☐
6. Intersection turning movement issues? **Yes** ☐ or **No** ☐
7. Traffic accidents/safety concerns along the segment/corridor? **Yes** ☐ or **No** ☐
8. Recurring congestion along the segment/corridor? **Yes** ☐ or **No** ☐

Figure 9.1: Excerpt from the Truck Driver Survey for Qn.1

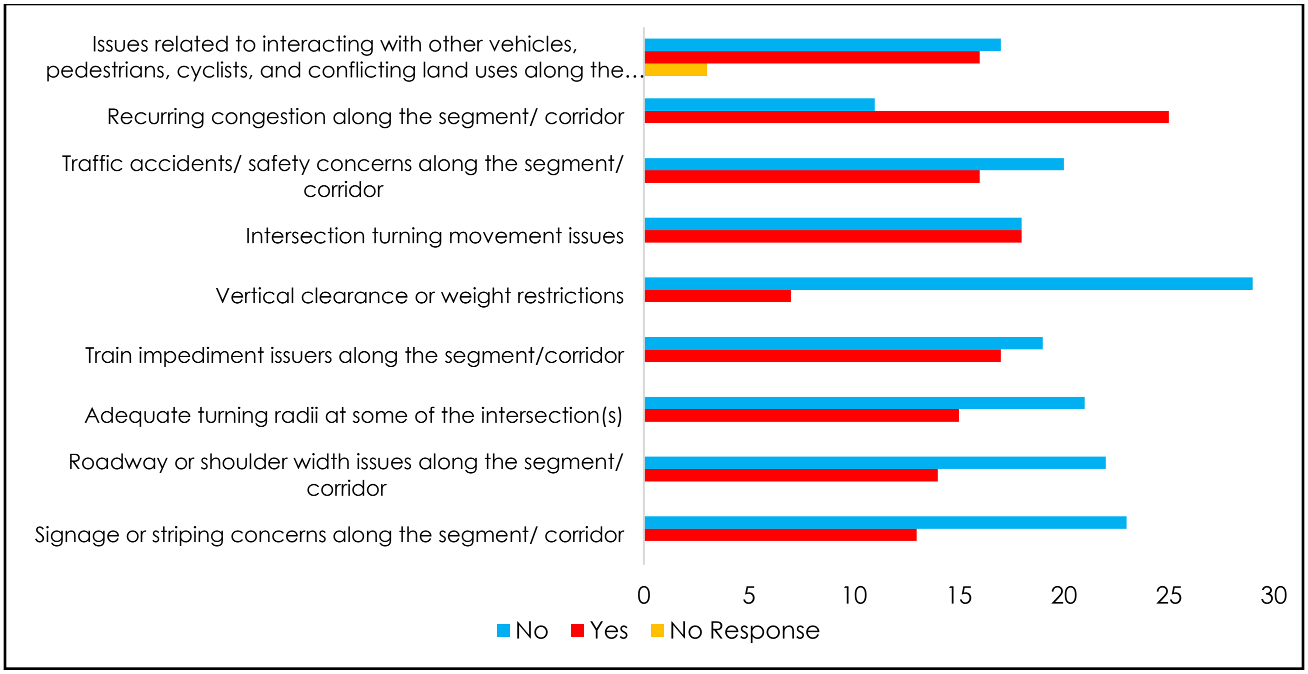
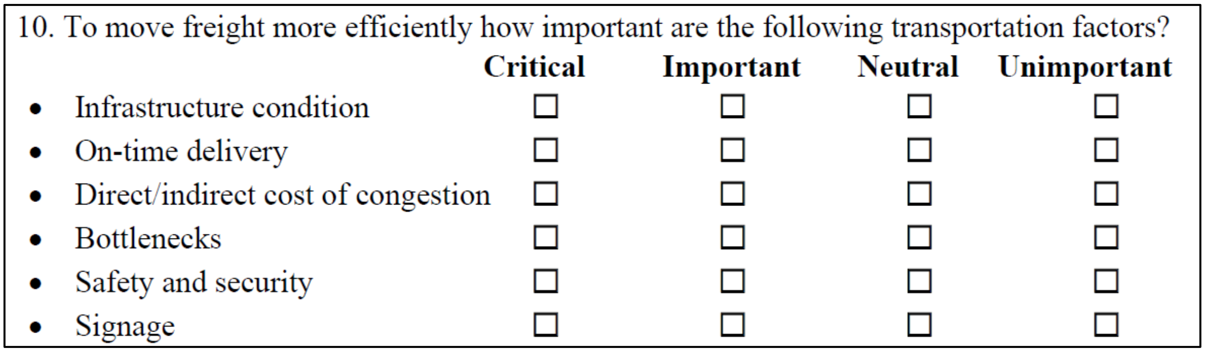


Figure 9.2: Issues related to Freight Intermodal Connectors



10. To move freight more efficiently how important are the following transportation factors?

	Critical	**Important**	**Neutral**	**Unimportant**
• Infrastructure condition	☐	☐	☐	☐
• On-time delivery	☐	☐	☐	☐
• Direct/indirect cost of congestion	☐	☐	☐	☐
• Bottlenecks	☐	☐	☐	☐
• Safety and security	☐	☐	☐	☐
• Signage	☐	☐	☐	☐

Figure 9.3: Excerpt from the Truck Driver Survey for Qn.10

From the survey data, bottlenecks were deemed to be the most critical for efficient transportation; 56% of the respondents reported this as illustrated in figure 9.4. In general, most of the respondents rated all the factors as either critical or important; this, therefore, highlights the need to carefully assess these factors to address the issue of efficiency in freight transportation in Tennessee.

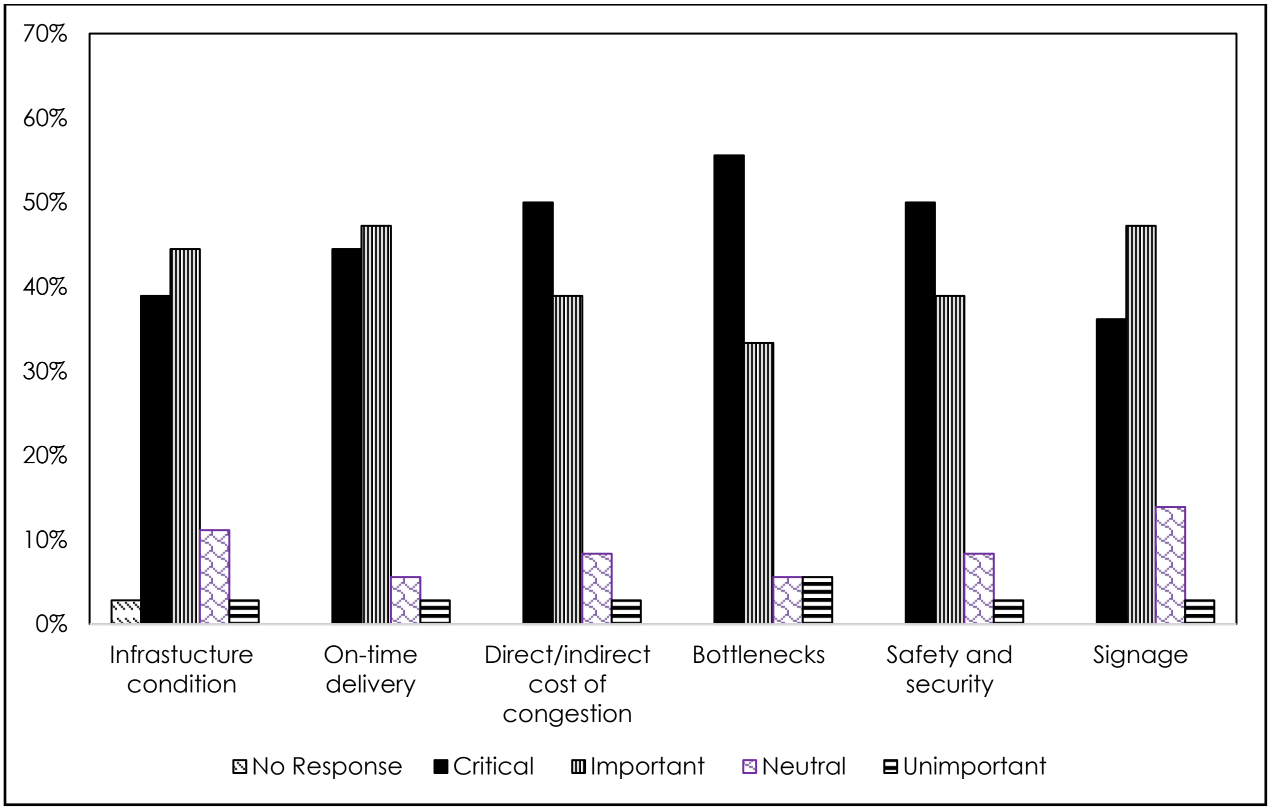
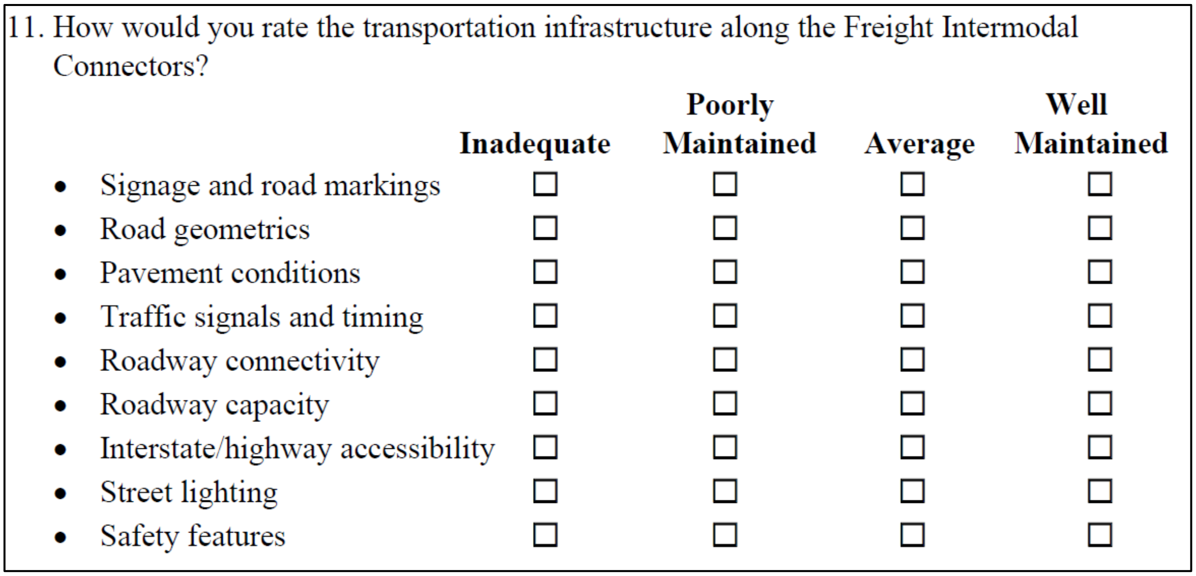


Figure 9.4: To move freight more efficiently, how important are the following transportation factors?

Figure 9.5 and 9.6 offer a statewide perspective of the transportation infrastructure along the FICs. The question addresses safety features, street lighting, interstate/highway accessibility, capacity, connectivity, traffic signals and timing, pavement conditions, roadway geometrics, signage, and pavement markings. The respondents designated pavement condition as being poorly maintained and the most significant cause for concern. This is also supported by responses in Figure 9.7 on pavement condition of the road segments where only 25% of the truck drivers perceive these to be in good conditions.



11. How would you rate the transportation infrastructure along the Freight Intermodal Connectors?

	Inadequate	Poorly Maintained	Average	Well Maintained
• Signage and road markings	☐	☐	☐	☐
• Road geometrics	☐	☐	☐	☐
• Pavement conditions	☐	☐	☐	☐
• Traffic signals and timing	☐	☐	☐	☐
• Roadway connectivity	☐	☐	☐	☐
• Roadway capacity	☐	☐	☐	☐
• Interstate/highway accessibility	☐	☐	☐	☐
• Street lighting	☐	☐	☐	☐
• Safety features	☐	☐	☐	☐

Figure 9.5: Excerpt from the Truck Driver Survey for Qn.11

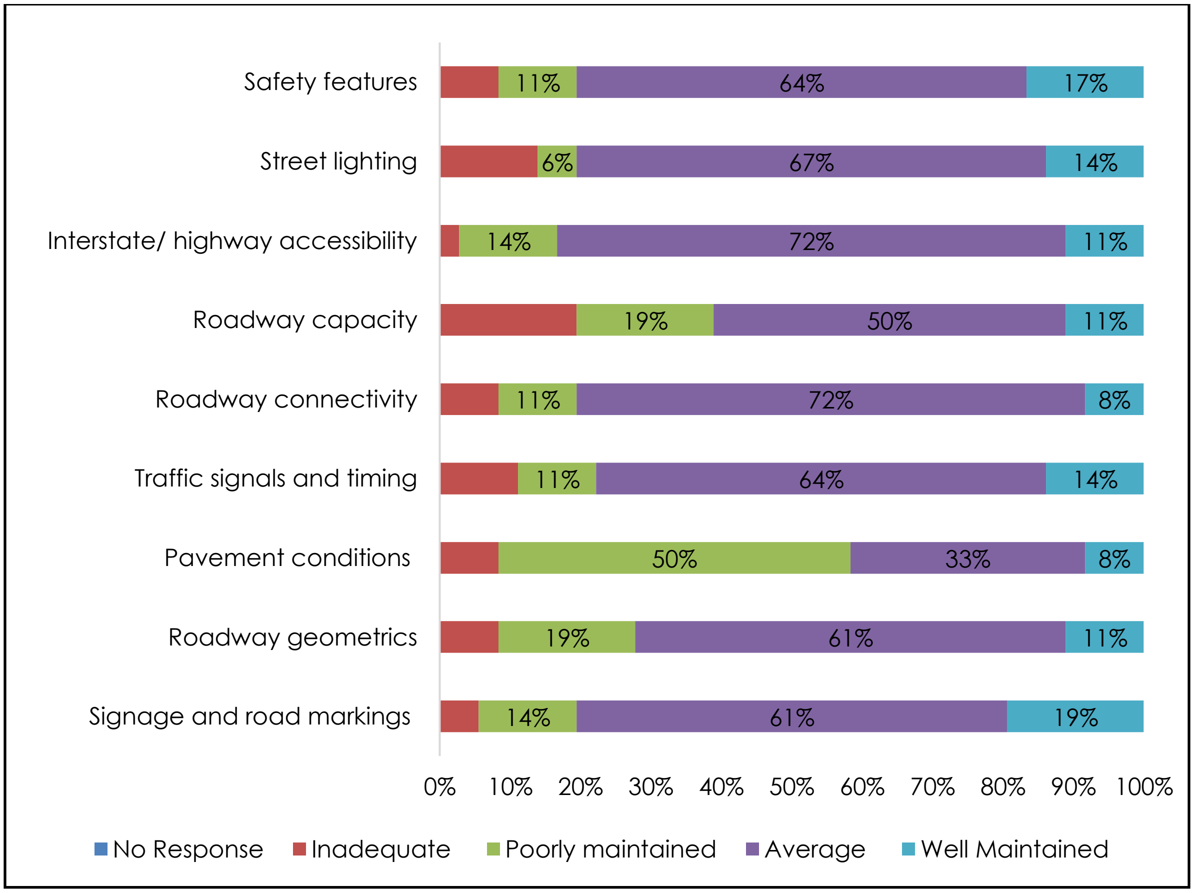


Figure 9.6: How would you rate the infrastructure along the Freight Intermodal Connectors?

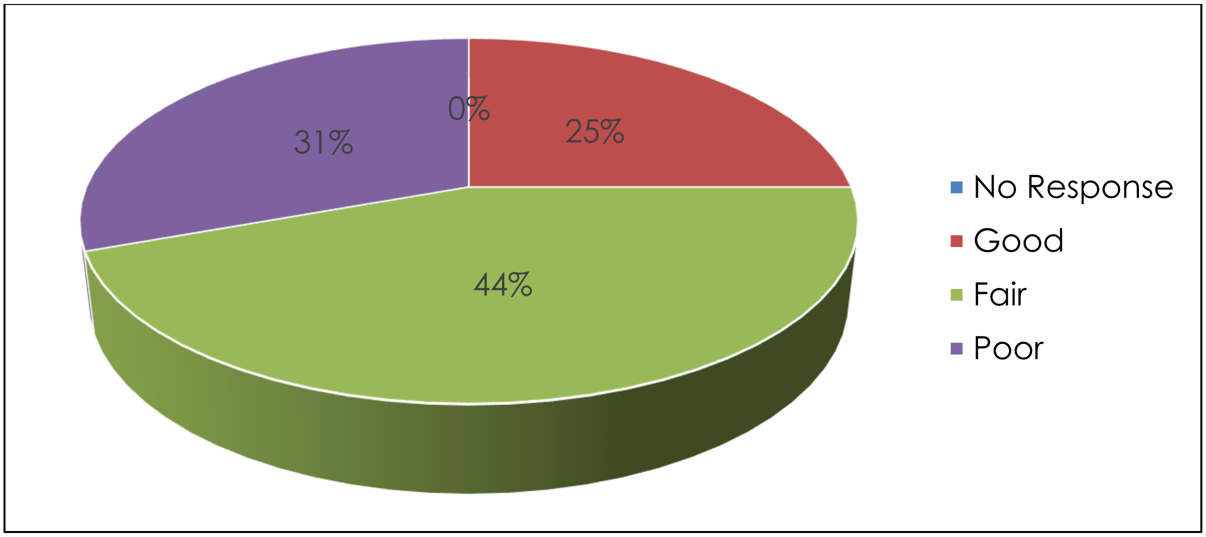
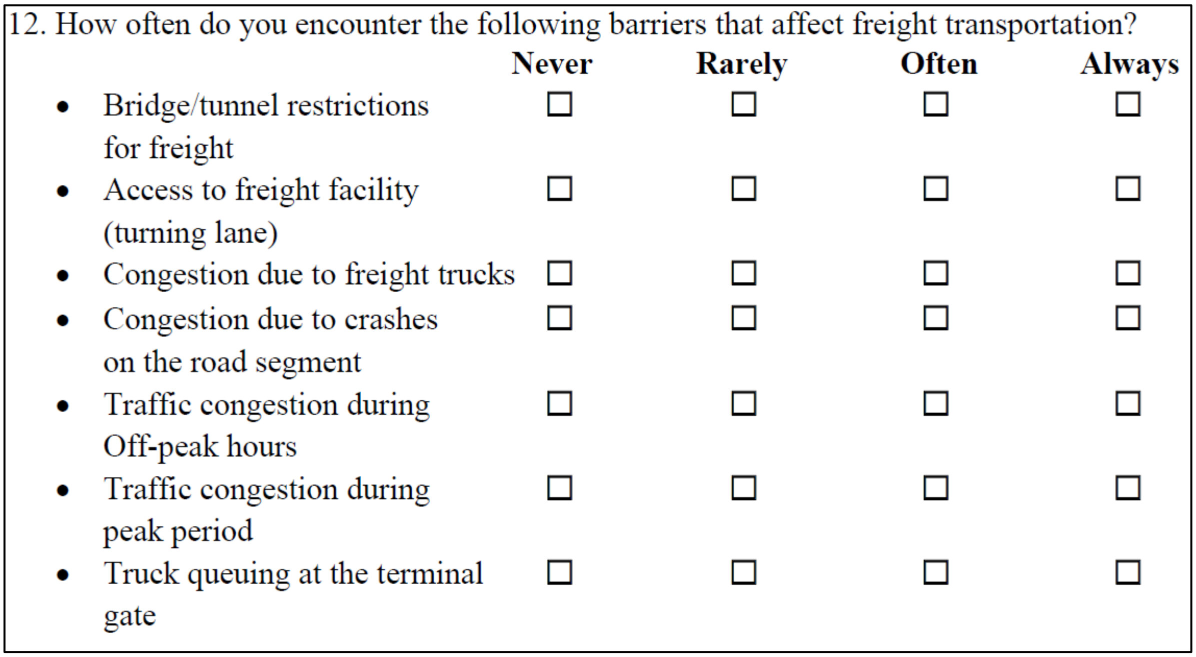


Figure 9.7: Pavement conditions of the road segment(s)?

In Figure 9.8 and 9.9, traffic congestion during the peak period is identified as the most recurrent barrier that is affecting freight transportation along FICs. 83 % of the truck drivers reported 'often' or 'always' in response to question 12 in Figure 9.8. Even though 42% of the respondents rarely encounter congestion, 58% often or always experience congestion along connectors. Responses in Figure 9.10 and 9.11 reinforces the concern for congestion and shows vehicles as the primary cause.



12. How often do you encounter the following barriers that affect freight transportation?

	Never	Rarely	Often	Always
• Bridge/tunnel restrictions for freight	☐	☐	☐	☐
• Access to freight facility (turning lane)	☐	☐	☐	☐
• Congestion due to freight trucks	☐	☐	☐	☐
• Congestion due to crashes on the road segment	☐	☐	☐	☐
• Traffic congestion during Off-peak hours	☐	☐	☐	☐
• Traffic congestion during peak period	☐	☐	☐	☐
• Truck queuing at the terminal gate	☐	☐	☐	☐

Figure 9.8: Excerpt from the Truck Driver Survey for Qn.12

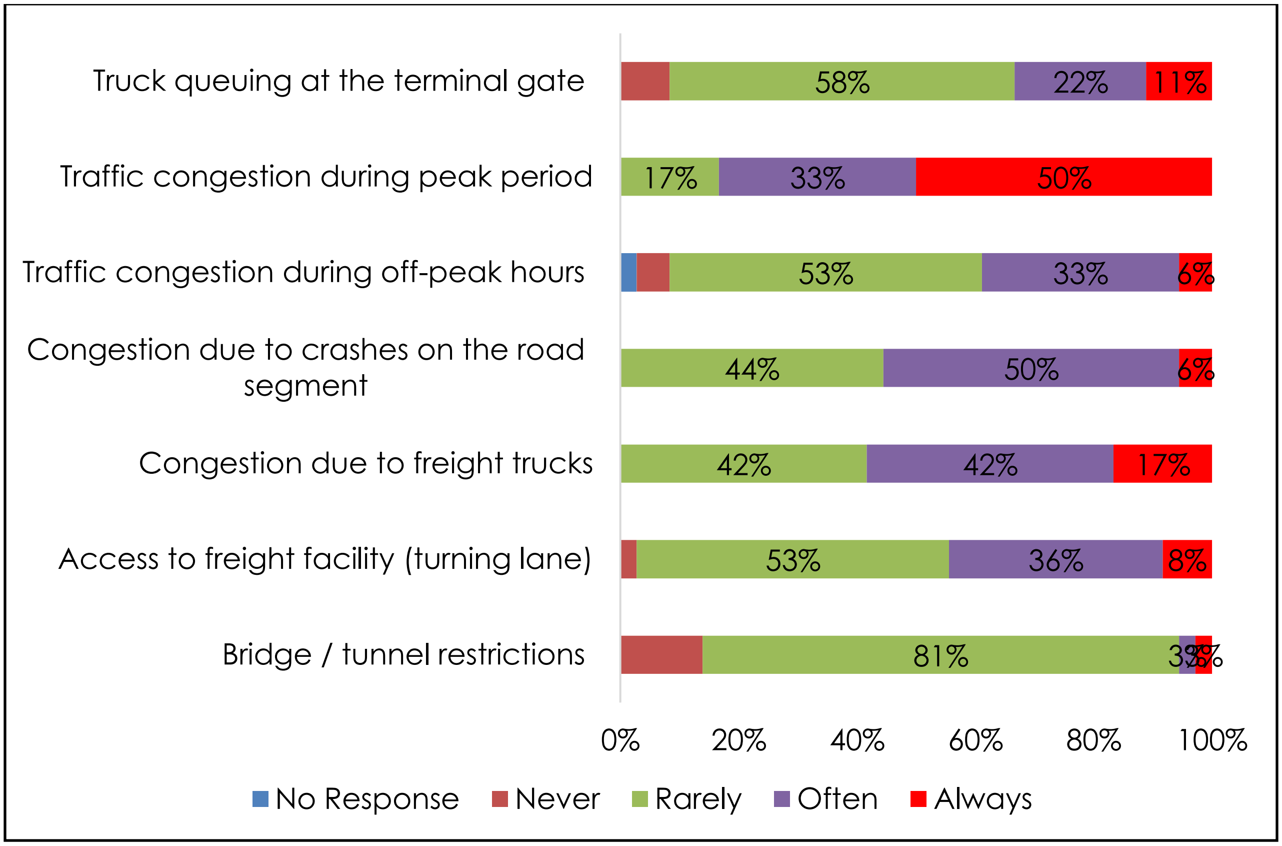


Figure 9.9: How often do you encounter the following barriers that affect freight transportation

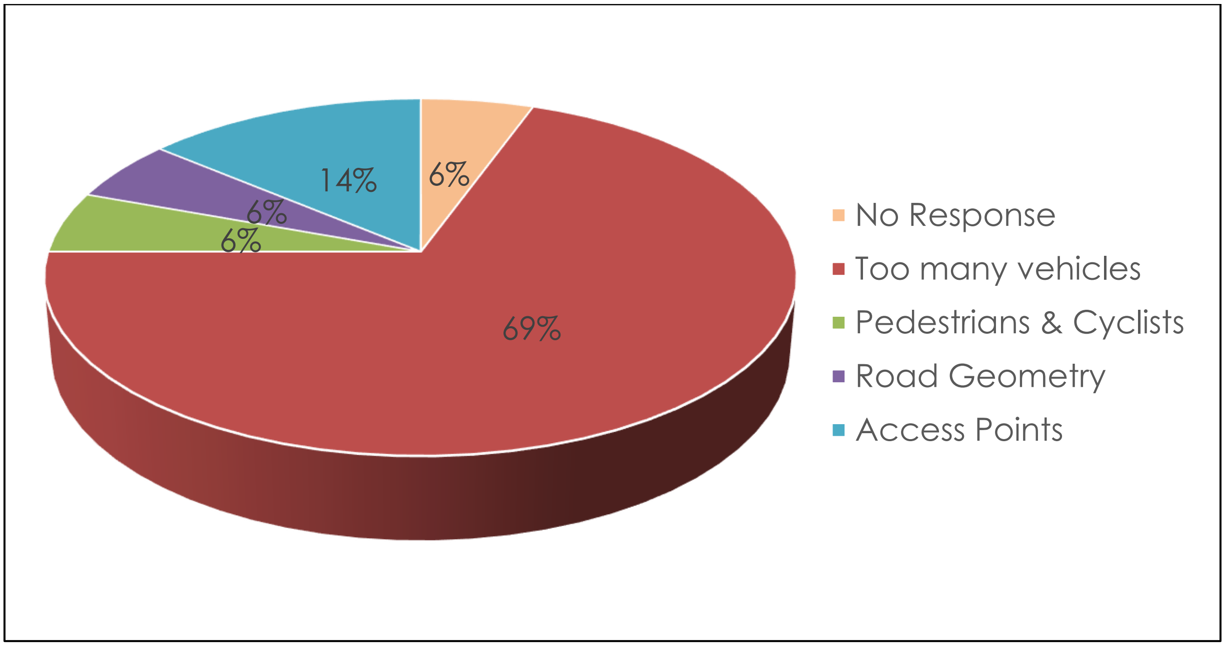


Figure 9.10: In your opinion, what causes traffic congestion along this segment(s)?

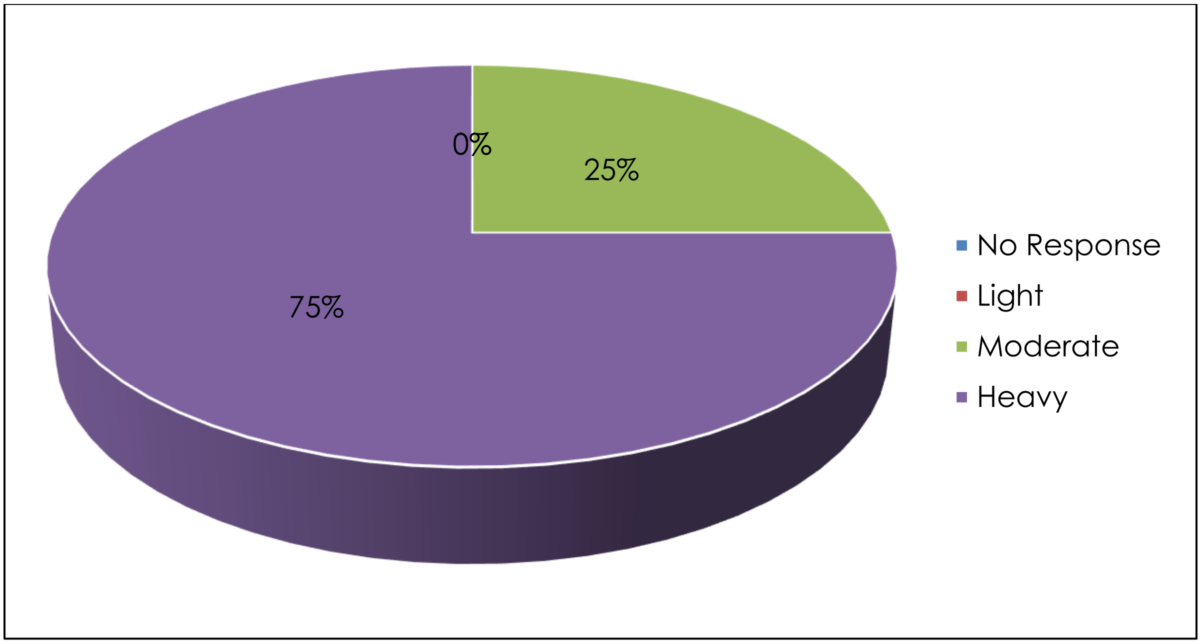


Figure 9.11: Rate the peak hour traffic congestion along the road segment(s)?

Despite these segments being freight intensive corridors, the safety of other road users is still of great importance. Figure 9.12 shows that 56%, 53% and 39% of the truck drivers pointed out the absence of bike lanes, sidewalks, and pedestrian crossings along their routes.

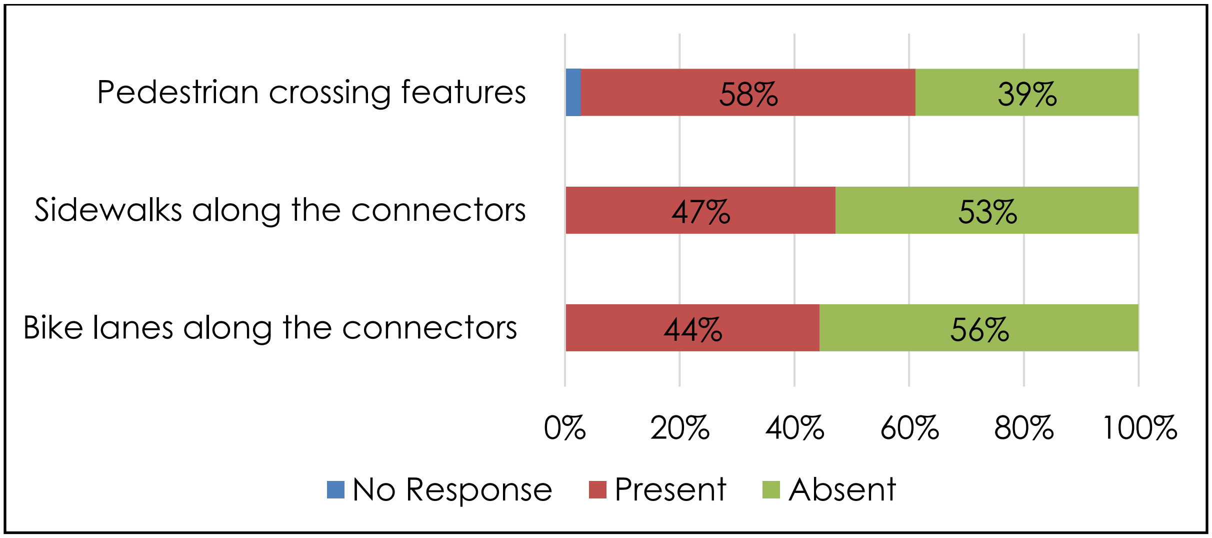


Figure 9.12: Are any of these features available?

The environmental impact of FICs is discussed in Chapter 10. As illustrated in Figure 9.13, only 28% of the respondent's experienced negative environmental issues when traveling along the FICs. About 61% of the truck drivers encountered situations whereby they have been forced to reroute, seen in Figure 9.14. About 19.4% of the respondents had alternative routes that helped them navigate from the freight facility to the highway and vice versa. Overall, the respondents provided the following concerns along the connectors: potholes, bottlenecks, clearer signs and better access points.

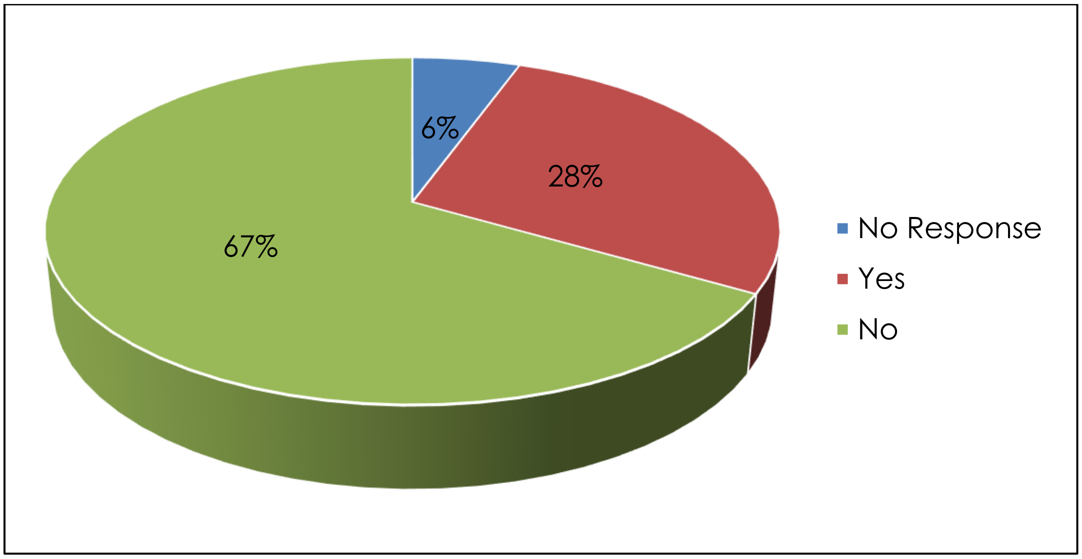


Figure 9.13: Do you experience any environmental issues while traveling along the road segment(s) (air pollution)?

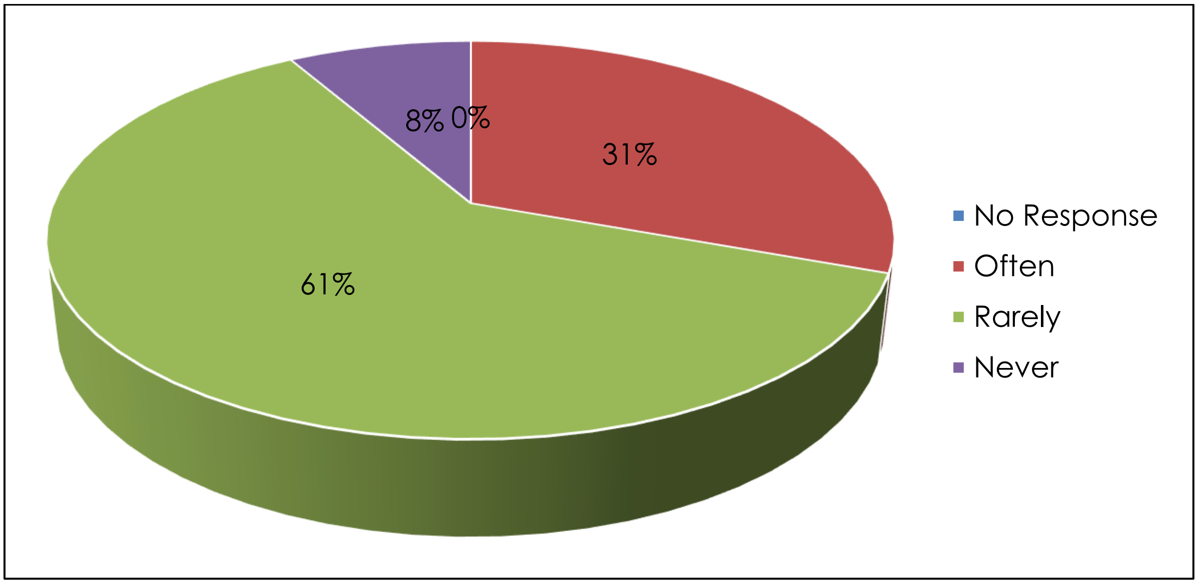


Figure 9.14: How often do you have to reroute to get to the freight facility?

10.0. EMISSION ANALYSIS

10.1. Emission Analysis Overview

The emission analysis aimed at evaluating CO, NO_x, PM 2.5 and VOCs using EPA mobile source emissions model, MOVES2014a to estimate total vehicle and truck emissions along the FIC segments on a second-by-second basis in combination with VISSIM simulation software. The emissions results along the different connectors were tabulated, ranked and compared.

10.2. Emission Evaluation Data

This portion of study was orchestrated by conducting data collection, model simulations, and data analysis. Data collection involved obtaining traffic and geometric data from different sources for use in simulation modeling to perform the required runs. 22 freight intermodal connectors were looked at, and each connector comprised of different connector segments that were combined in model simulations. Synchro, VISSIM, and MOVES were used to execute these simulations, and the emissions results along different connectors were tabulated, ranked and compared. The analysis also comprised of comparing the emission results with vehicle characteristics such as vehicle volume, composition, and posted speed limits. These in-depth relationships were established with the use of nonlinear least-squares estimation. Conventional statistical analysis endorses the use of regression models to investigate observational relationships and generate predictions.

The Enhanced Tennessee Roadway Information Management System (E-TRIMS), Google Earth, TDOT traffic history website and site inventory provided the data required for model simulations. Data obtained included speed limits, road geometrics, lane widths, beginning log miles, end log miles, number of lanes, the FICs' route numbers, directional distributions and AADT, which were used to compute the hourly peak flows. A list of Tennessee's designated FICs was reviewed on the E-TRIMS database and verified with the use of site inventory. Google Earth served the purpose of ascertaining the geometric data retrieved from E-TRIMS for the studied road segments. A summary of the data that was gathered is given in Table 10.1.

Table 10.1: Data collected for the FICs

FIC No.	FIC Facility Name	Length (miles)	AADT	Peak Hour Volume	Passenger Car %	Truck %
1	Chattanooga Metro Airport	0.78	15700	1256	95	5
2	Colonial & Plantation Pipeline	1.328	45340	3627	92	8
3	Colonial Pipeline-Chattanooga	0.59	12090	1088	95	5
4	CSX Corporation-Kingsport	0.9	9570	957	98	2
5	Forest Yards-Memphis Norfolk Southern	0.92	9100	819	96	4
6	Forest Yards-Memphis Norfolk Southern	1.07	24350	1948	98	2
7	Greyhound Bus Terminal-Knox	2.352	14390	1295	92	8
8	J.I.T Terminals-Chattanooga	0.65	15080	1508	77	23
9	Johnston Yards-Memphis Illinois Central	1.66	20560	1850	88	12
10	Johnston Yards-Memphis Illinois Central	0.41	4490	404	98	2
11	Johnston Yards-Memphis Illinois Central	1.03	9480	853	96	4
12	Leewoods Yards-Memphis CSX	2.86	27420	2193	95	5
13	Memphis Intern. Airport	2.54	24120	1929	92	8
14	Memphis Intern. Airport	2.08	49490	3959	95	5
15	Mid-South Terminals	2.35	3120	374	77	23
16	President's Island-Memphis	7.823	10780	862	61	39
17	Radnor Yards-Nashville CSX	2	20030	2003	99	1
18	Southern Foundry Supply-Chattanooga	0.316	6665	667	98	2
19	Tennessee Yards-Memphis Burlington Northern	0.63	31390	2511	83	17
20	Tri-Cities Regional Airport-Kingsport	2.44	8070	726	95	5
21	Vulcan Materials Company-Chattanooga	0.192	14726	1178	98	2
22	Greyhound Bus Terminal	0.86	5510	606	95	5

10.3. EPA MOVES & VISSIM Modeling

The road segments were modeled in VISSIM. The modeling process involved entering the traffic volumes, desired speed, and roadway geometry. The analysis was performed for PM peak hours. VISSIM modeling of road segments utilized two vehicle types, one representing a typical passenger car (type 100 in VISSIM) and the other trucks (type 200 in VISSIM). For accurate modeling, VISSIM documentation specifies a value between 5 and 20 for simulation runs, therefore 10 runs (agreed upon by PI and TDOT) were performed for each of the FICs. The attributes were set to obtain link results showing average speed and volume for simulation runs of the segments. Also, the direct output from VISSIM was configured to give acceleration, speed, vehicle type and location within each FIC on a second-by-second basis for 3600s. Table 10.2 shows an excerpt from a VISSIM output file showing vehicle trajectory data for the different vehicle types.

Table 10.2: Excerpt from a VISSIM trajectory file

VEHICLE: SIMSEC	VEHTYPE	LANE\LINK\NO	ACCELERATION	SPEED
301.00	100	2	0.51	32.22
301.00	100	2	-0.65	30.14
301.00	100	1	0.77	36.09
301.00	100	2	-0.04	32.28
301.00	100	2	0.70	31.82
301.00	200	1	0.60	32.13
301.00	200	2	-0.85	34.69
301.00	100	2	0.80	35.74
301.00	100	2	0.69	33.09
301.00	100	2	0.68	31.71
301.00	100	1	0.62	32.39
301.00	200	2	-0.49	32.89
301.00	100	2	-0.03	33.94
301.00	100	2	-0.99	31.13
301.00	100	2	-1.02	31.98
301.00	100	2	0.46	31.39

The resulting trajectory files were then imported and sorted in MS Excel. For each intersection, data from the simulation runs were averaged to provide second-by-second distributions that are accurately representative of each model. These files were then used to calculate the corresponding VSP and STP values. The VSP for a typical U.S light-duty vehicles is given as:

$$VSP\ \left(\frac{kW}{ton}\right) = 1.1 * v * a + 9.81 * grade * v + 0.213 * v + 0.000305 * (v + v_w)^2 * v \qquad (10.1)$$

Where:

v is the instantaneous vehicle speed (m/s)
v_w is headwind into the vehicle (m/s)
a is the acceleration (m/s^2)
$grade$ is defined as vertical rise/ horizontal rise

For this study, headwind and grade data for the segments and intersections analysed were not readily available, hence were assumed to be "0" and the abovementioned parameter was only used for characterizing emissions from light-duty vehicles.

For heavy goods vehicles (HGVs), STP is given as:

$$STP_t\left(\frac{kW}{ton}\right) = \frac{Av_t + Bv_t + Cv_t{}^3 + mv_t a_t}{f_{scale}} \qquad (10.2)$$

Where:

A is rolling resistance coefficient ($kW\ s/m$);
B is rotational resistance coefficient ($kW\ \ s^2/m^2$)
C is the aerodynamic drag coefficient $kW\ \ s^3/m^3$;
m is mass of vehicle (metric ton);
f_{scale} is fixed mass factor;
v_t is instantaneous vehicle velocity at time t (m/s);
a_t is instantaneous vehicle acceleration (m/s^2)

The coefficients A, B, C and f_{scale} for this expression factor in the tire rolling resistance, aerodynamic drag, and friction losses in the drivetrain [64]. The STP coefficients for heavy-duty diesel vehicles given by Yao et al [64] are A = 0.000831, B = 0, C = 2.890000019, f_{scale} = 17.10 and 27.7 metric tons for the average running weight. The processed output from the VISSIM model was used as input into MOVES2014a for project-level analysis to determine the CO, NOx, PM2.5, and VOCs emissions. As an initial step, a project-level database was created for input data importation. Input files included meteorological data, fuel information, distribution of vehicles age, inspection and maintenance programs, link information and operating mode distributions (OMDs) for running emissions. Link information and OMDs were obtained from the VISSIM traffic model, and default input data was used for the rest as recommended. A summary of the parameters used in this analysis that were generic for all the road segments, as shown in Table 10.3.

Table 10.3: Summary of MOVES project level analysis parameters

Scale	Project Level (On-road, Inventory)
Calendar Year	2018
Month, Days	August, Weekdays
Time of the day	17:00 – 17:59
Vehicle Type	Passenger car (type 21) and HGV (type 62)
Processes	Running exhaust
Pollutants (Output)	CO, NO_x, PM2.5, and VOCs

The project data manager was critical in MOVES simulations. It provided templates which were edited to suit project specifications. Most importantly, it assisted in distributing the calculated VSP/ STP data across operating modes. Operating modes are modes of vehicle activity that have a distinct emission rate. The classification for each operating mode is described in Table 10.4. Acceleration is the first parameter of analysis. Second-by-second data with negative acceleration is categorized under opModeID “0”, or deceleration/ braking. For data with positive acceleration, the vehicle speed is then examined, and vehicle speed data ranging between -1 and 1 are classified as opModeID “1” which represents idling. The remaining data is then categorized based on individual vehicle speed and the corresponding VSP/ STP. These fall in opModeID “11 – 40”. The total time spent in each mode for each vehicle type in the intersection under investigation is determined to obtain the opMode fraction. With the necessary input data, the runs were executed. The outputs for the runs were accessed through MySQL workbench by running a simple MySQL script to the output database. Summary reports for each of the FICs were also obtained from MySQL workbench.

Table 10.4: MOVES Default Operating Distribution Modes

opModelD	opModeName	VSP/ STP	v (mph)	a (mph/s)
0	Braking	-	-	$a \le -2$ OR $a_{t-2} \le -1$ AND $\le a_{t-1} \le -1$ AND $a_t \le -1$
1	Idling	-	-1 ≤ v < 1	-
11	Low Speed Coasting	VSP/STP< 0	1 ≤ v < 25	-
12	Cruise/Acceleration	0≤ VSP/ STP < 3	1 ≤ v < 25	-
13	Cruise/Acceleration	3 ≤ VSP/ STP < 6	1 ≤ v < 25	-
14	Cruise/Acceleration	6 ≤ VSP/ STP < 9	1 ≤ v < 25	-
15	Cruise/Acceleration	9 ≤ VSP/ STP <12	1 ≤ v < 25	-
16	Cruise/Acceleration	12 ≤ VSP/ STP	1 ≤ v < 25	-
21	Coasting	VSP/ STP < 0	25 ≤ v < 50	-
22	Cruise/Acceleration	0 ≤ VSP/ STP < 3	25 ≤ v < 50	-
23	Cruise/Acceleration	3 ≤ VSP/ STP < 6	25 ≤ v < 50	-
24	Cruise/Acceleration	6 ≤ VSP/ STP < 9	25 ≤ v < 50	-
25	Cruise/Acceleration	9 ≤ VSP/ STP < 12	25 ≤ v < 50	-
27	Cruise/Acceleration	12 ≤ VSP/ STP < 18	25 ≤ v < 50	-
28	Cruise/Acceleration	18 ≤ VSP/ STP < 24	25 ≤ v < 50	-
29	Cruise/Acceleration	24 ≤ VSP/ STP < 30	25 ≤ v < 50	-
30	Cruise/Acceleration	30 ≤ VSP/ STP	25 ≤ v < 50	-
33	Cruise/Acceleration	VSP/ STP < 6	50 ≤ v	-
35	Cruise/Acceleration	6 ≤ VSP/ STP < 12	50 ≤ v	-
37	Cruise/Acceleration	12 ≤ VSP/ STP < 18	50 ≤ v	-
38	Cruise/Acceleration	18 ≤ VSP/ STP < 24	50 ≤ v	-
39	Cruise/Acceleration	24 ≤ VSP/ STP < 30	50 ≤ v	-
40	Cruise/Acceleration	30 ≤ VSP/ STP	50 ≤ v	-

10.4. Correlating Emission with Independent Variables

Nonlinear least-squares estimation was used with the objective of developing a relationship between total emissions from each pollutant to traffic volume, the composition of HGVs and the posted speed limit along the segments. Data was fit on an arbitrary nonlinear regression function adopted from Abou-Senna et al [26] using least squares. Tables 10.5 to10.8 show the resulting relationships and their respective significance levels expressed in equations 10.3 to 10.6. Low p-values (<0.05) were used to determine significant variables. All variables are significant except truck % of CO estimation and the square of speed in both PM 2.5 and VOC models. This implies that most predictors are meaningful additions to the models. There is a positive correlation between truck % and pollutant emissions except for CO. This exception is consistent with EPA documentation which states that heavy-duty gasoline-fueled vehicles emit 6 times more CO compared to heavy-duty diesel vehicles [65]. This is relevant since only diesel trucks and gasoline passengers are considered. This implies that by increasing the truck %, gasoline passenger cars, which are the dominant source of CO, are reduced, resulting in fewer CO emissions. For NO_x, PM2.5 and VOC, a unit increase in truck %, results in an increase in emissions. The influence of truck % on NO_x emissions is attributed to the weight of trucks and its effect on engine loading. Also, the fact that diesel engines (trucks) produce significantly more NO_x compared to gasoline engines (passenger cars) adds on the effect of trucks on NO_x emissions. NO_x emissions from diesel engines can also undergo chemical reactions in the atmosphere resulting in the formation of PM 2.5 [66]. This aids in explaining why the model for PM 2.5 has a truck % coefficient of the highest magnitude relative to the rest of the emission models. The nonlinear least-squares estimations also highlight the positive correlation of emissions and vehicle volume. An increase in vehicle volume increases the number of emission sources which also results in congestion which increases emissions due to frequent accelerations at lower speeds [65]. This increase occurs until a peak volume that is dependent on the other investigated parameters. Any increase in volume beyond this peak lowers the cumulative emissions due to saturation of the road segment; vehicle movement will approach zero. The variation of the posted speed limits along the studied FICs is limited; they vary between 35 mph and 45 mph considering that these roads pass through residential and commercial areas. Despite this limitation, the posted speed variable is significant at 95% confidence level for all the pollutant models. For both posted speed limits, their cumulative effect results in an increase in pollutant emissions. The total truck emissions obtained from MOVES were plotted against the number of trucks along an intermodal connector. Based on the scatter plots, trend lines were traced for each of the studied pollutant types as presented in Figure 10.1. These 'lines of best fit' portrayed the effect of truck count on emissions based on the gradient of each trend line. NO_x proved to be the most sensitive and, PM2.5 and VOCs being the least responsive variables.

Table 10.5: Nonlinear least-squares estimation for CO

ln(CO)	Coefficient	t-Statistics	P-Value
$(volume)^2$	-1.28e-07	-3.22	0.005
$(speed)^2$	-0.00199	-8.85	0.000
volume	0.00123	7.32	0.000
speed	0.15800	14.63	0.000
truck %	-0.00568	-1.23	0.234

$$\ln(CO) = -1.28e^{-07} * \ (volume)^2 - 0.00199\ (speed)^2 + 0.0123(volume) + 0.158(speed) - 0.00568(truck\ \%)\ * \tag{10.3}$$

Table 10.6: Nonlinear least-squares estimation for NOx

$\ln(NO_x)$	Coefficient	t-Statistics	P-Value
$(volume)^2$	-1.58e-07	-2.33	0.032
$(speed)^2$	-0.00117	-3.04	0.007
volume	0.00129	4.48	0.000
speed	0.07	3.78	0.001
truck %	0.0661	8.40	0.000

$$\ln(NO_x) = -1.58e^{-07} * (volume)^2 - 0.00117\ (speed)^2 + 0.00129(volume) + 0.07(speed) + 0.0661(truck\ \%)\ * \tag{10.4}$$

Table 10.7: Nonlinear least-squares estimation for PM2.5

ln(PM 2.5)	Coefficient	t-Statistics	P-Value
$(volume)^2$	-1.99e-07	-2.45	0.026
$(speed)^2$	0.000675	1.47	0.160
volume	0.00142	4.14	0.001
speed	-0.0776	-3.50	0.003
truck %	0.0753	7.99	0.000

$$\ln(PM2.5) = -1.99e^{-07} * (volume)^2 + 0.000675\ (speed)^2 + 0.00142(volume) - 0.0776(speed) + 0.0753(truck\ \%)\ * \tag{10.5}$$

Table 10.8: Nonlinear least-squares estimation for VOC

ln(VOC)	Coefficient	t-Statistics	P-Value
$(volume)^2$	-1.49e-07	-3.78	0.001
$(speed)^2$	0.000292	1.31	0.209
volume	0.00124	7.45	0.000
speed	-0.0305	-2.83	0.011
truck %	0.0309	6.75	0.000

$$\ln(VOC) = -1.49e^{-07} * (volume)^2 + 0.000292\ (speed)^2 + 0.00124(volume) - \ 0.0305(speed) + 0.0309(truck\ \%)\ * \tag{10.6}$$

* Where: $volume$ = peak hour traffic volume
$speed$ = posted speed (mph)
$truck$ % = percentage of trucks

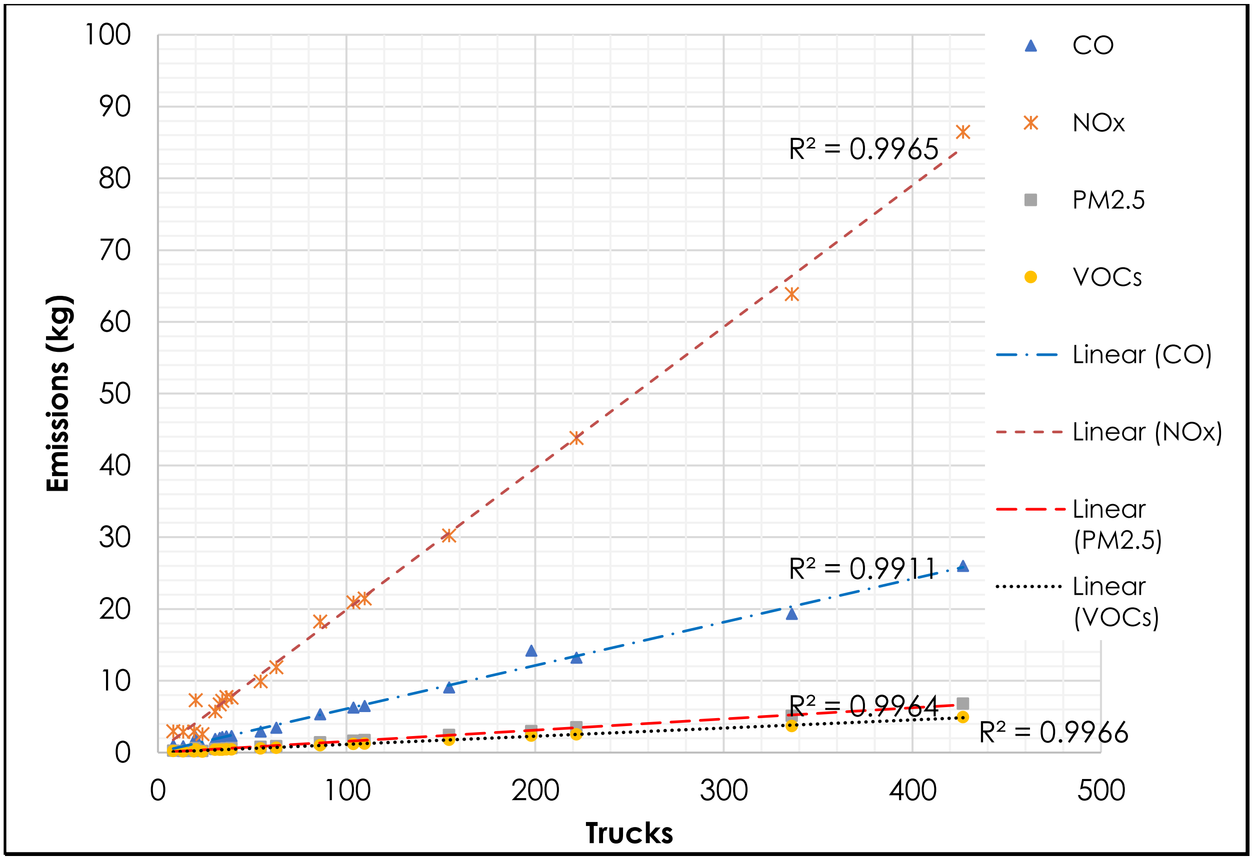


Figure 10.1: Linear relationship of pollutant emission and truck volume

10.5. Total and Truck Emission Results

For an in-depth analysis, the emission results were assessed based on the total emissions obtained directly from MOVES. For each pollutant type, the traffic volume-weighted presentation provided both the total emissions per 1000 vehicles and total emissions per 1000 trucks thus giving an equal footing for ranking and comparison purposes. Table 10.9 shows the total vehicle emissions along the connectors. It also illustrates the proportion of emissions that the trucks contributed. At a glance, Table 10.9 reveals that connector 14 which facilitates freight transportation to/from Memphis International Airport had the highest emissions. The most outstanding characteristic of this FIC is its high peak hour volume of 3959 vph. Connector 19 (to Tennessee Yards-Memphis Burlington) also contributes significant amounts overall. Conversely, connector 10 has the lowest emissions. Table 10.9 shows that connector 10 (to Johnston Yards-Memphis Illinois Central) has the lowest peak hour volume of 404 vph and a segment length of 0.41 miles. From Figure 10.2, connector 19 for Tennessee Yards-Memphis Burlington had the highest CO emissions and connector 21 (to Vulcan Materials – Chattanooga) had the lowest. The outstanding characteristics of these two connectors are length and truck %. Even though connector 19 only extends for 0.63 miles, it facilitates a high peak hour volume of 2511 vph and has a high volume of trucks at 17%. On the other hand, connector 21 has a 2% volume of trucks. When considering CO emissions per 1000 total vehicles, connector 14 for the Memphis International airport ranks first and so does connector 10 when focusing on CO emissions per 1000 trucks. These results offer compelling findings regarding the operation of vehicles along the studied connectors. The connectors which rank first in this regard might not be critical when considering total emissions, but if placed on an equal footing the vehicles prove to emit carbon monoxide more critically due to their operating modes along these road segments. As shown in Table 10.9, similar findings are obtained for NOx, PM 2.5 and VOCs. The most striking observation from the graphical representation of NOx, PM 2.5 and VOCs emissions is the impact of truck percentage on the contribution of the total emissions per connector. Overall, for the investigated scenarios, connectors 19, 16, 14 and 10 prove to be critical, and connectors 21, 10, 8 and 2 are the least critical as shown in Table 10.9. The emissions results were further assessed; the pollutant types were isolated and ranked based on total emissions, emissions per 1000 total vehicles and emissions per 1000 trucks, Table 10.10. The graphical representations of the rankings are given in Figure 10.2 to 10.13. For total CO emissions, only those from trucks were looked at as the magnitude of emissions from passenger cars was deemed insignificant for a graphical representation.

One of the limitations that faced the emission analysis was the availability of hourly and AADT for all of the segments studied in this project. The environmental impact of FICs in Tennessee as assessed through this study can be complemented and made robust by expanding analysis along the entire FICs segments. This will provide a better accuracy and cement the use of these models for FICs evaluation in Tennessee.

Table 10.9: MOVES Emission Results

FIC No.	**Facility Name**	**CO (kg)**		**NOx (kg)**		**Total PM2.5 (kg)**		**VOC (kg)**	
		Total	Trucks	Total	Trucks	Total	Trucks	Total	Trucks
1	Chattanooga Airport	95.5	3.4	16.8	11.9	1.0	0.9	2.2	0.6
2	Colonial & Plantation Pipeline Co	314.4	4.1	27.9	13.8	1.6	1.1	6.0	0.8
3	Colonial Pipeline-Chattanooga	76.6	2.9	13.7	9.9	0.9	0.8	1.9	0.6
4	CSX Corporation-Kingsport	67.8	0.9	6.7	2.9	0.3	0.2	1.5	0.2
5	Forest Yards-Memphis Norfolk Southern	62.2	2.0	9.8	6.7	0.6	0.5	1.4	0.4
6	Forest Yards-Memphis Norfolk Southern	155.7	2.3	15.1	7.7	0.9	0.6	3.2	0.4
7	Greyhound Bus Terminal-Knoxville	97.4	6.3	25.6	20.9	1.8	1.7	2.9	1.2
8	J.I.T Terminals-Chattanooga	63.6	12.8	46.6	43.7	3.2	3.1	3.3	2.4
9	Johnston Yards-Memphis Illinois Central	142.7	13.2	50.0	43.8	3.7	3.5	4.9	2.5
10	Johnston Yards-Memphis Illinois Central	26.0	1.0	4.5	3.0	0.3	0.3	0.8	0.2
11	Johnston Yards-Memphis Illinois Central	68.1	2.2	10.5	7.2	0.7	0.5	1.6	0.4
12	Leewoods Yards-Memphis CSX	154.8	6.5	29.2	21.5	2.0	1.7	4.1	1.3
13	Tchulahoma and Democrat Memphis	148.6	9.1	36.9	30.2	2.7	2.4	4.3	1.8
14	Airways Blvd, Plough Blvd and Winchester Memphis	420.0	14.2	74.8	52.0	3.6	3.0	8.7	2.3
15	Mid-South Terminals	27.4	5.3	19.4	18.2	1.4	1.4	1.4	1.0
16	President's Island-Memphis	57.8	19.3	65.8	63.9	5.2	5.1	4.4	3.7
17	Radnor Yards-Nashville	164.7	2.1	14.7	7.3	0.9	0.6	3.3	0.4
18	Southern Foundry Supply-Chattanooga	52.1	0.9	5.7	2.9	0.3	0.2	1.1	0.2
19	Tennessee Yards-Memphis Burlington Northern	195.1	26.0	94.6	86.5	7.1	6.8	7.9	4.9
20	Tri-Cities Regional Airport-Kingsport	52.4	2.3	10.5	7.7	0.7	0.6	1.4	0.4
21	Vulcan Materials - Chattanooga	51.2	0.7	5.1	2.6	0.3	0.2	1.0	0.1
22	Greyhound Bus Terminal	46.2	1.9	8.1	5.7	0.6	0.5	1.2	0.4

Table 10.10: Ranking of FICs based on emissions

FICs ID	CO			NO_x			PM 2.5			VOC		
	Total Truck Emissions	Per 1000 vehicles	Per 1000 Trucks	Total Emissions	Per 1000 vehicles	Per 1000 Trucks	Total Emissions	Per 1000 vehicles	Per 1000 Trucks	Total Emissions	Per 1000 vehicles	Per 1000 Trucks
1	19	14	10	19	16	10	19	16	10	14	16	10
2	16	2	17	14	15	17	16	15	17	19	15	17
3	14	17	14	16	19	14	9	19	15	2	19	22
4	9	6	18	9	8	18	14	8	20	9	9	18
5	8	11	11	8	9	20	8	9	7	16	7	11
6	13	18	22	13	7	15	13	7	19	13	13	20
7	12	19	20	12	13	11	12	13	18	12	14	14
8	7	9	15	2	14	5	7	20	9	17	8	15
9	15	13	5	7	20	19	2	22	22	8	22	7
10	2	22	19	15	1	7	15	12	6	6	20	19
11	1	1	7	1	22	9	1	14	13	7	10	6
12	3	5	9	6	12	6	3	3	12	1	12	9
13	6	7	6	17	3	12	6	1	11	3	11	12
14	20	15	12	3	11	13	17	10	16	11	1	5
15	11	20	13	20	5	16	20	11	5	4	3	13
16	17	4	16	11	10	22	11	5	14	5	5	16
17	5	12	1	5	18	1	5	18	3	15	17	3
18	22	3	3	22	6	3	22	6	1	20	18	1
19	10	16	4	4	2	4	4	2	4	22	2	4
20	18	10	8	18	17	8	10	17	8	18	6	8
21	4	21	21	21	4	21	18	4	21	21	4	21
22	21	8	2	10	21	2	21	21	2	10	21	2

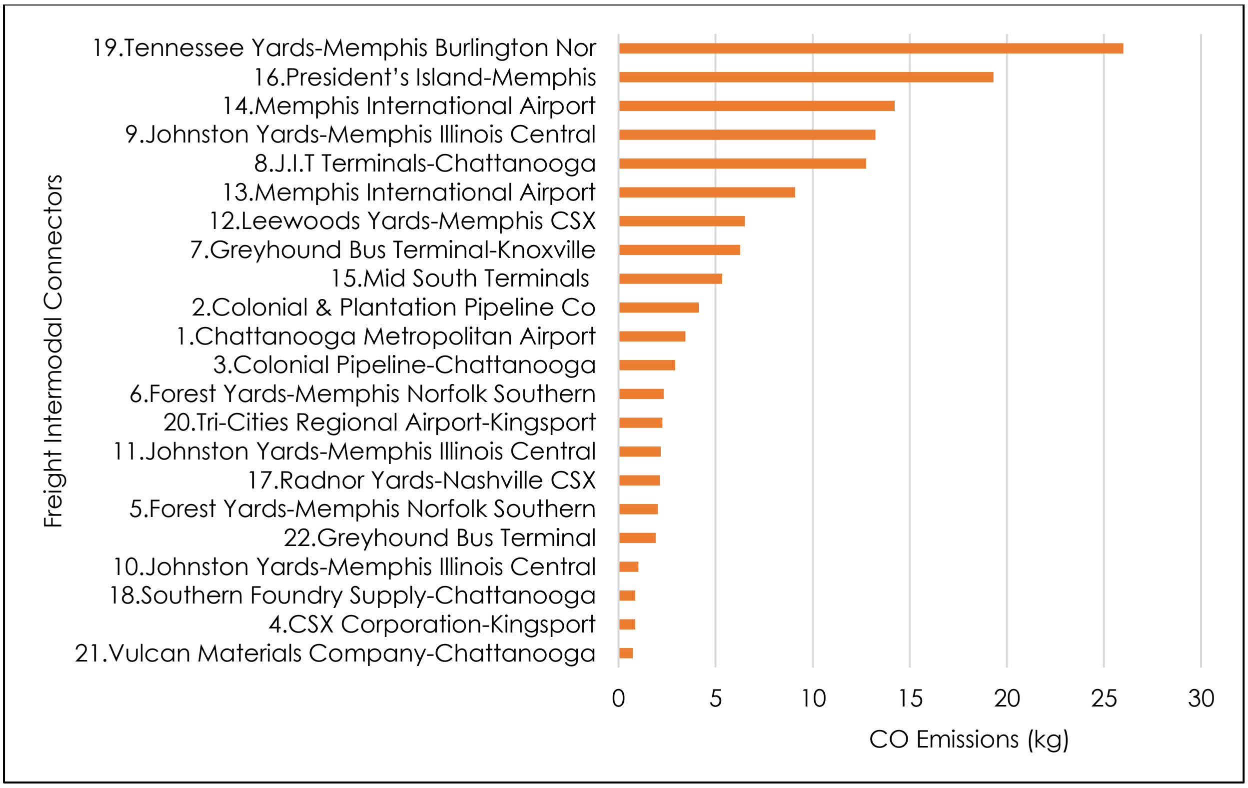


Figure 10.2: Ranking FICs CO Emissions from Trucks

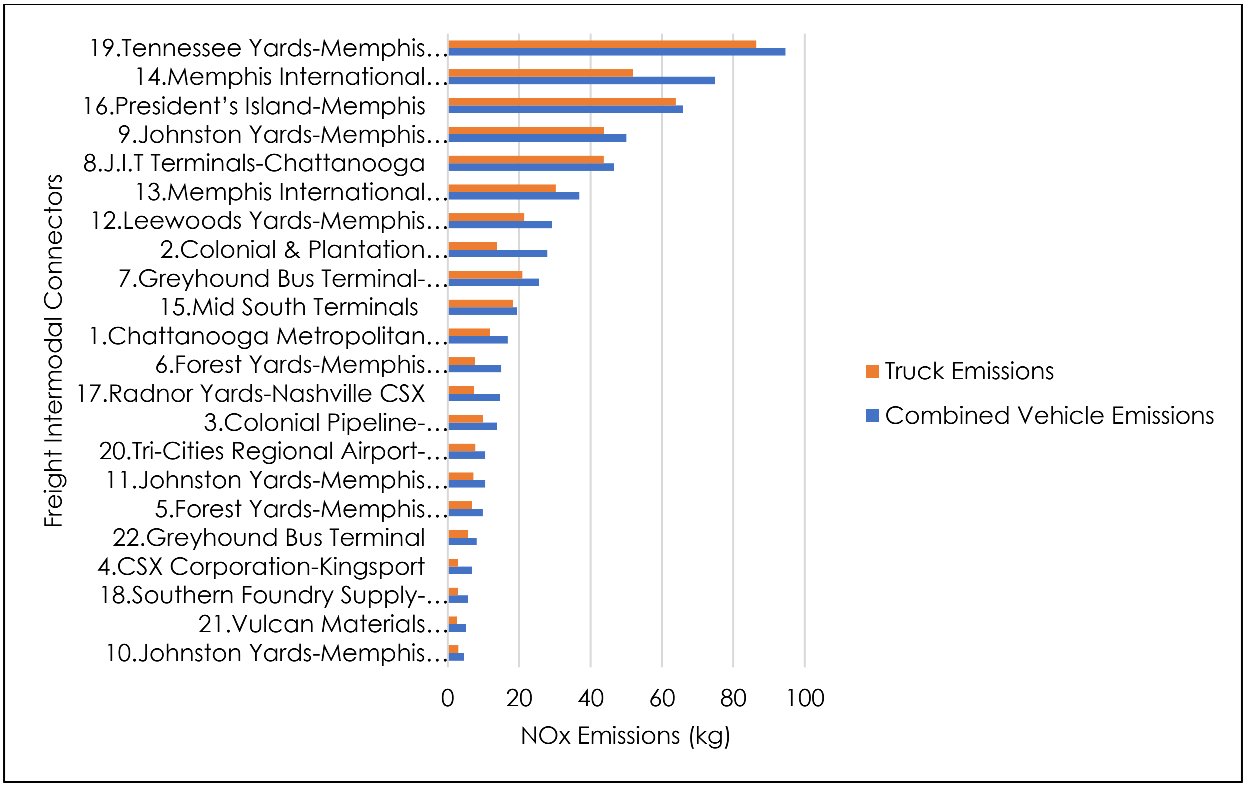


Figure 10.3: Ranking FICs by total NOx Emissions

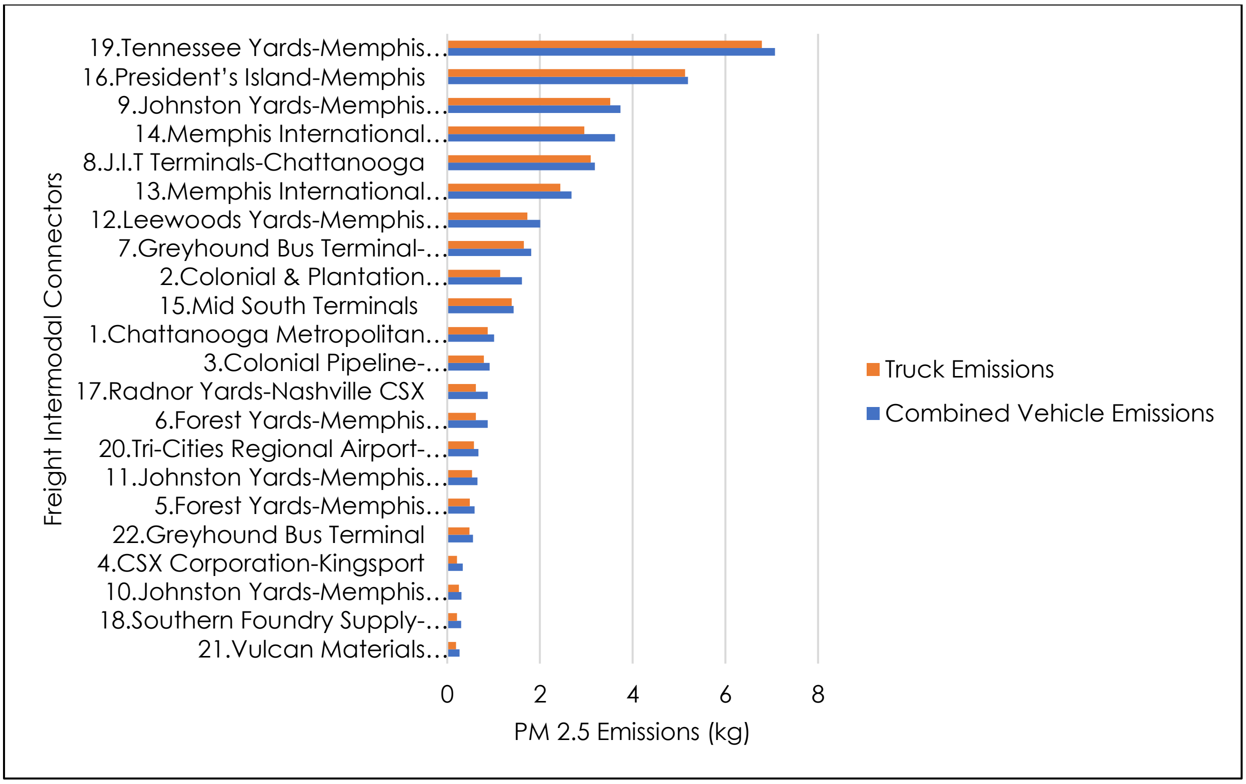


Figure 10.4: Ranking FICs by total PM2.5 Emissions

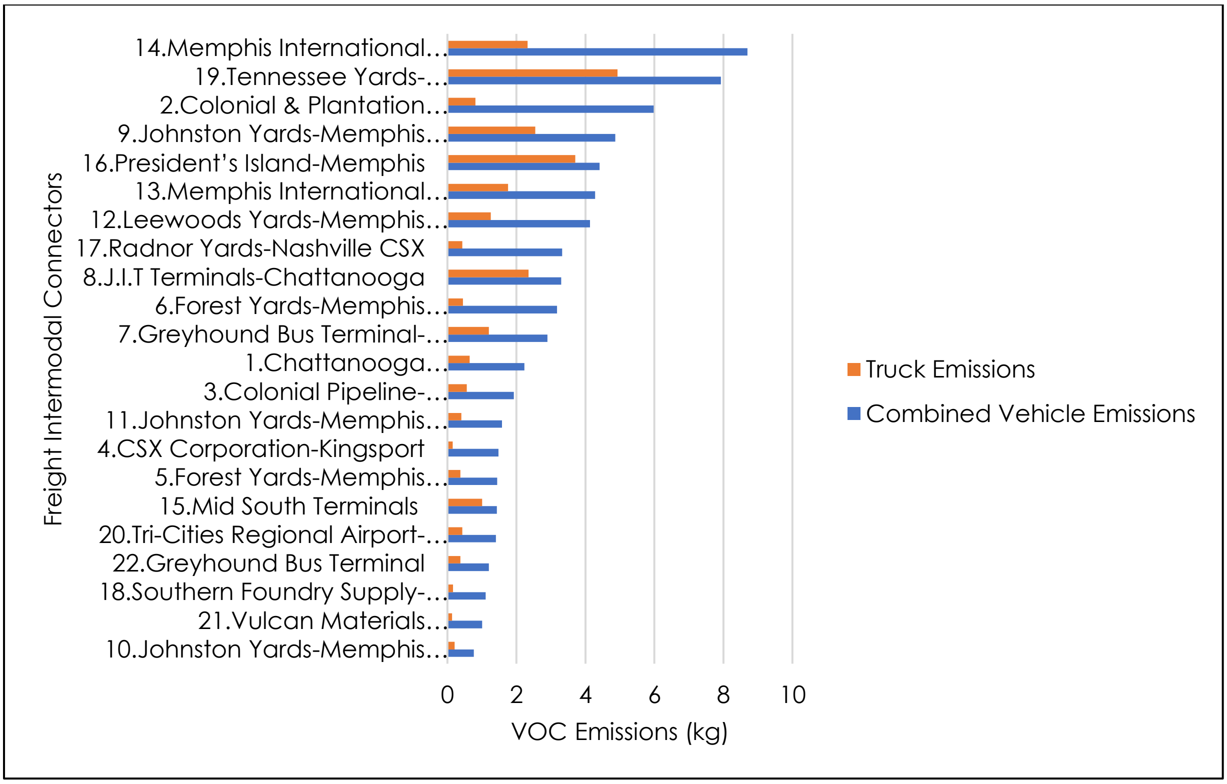


Figure 10.5: Ranking FICs by total VOC Emissions

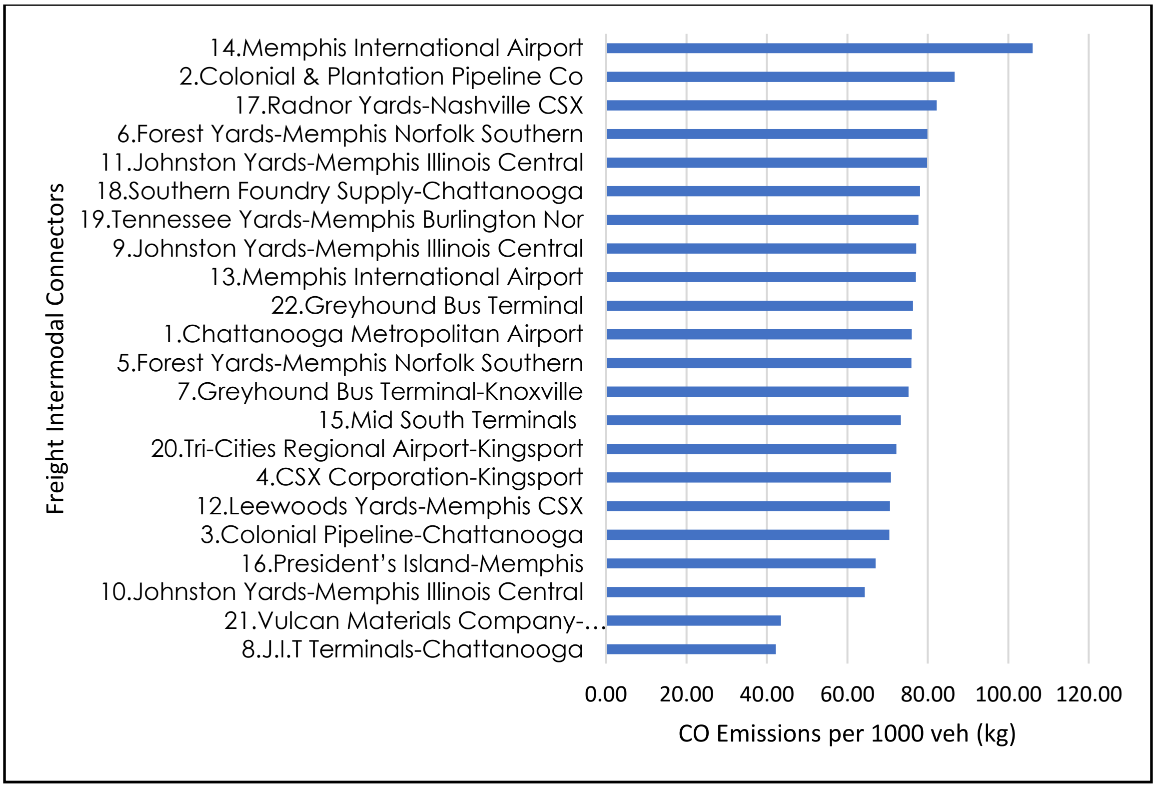


Figure 10.6: Ranking FICs by CO Emissions per 1000 total vehicles

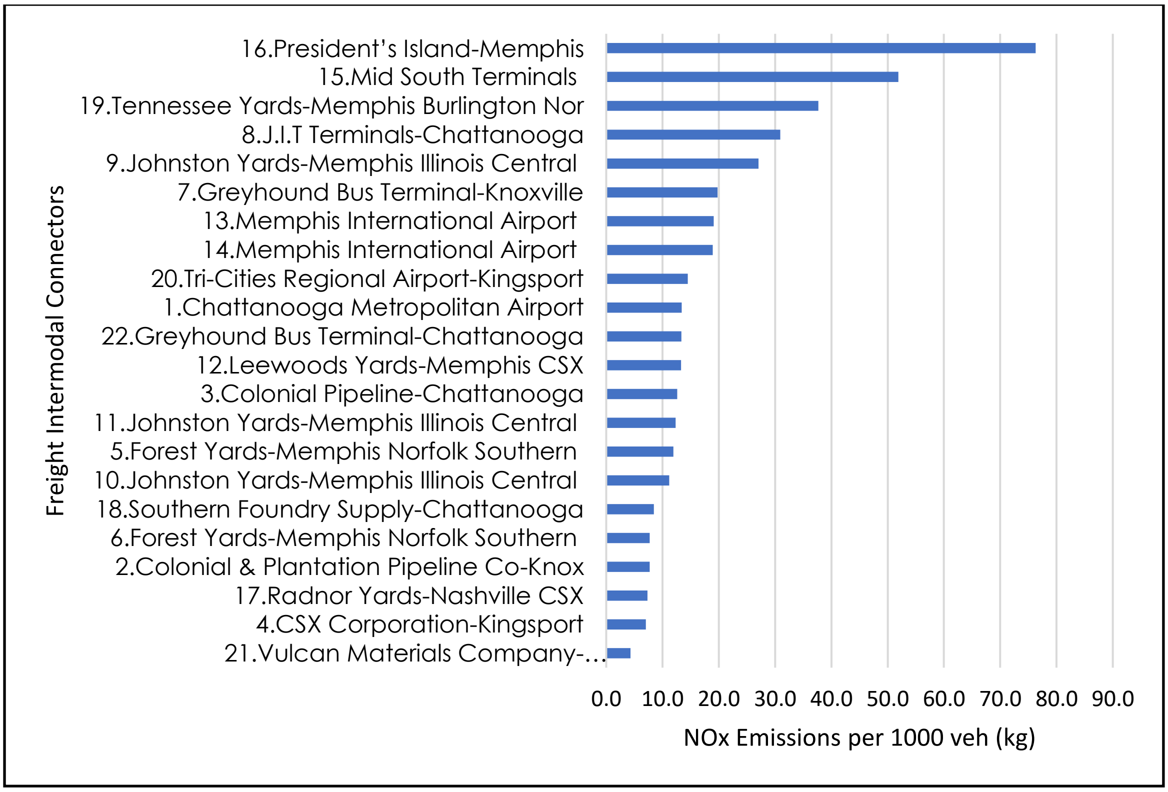


Figure 10.7: Ranking FICs by NOx Emissions per 1000 total vehicles

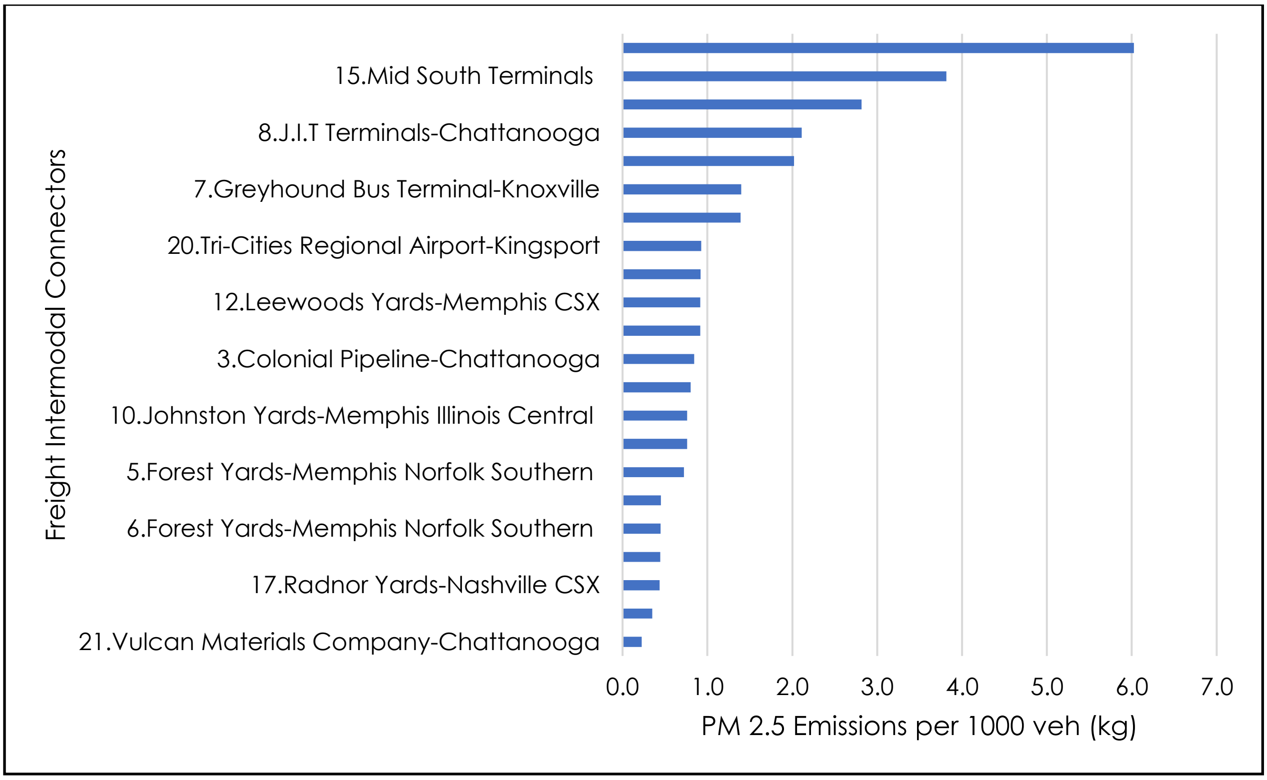


Figure 10.8: Ranking FICs by PM 2.5 Emissions per 1000 total vehicles

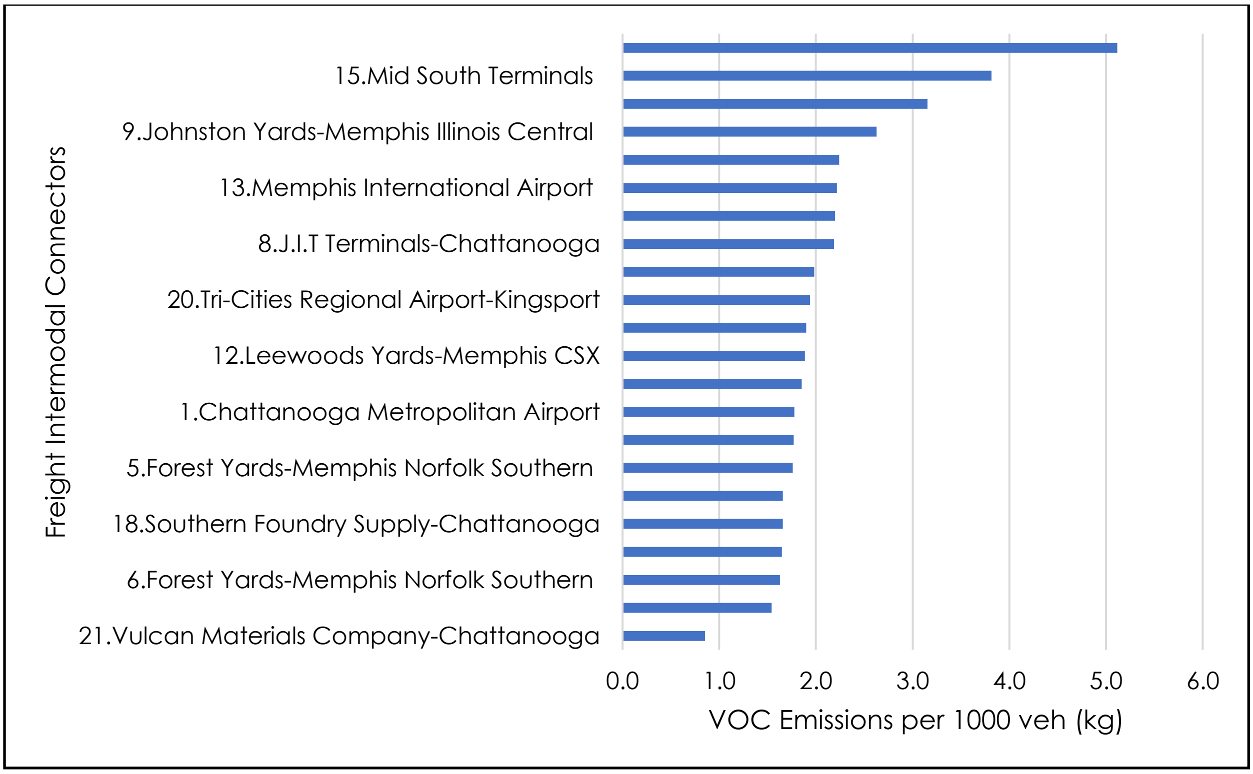


Figure 10.9: Ranking FICs by VOC Emissions per 1000 total vehicles

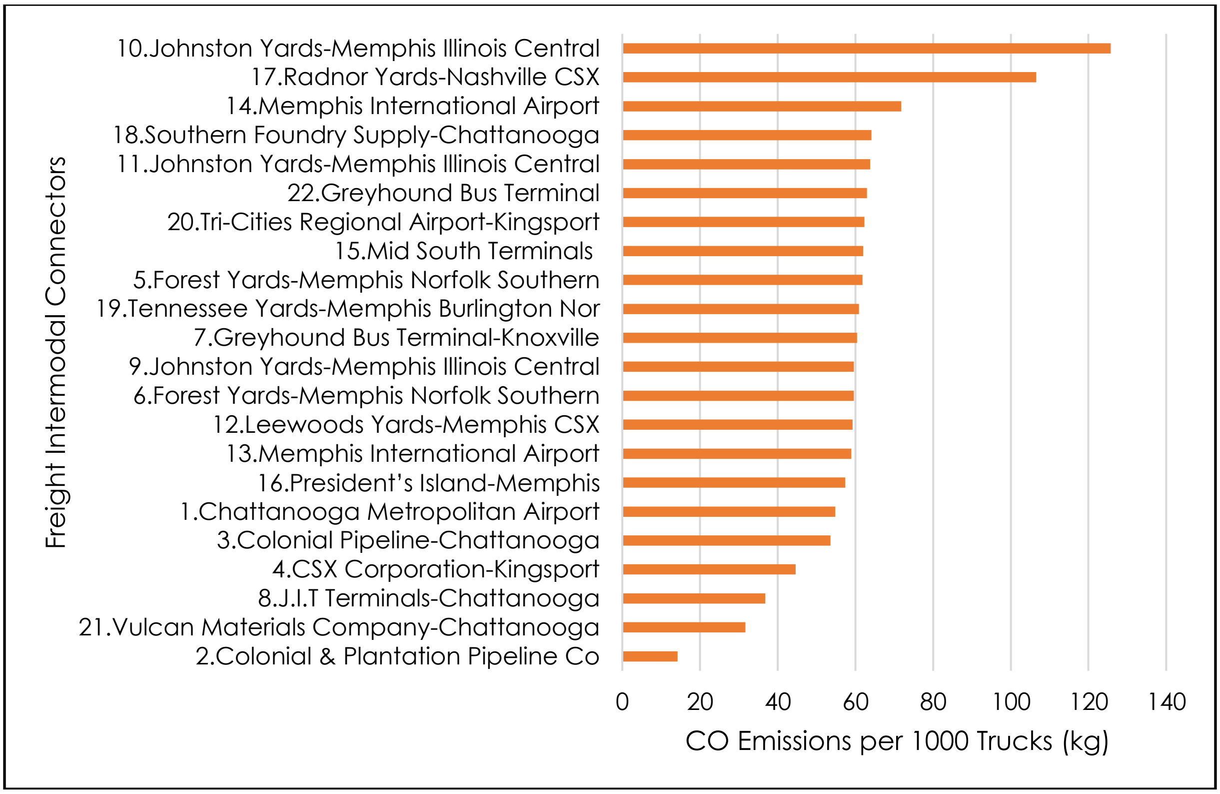


Figure 10.10: Ranking FICs by CO Emissions per 1000 total vehicles

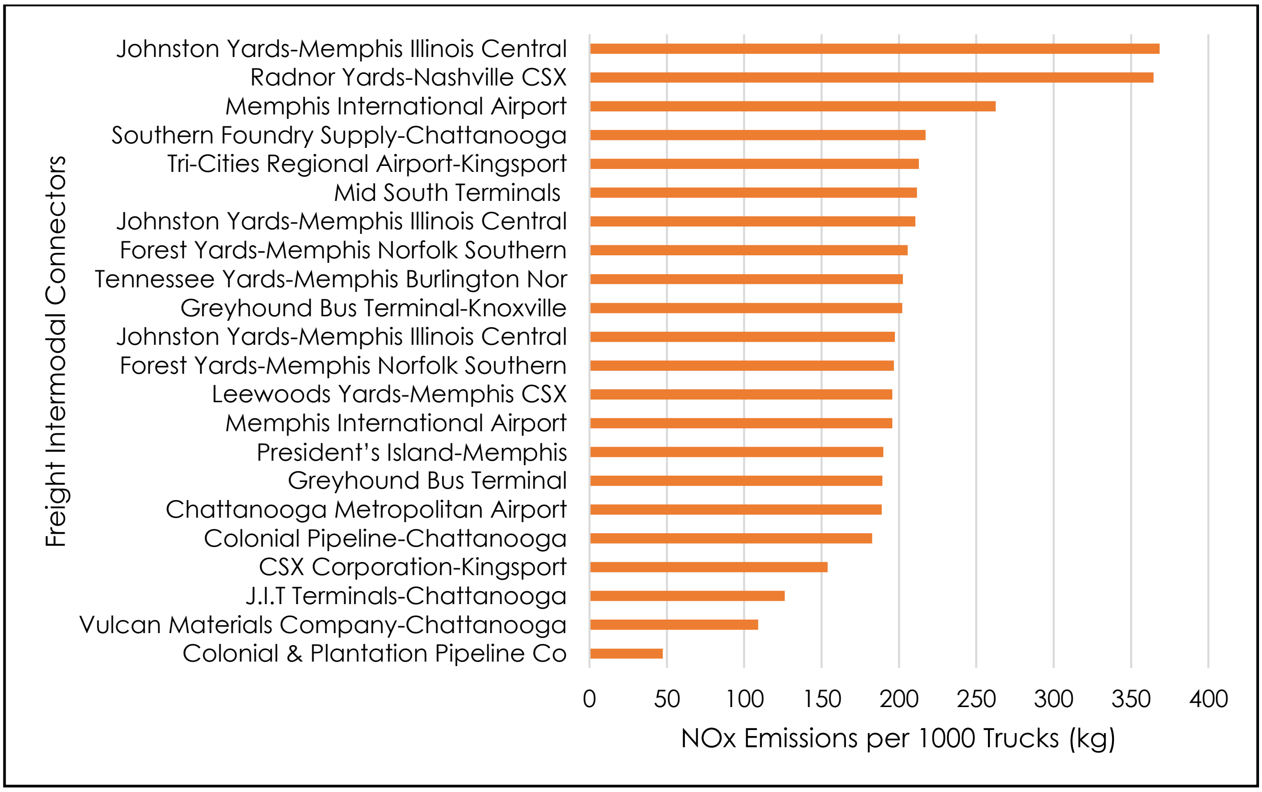


Figure 10.11: Ranking FICs by NOx Emissions per 1000 trucks

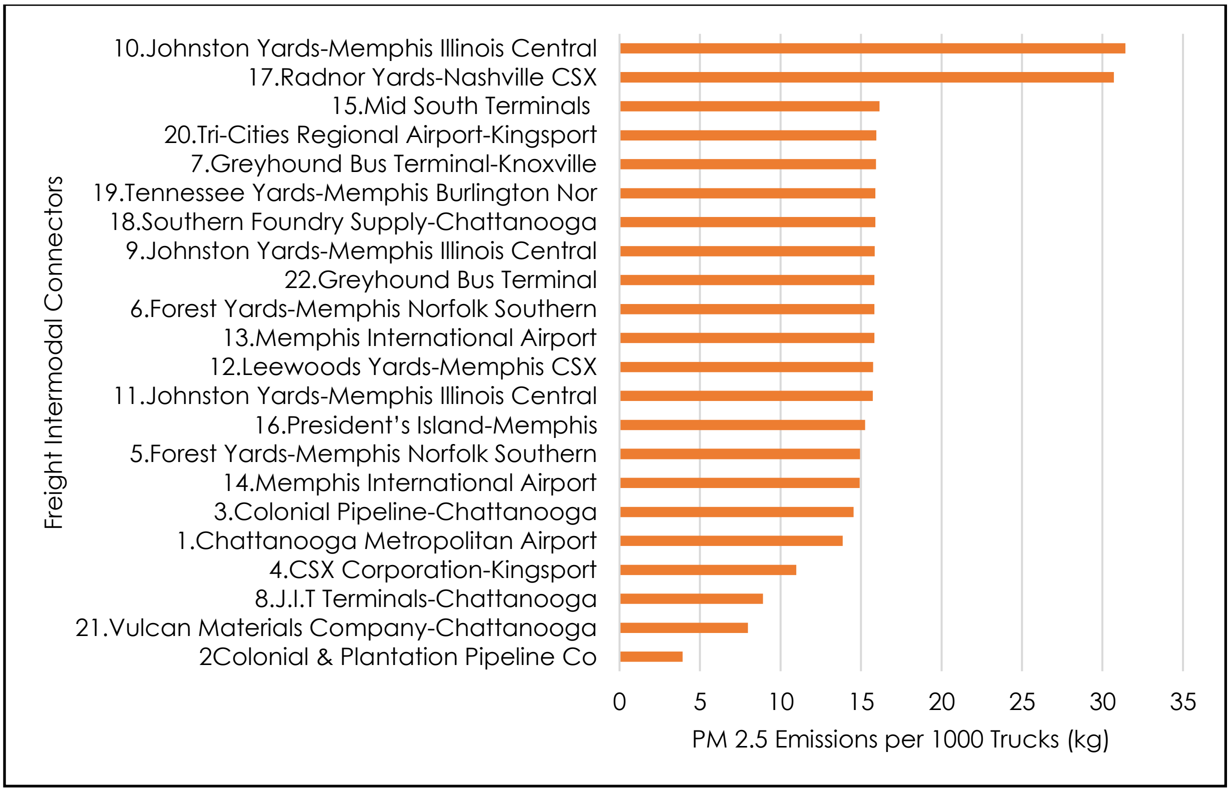


Figure 10.12: Ranking FICs by PM 2.5 Emissions per 1000 Trucks

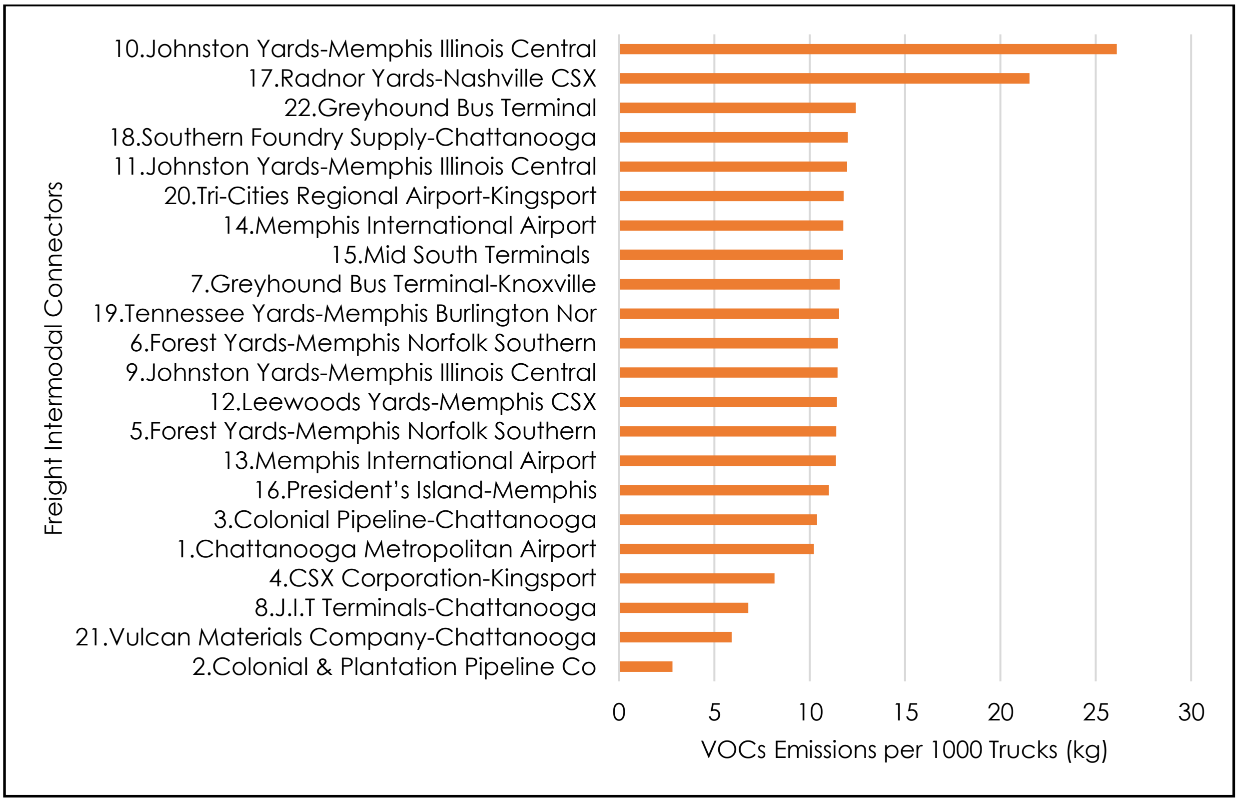


Figure 10.13: Ranking FICs by VOC Emissions per 1000 Trucks

11.0. CONCLUSIONS AND RECOMMENDATIONS

Intermodal freight logistic hubs attract a significant amount of trucks, which deliver and pick up goods, containers and services through public roadway segments. This project evaluated Freight Intermodal Connectors (FICs) in Tennessee to identify deficiencies related to congestion, capacity, safety, and supply chain demand needs. The study focused on "roadway connectors", segments, corridors and intersections, that connect Tennessee freight trucks to/from the major freeways from/to high-priority facilities such as truck hubs, airport terminals, freight rail terminals, passenger rail and intercity bus terminals, waterways, warehouses, depots, centers, etc. For efficient intermodal freight movement, these roadway connectors must be in desired service conditions (operational, safety, and environmental) capable of accommodating truck and freight needs. If FICs have little capacity, they will cause traffic congestion that, in turn, will dramatically increase travel time, energy consumption, and air pollution. On the other hand, if FICs have too much capacity, their utilizations will be too low to justify monetary investment on them. In other words, FICs need to match operational and safety needs as well as the supply chain demand along the connectors.

This FIC study performed a multimodal inventory check and evaluated some of the critical freight connectors in Tennessee by identifying improvement needs. The study provided technical analysis and summary of freight-related deficiencies that exist along roadway connectors, especially trucks to known warehouses, depots, hubs and terminals. The study determined potential deficiencies warranting improvement needs which eventually will improve FICs' capacity, congestion, supply chain demand, and safety. A comprehensive literature search was taken to uncover both ongoing or previous published and unpublished reports and papers on Freight Intermodal Connectors (FICs), and other relevant materials on this subject. The review helped to determine information and practices from other states.

To better understand the context of selected roadway connectors and corridors and clarify specific freight issues and concerns, individual interviews were conducted with a number of key freight movement stakeholders in Tennessee. The freight stakeholders and partners were interviewed to identify issues that can be addressed by TDOT and other funding agencies. The study gathered data through a review of available databases and studies from TDOT and stakeholders. The field review was aimed at seeking input regarding the study's focus, specific areas of concern related to FICs. The field review included a windshield survey of the facilities looking for obvious signs of deficiencies like tire marks on curbs, indications of queue storage lengths being exceeded, and delays at intersections.

Analysis was conducted to identify operational deficiencies and issues along selected FICs based gathered data. Analysis included evaluation of factors such as adequate capacity and access to hubs, turning radii, queuing storage, pavement quality, and freight access limitations. FICs identified with deficiencies were cross-referenced with TDOTs' long-range transportation plans. Potential improvements were identified to address the deficiencies and issues for each connector. Safety analysis and risk assessment was performed on the FICs including crash frequency and severity. The FICs were ranked based on safety and operational performances.

The study evaluated the traffic safety along these Freight Intermodal Connectors (FICs) by digesting and ranking the connectors in terms of crash frequency, crash rates and statistical significance of attributing traffic and geometric factors. It was found that connectors leading to pipeline terminals have high crash rates (almost double) compared to other type of terminals while port terminal connectors have the lowest safety problem indices. The study established correlative contributing causes of crash frequencies and rates along FICs that included AADT, lanes, shoulders, access and median types. Signal density was found to strongly and significantly affect the probability of crashes together with the presence of two-way left turn lane (TWLT), which surprisingly tends to decrease probability of crashes along these connectors. The presence of shoulders along intermodal connectors was found to help reduce the probability of crashes while presence of curbs and gutters tends to increase crash frequency. Analysis indicated that most of the connectors with high crash rates were also operating at lower levels of service especially for critical movements towards freight facilities due to high truck volumes.

Applying a risk management approach, this study investigated both the economic and societal impact of motor vehicle crashes on freight intermodal connectors in Tennessee. First, based on different severity impacts, four different risks were classified: property damage only crashes, non-incapacitating injury crashes, incapacitating injury crashes, and fatal crashes. Second, the respective frequencies were calculated. Then, the scores were obtained by multiplying their economic and societal impacts by their frequencies. Crash data show that (1) property damage only and non-incapacitating injury crashes occur more regularly with much less impact than incapacitating injury and fatal crashes and (2) total risk varies drastically even for the same types of connectors and for similarly located connectors. Finally, a risk mitigation strategy is concluded: to transfer the financial liability to a third party for rare but significant risk (i.e., incapacitating injury and fatal) by pooling individual drivers and trucking companies their risk together onto a third party (i.e., an insurance company). Statistical modeling of FICs crashes showed correlation between signal density and crashes frequency, though a more sophisticated model for future studies may be required. Additionally, analysis did not analyze whether or not a truck was involved in individual crashes, therefore, future study should focus on this aspect of FICs safety.

The study integrated intersection performance measures that include level of service (LOS), delay and queue length with measures of effectiveness including reliability index, travel time and cost per mile to determine the overall operational performance of the freight intermodal connectors (FICs). FICs located in Knox and Shelby counties in Tennessee were used as testbeds. Data collected from these FICs through different methodologies including GPS were used to model segments and thirteen intersections along the FICs with the objective of estimating the aforementioned performance measures. Using regression analysis, the performance measures, geometric and traffic parameters were then used to determine the influence of various parameters on the trucking costs for each. A scoring model was developed which was further used to weigh the investigated parameters and provided an overall relative operational performance measure for each of the connectors. The results showed that the rail connectors have the highest operational performance followed by intercity bus terminals and airport terminal connectors. The pipeline connectors showed the lowest operational performance. FICs with one lane in each direction (2-lane) was found to have higher likelihood of having more delay than in multilane highways. As the length of the connector increases the delay cost per unit length decreases which is associated with the fact that the acceleration and deceleration phases are not accounting for a large portion of the trip, and for most of the route, the truck is traveling at constant speed close or equal to the speed limit.

Further, the study used an EPA mobile source emissions model, MOVES, to estimate truck emissions along the FICs on a second-by-second basis in combination with VISSIM simulation. The MOVES model estimations were compared/combined with estimates from VISSIM microscopic traffic simulation model to obtain emission results. The VISSIM/MOVES model was used to determine emissions factors for VOCs, NOx, P.M 2.5 and CO along the FICs. There are three methods which can be used under a project-level scale: average speed method, link drive schedule and operation mode distribution. To use these methods in the MOVES emission model, all connector networks were coded in VISSIM, where outputs were used to obtain emission quantities.

A questionnaire survey was used to provide insight from truck drivers since they use these road segments regularly. The survey provided a platform to engage with the stakeholders to aid in meeting the needs of the public in the best way possible. The biggest issue that the drivers are currently facing is recurring congestion along the FICs where 83 % of the respondents reported it as an ‘often’ or ‘always’ situation. Turning movement at intersections is also another issue of concern as indicated by 50% of the truck drivers who participated in this study. For freight transportation efficiency along FICs, signage, safety, and security, bottlenecks, and direct indirect cost of congestion, on-time delivery, and infrastructure condition are key factors that ought to be addressed. The absence of safety features such as bike lanes, sidewalks, and pedestrian features was also pointed out by the drivers.

TDOT should consider improving these FICs connectors focusing on the following:

1. Improvements that mitigate congestion as the safety analysis, questionnaire survey and operational analysis identified congestion as the major issue affecting these connectors.

2. TDOT should conduct operational analysis to determine how to improve the level of service at the intersections along the following roadway segments which resulted with high intersection or critical movement delays:
   - Winchester Rd segment of FIC to Airport Terminal in Memphis.
   - Airways Blvd segment of FIC to Airport Terminal in Memphis.
   - Plough Blvd segment of FIC to Airport Terminal in Memphis.
   - The intersection of Democrat Rd and Airways Blvd in Memphis.
   - The intersection of Democrat Rd and Tchulahoma Rd in Memphis.

3. TDOT should conduct a detailed analysis to determine how to improve safety along the following roadway segments which resulted with a high number of crashes as well as exceeding critical crash rates:
   - Jackson Ave segment of FIC to Truck/Rail facility in Memphis.
   - Democrat Rd segment of FIC to Airport Terminal in Memphis.
   - Shelby Dr segment of FIC to Truck/Rail facility in Memphis.
   - East Parkway S and Airways Blvd segment of FIC to Truck/Rail facility in Memphis.
   - Western Ave segment of FIC to Pipeline facility in Knoxville.
   - E. Magnolia Ave segment of FIC to Intercity Bus terminal in Knoxville.
   - Tchulahoma Rd segment of FIC to Airport in Memphis.
   - N. Cherry St segment of FIC to Intercity Bus terminal in Knoxville.
   - Jersey Pike segment of FIC to Pipeline facility in Chattanooga.
   - Middlebrook Pike segment of FIC to Pipeline facility in Knoxville.
   - Manufactures Rd segment of FIC to Port terminal in Chattanooga.

4. TDOT should use the microscopic emission models developed through this study to estimate CO, NOx, PM 2.5 and VOCs emissions at project levels. As the study demonstrated that a unit increase in traffic volume, speed and truck percentages results in an increase in emissions; TDOT can use the developed emission models to evaluate traffic strategies related to the environmental effects along the FICs.

APPENDICES

APPENDIX A: SPEED DISTANCE CHARTS FOR FICSs

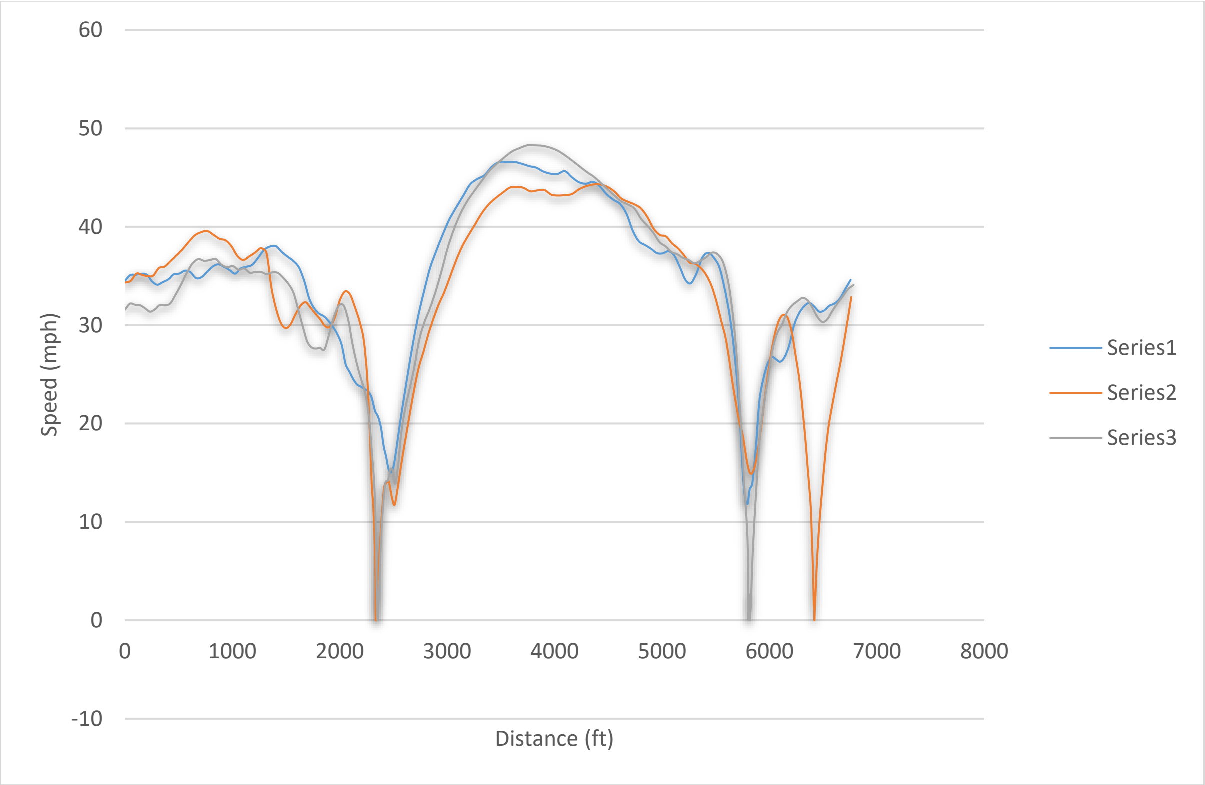


Figure A-1. Wester Ave -Pipeline -Knox (to the facility) AM

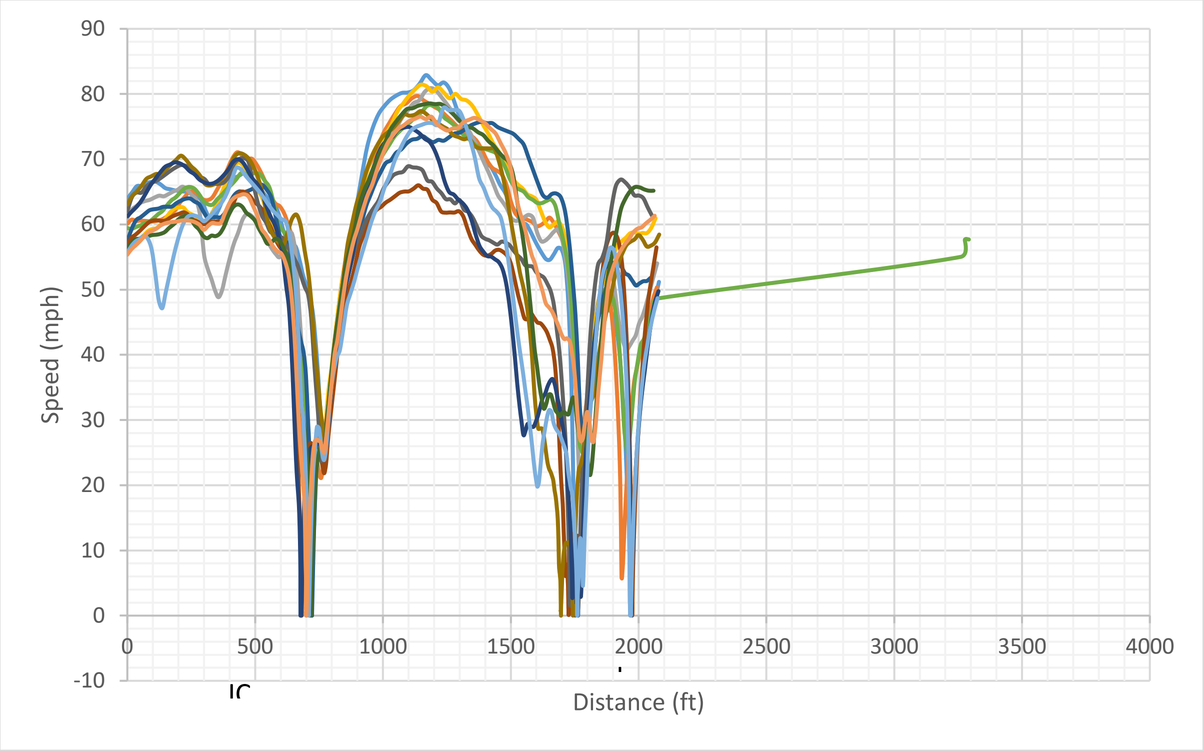


Figure A-2. Wester Ave -Pipeline -Knox (to the facility) PM

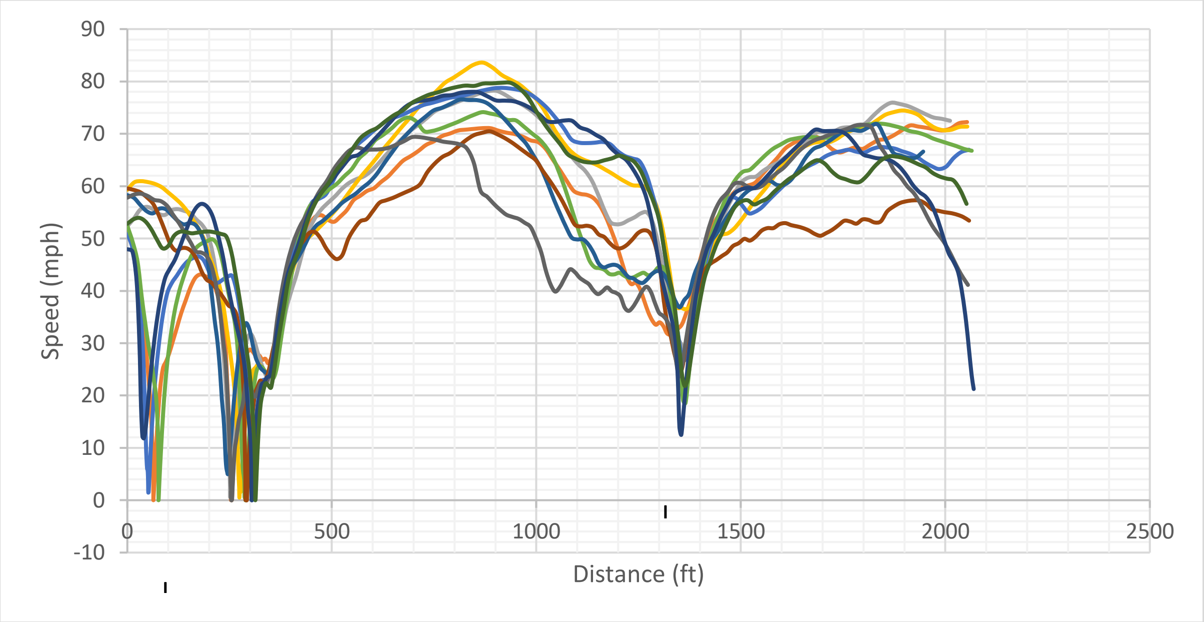


Figure A-3. Wester Ave -Pipeline -Knox (to the facility) PM

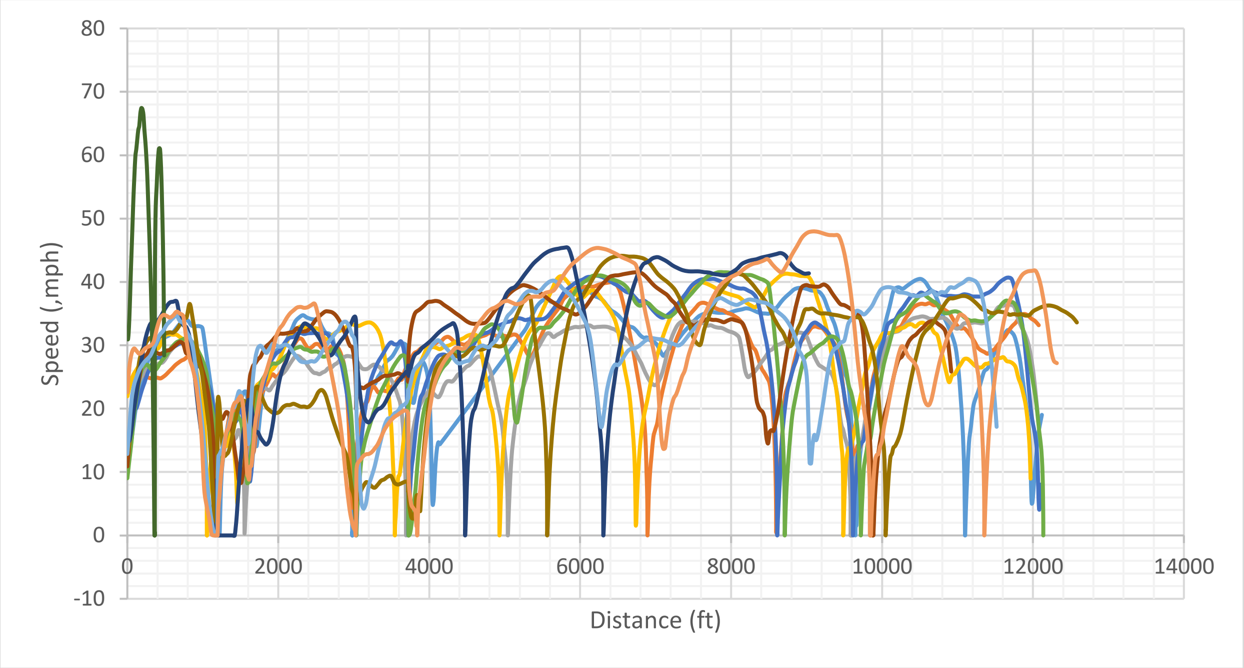


Figure A-4.Old Magnolia Ave – Bus terminal -Knox (to the facility) AM

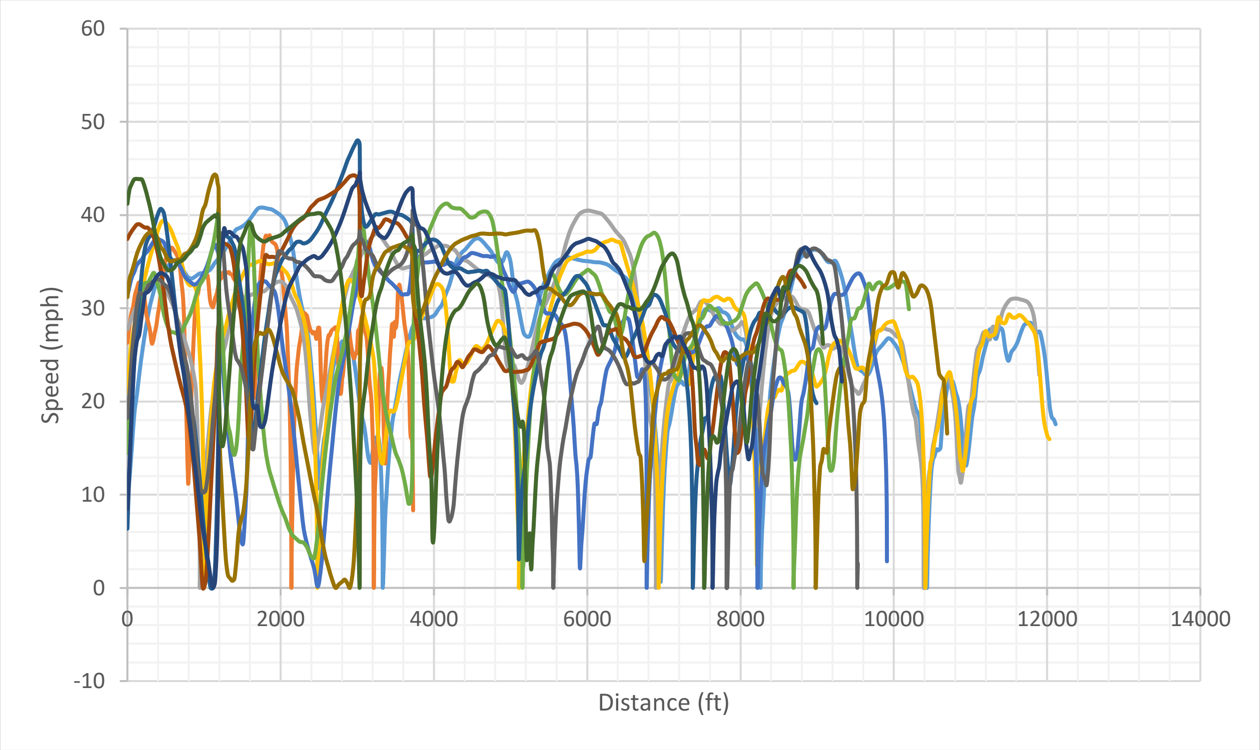


Figure A-5. Old Magnolia Ave – Bus terminal -Knox (to the facility) AM

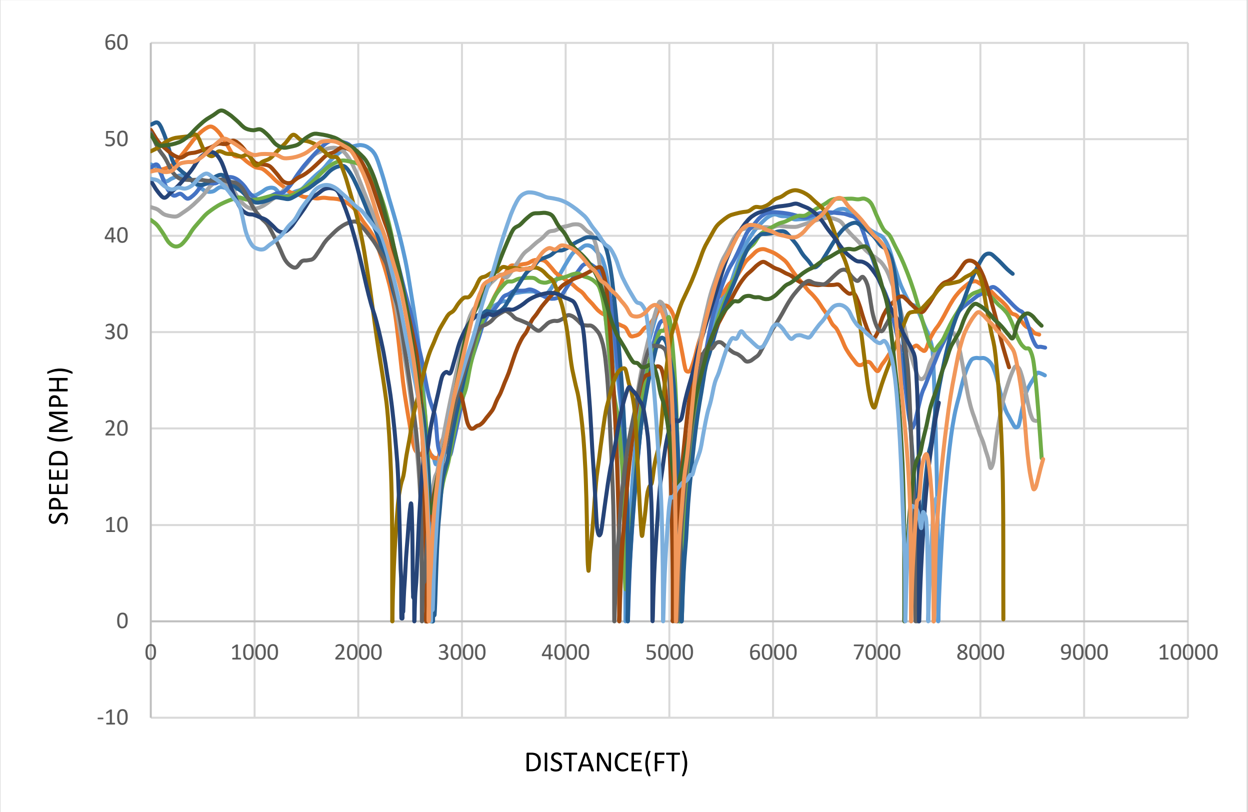


Figure A-6. Old Magnolia Ave – Bus terminal -Knox (from the facility) AM

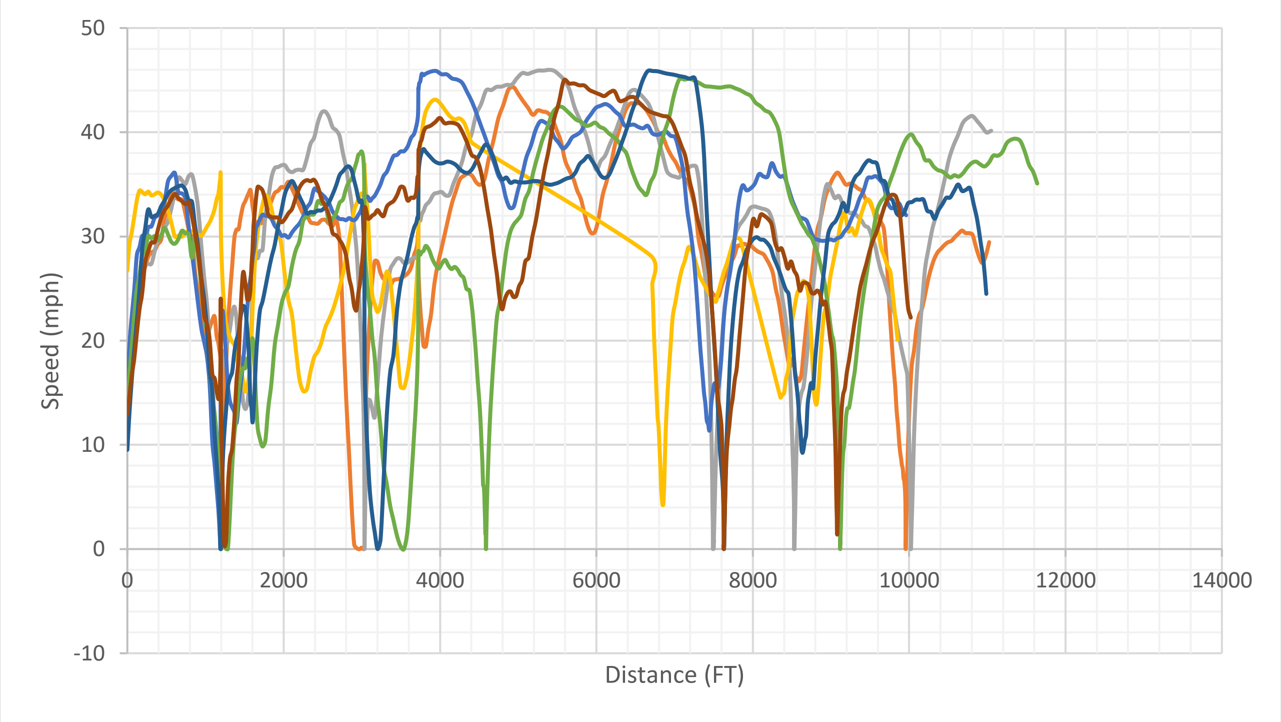


Figure A-7. Old Magnolia Ave – Bus terminal -Knox (to the facility) PM

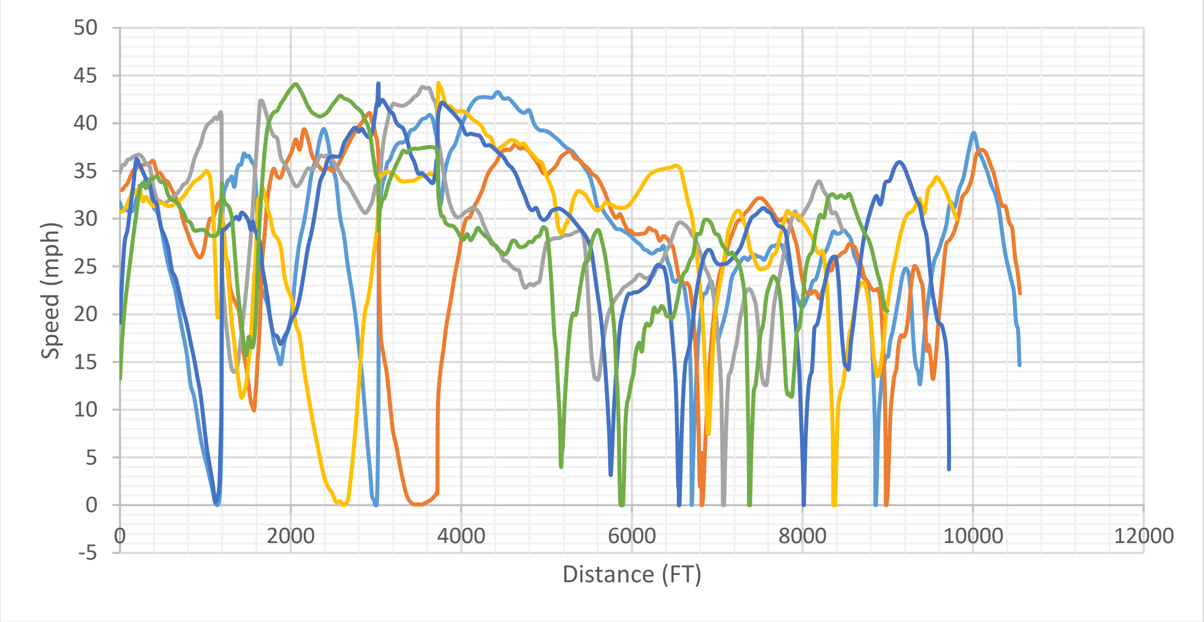


Figure A-8. Old Magnolia Ave – Bus terminal -Knox (from the facility) PM

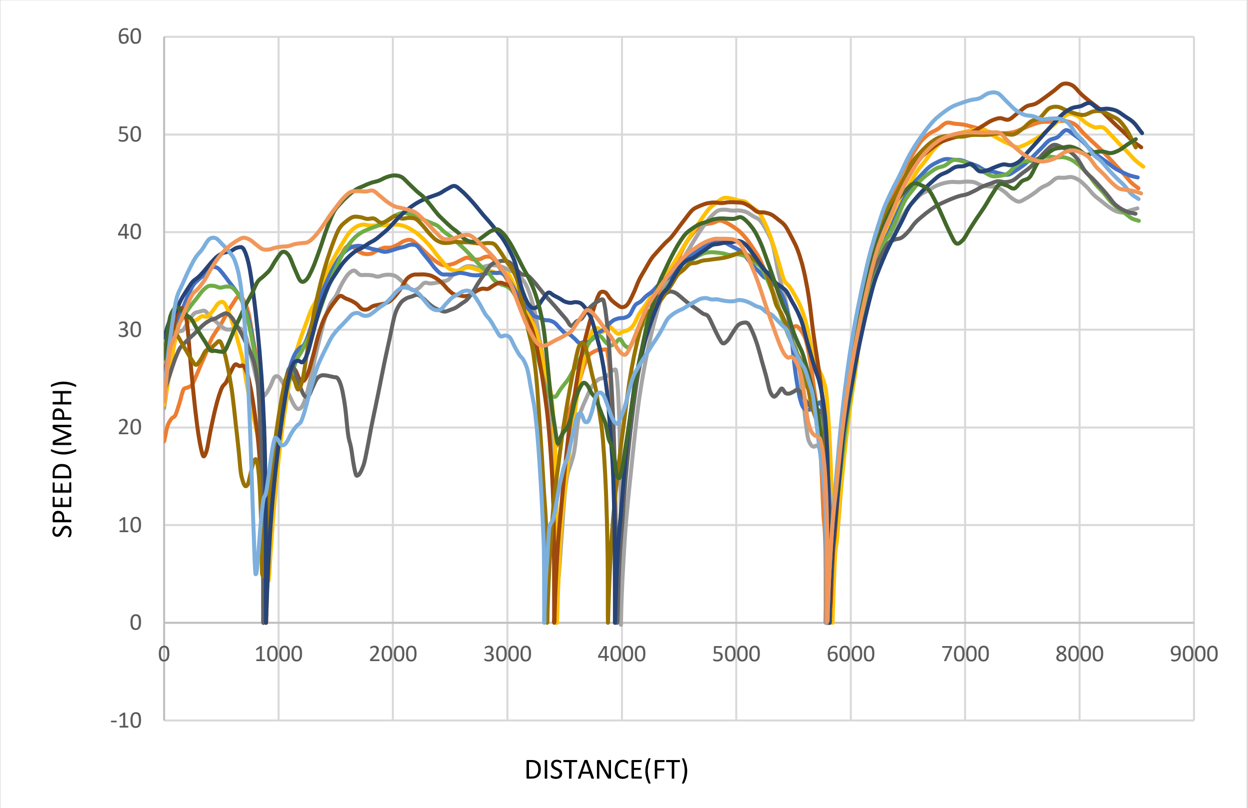


Figure A-9.Johston Yards-Memphis Illinois Central (from the facility) AM

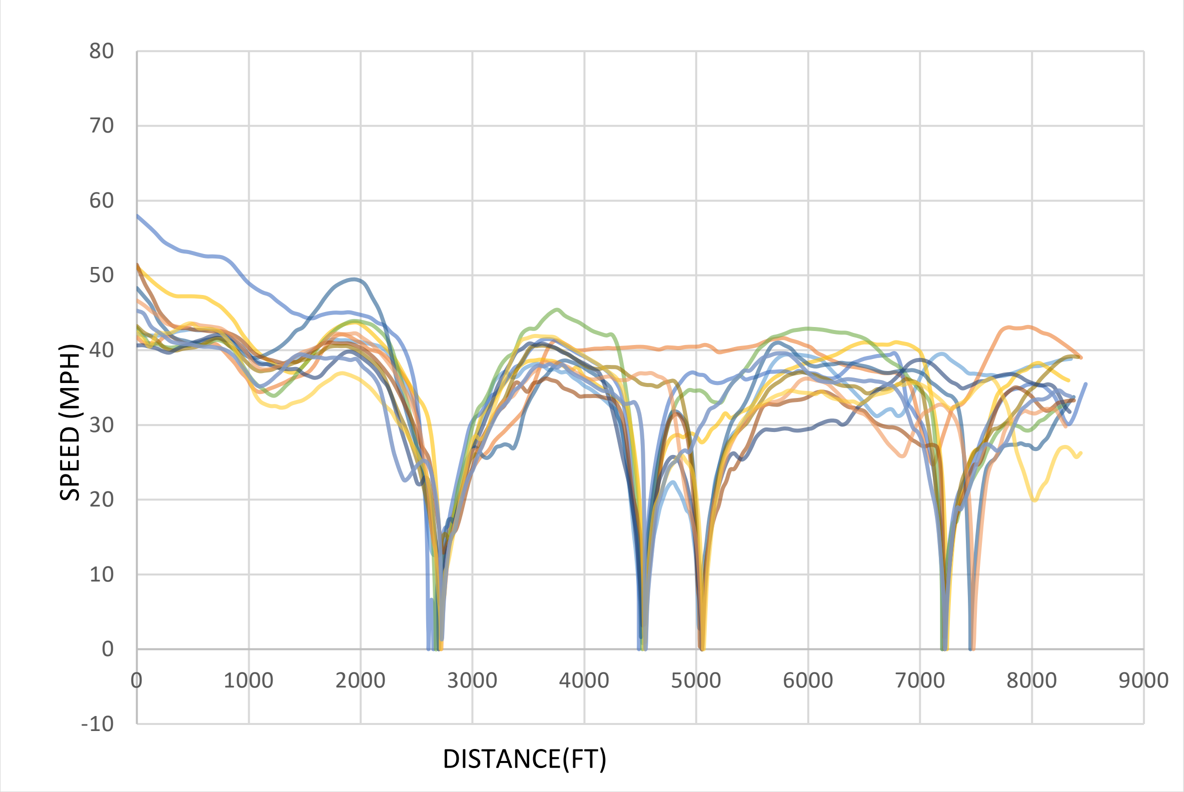


Figure A-10.Johston Yards-Memphis Illinois Central (to the facility) PM

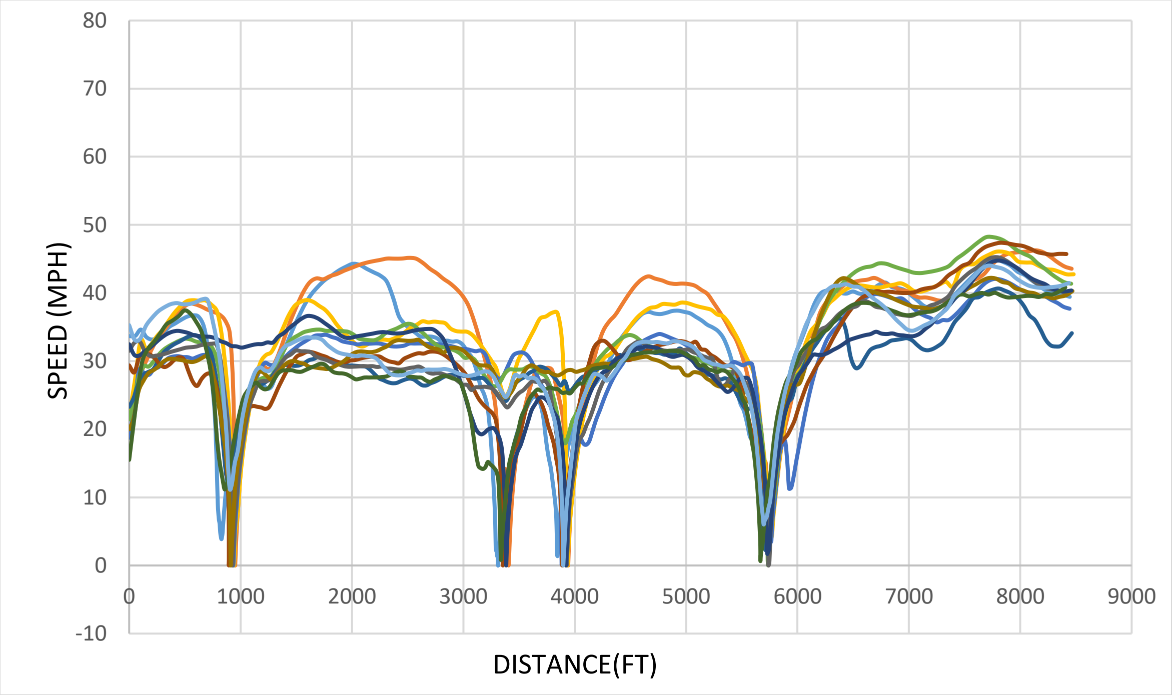


Figure A-11.Johston Yards-Memphis Illinois Central (from facility) PM

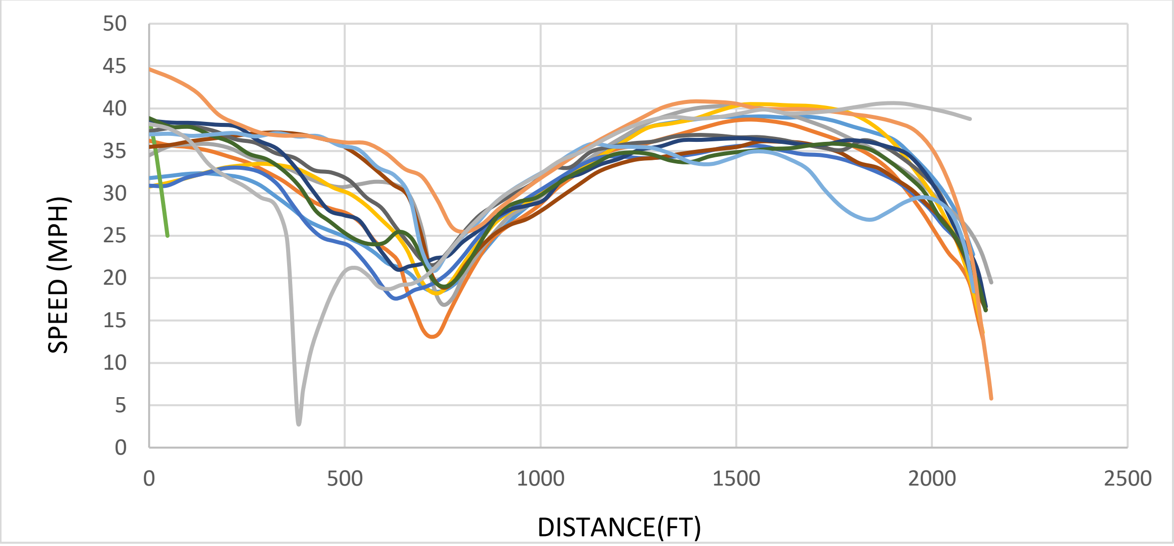


Figure A-12.Johston Yards-Memphis Illinois Central (to the facility) AM

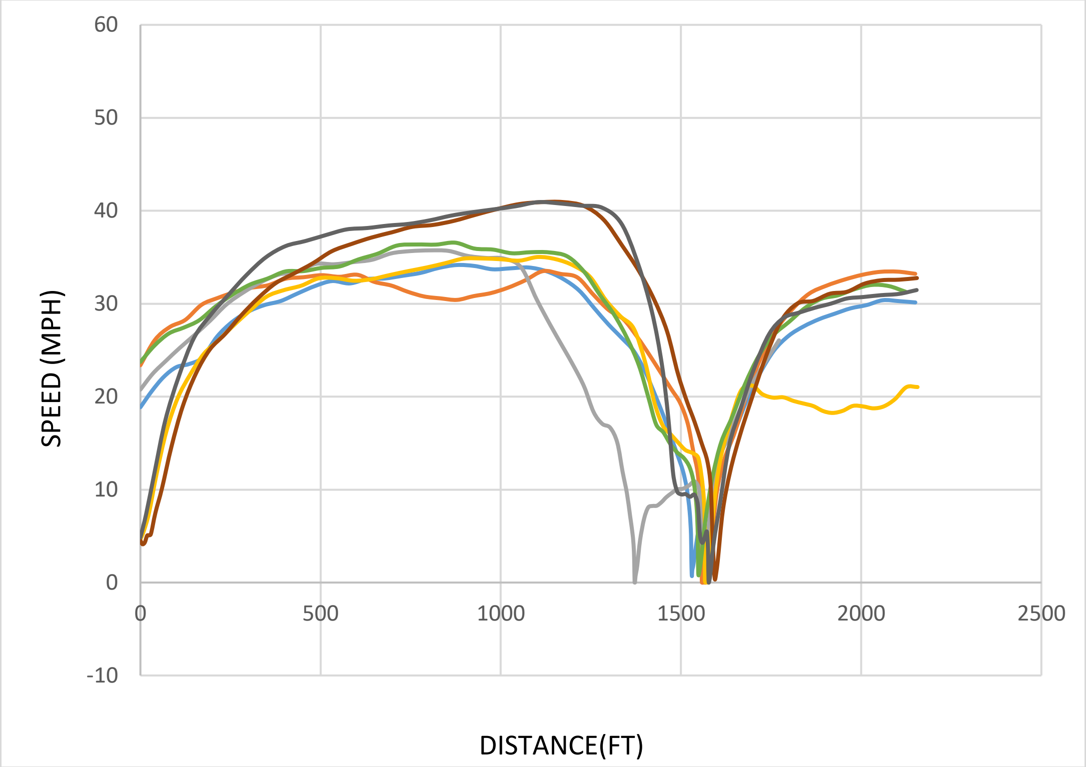


Figure A-13.Johston Yards-Memphis Illinois Central (from the facility) AM

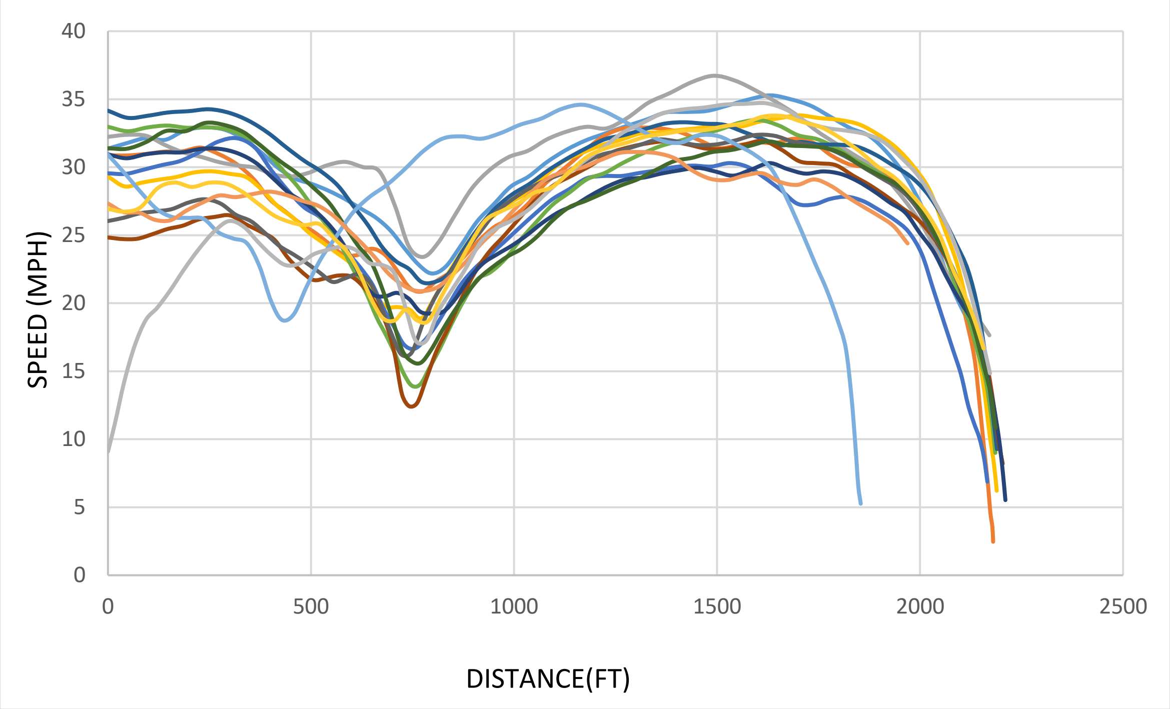


Figure A-14.Johston Yards-Memphis Illinois Central (to the facility) PM

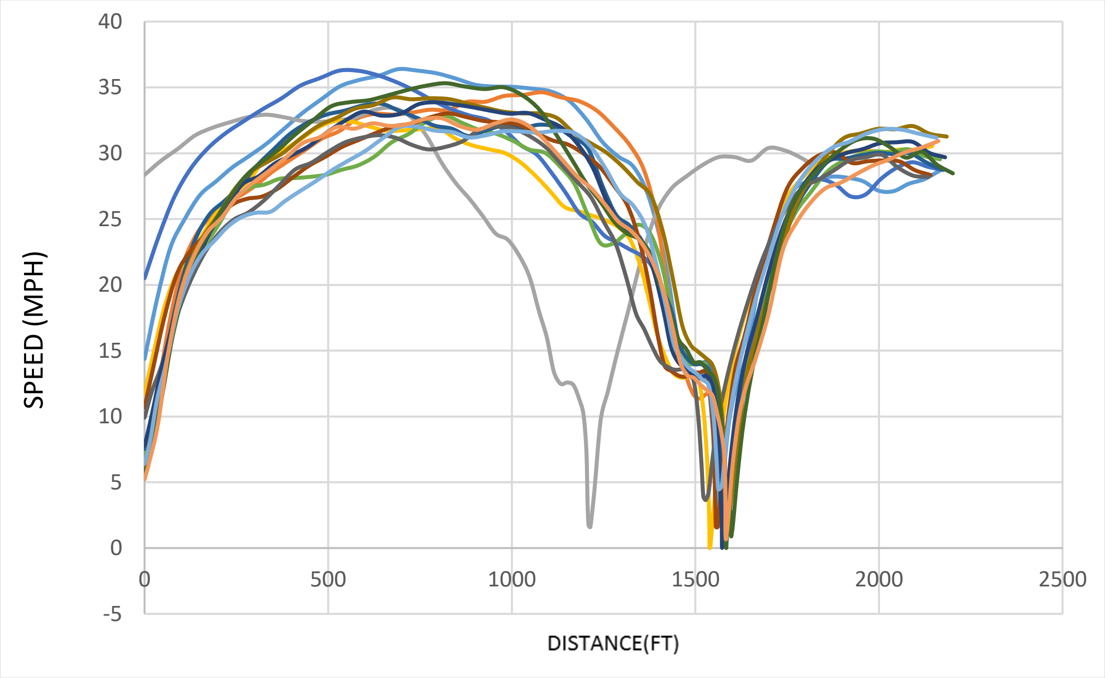


Figure A-15.Johston Yards-Memphis Illinois Central (from the facility) PM

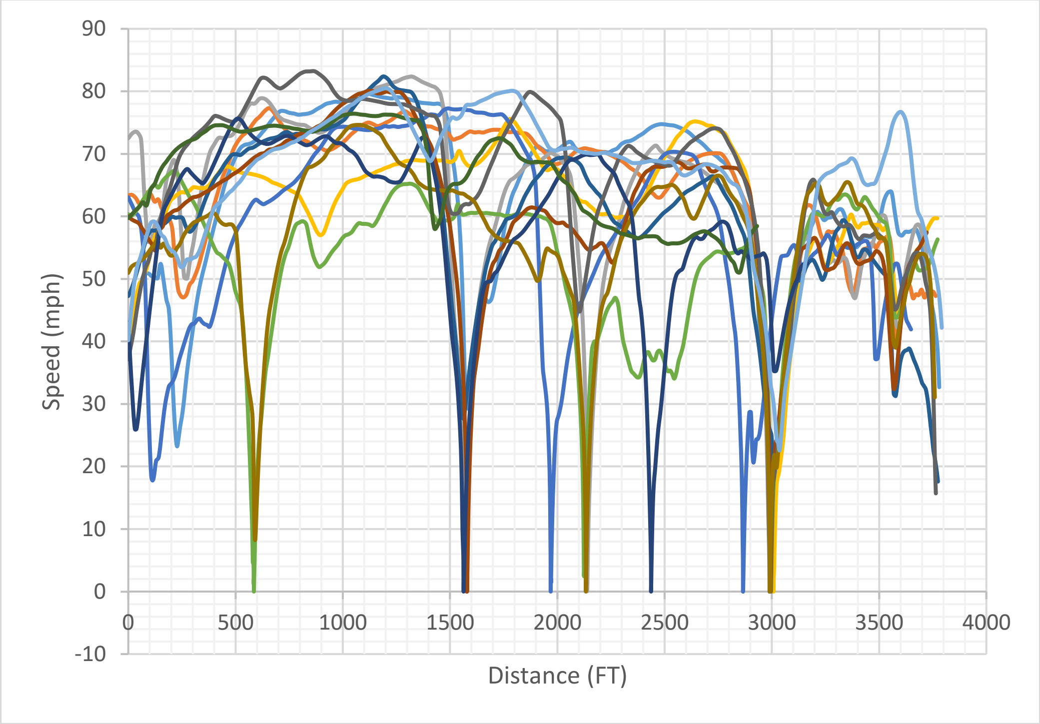


Figure A-16. Memphis International Airport (towards the facility) -AM

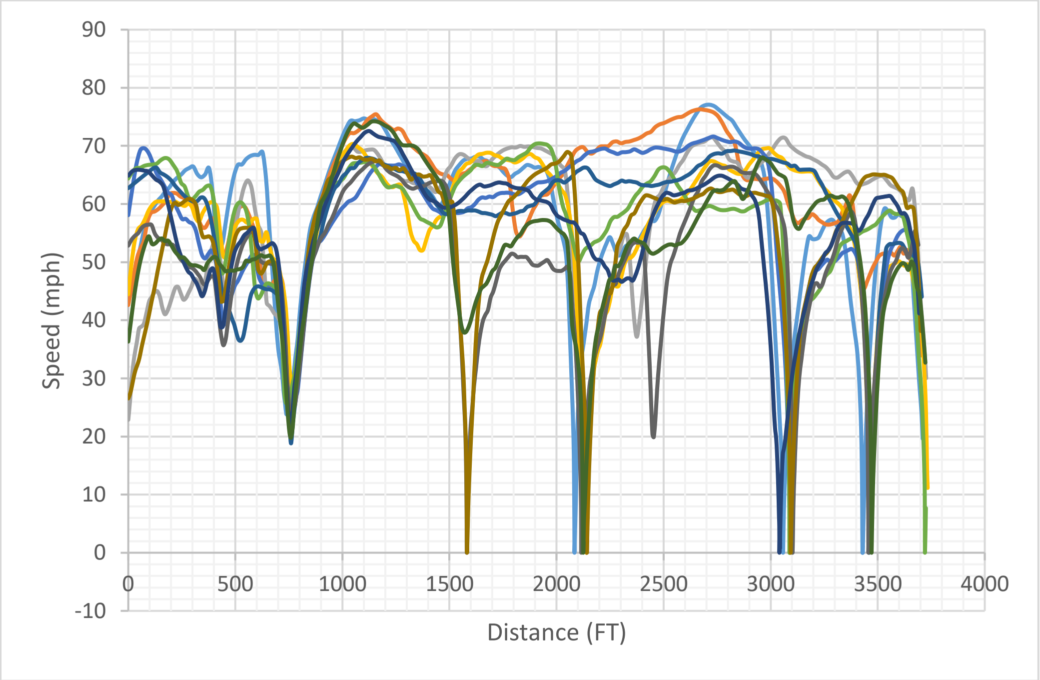


Figure A-17. Memphis International Airport (from the facility) -AM

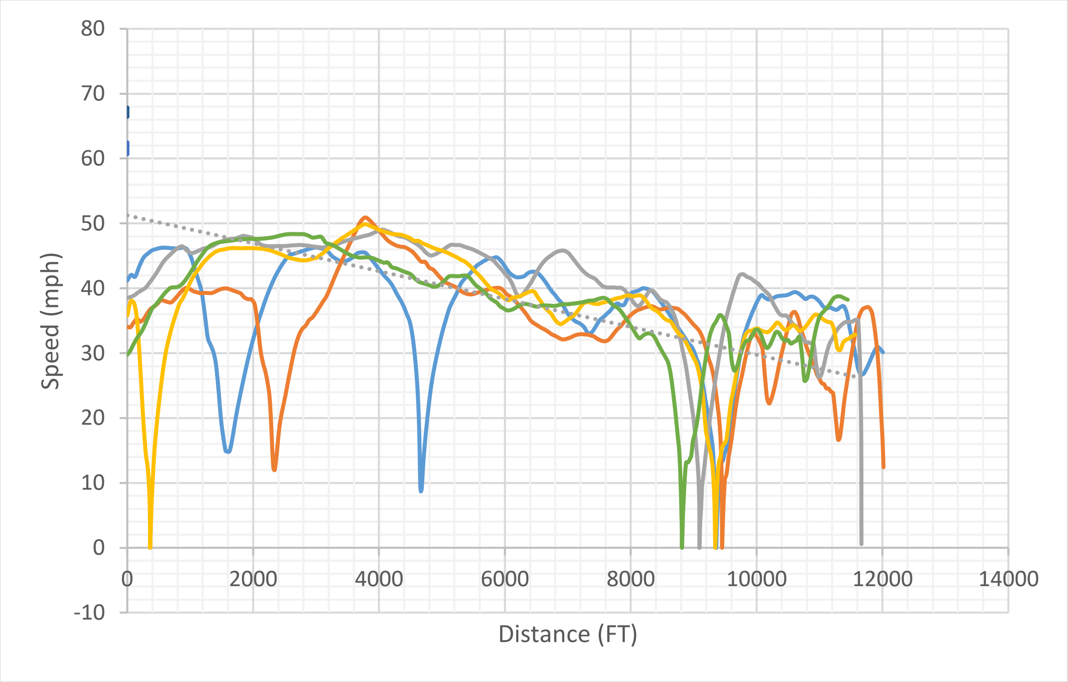


Figure A-18. Memphis International Airport (towards facility) -PM

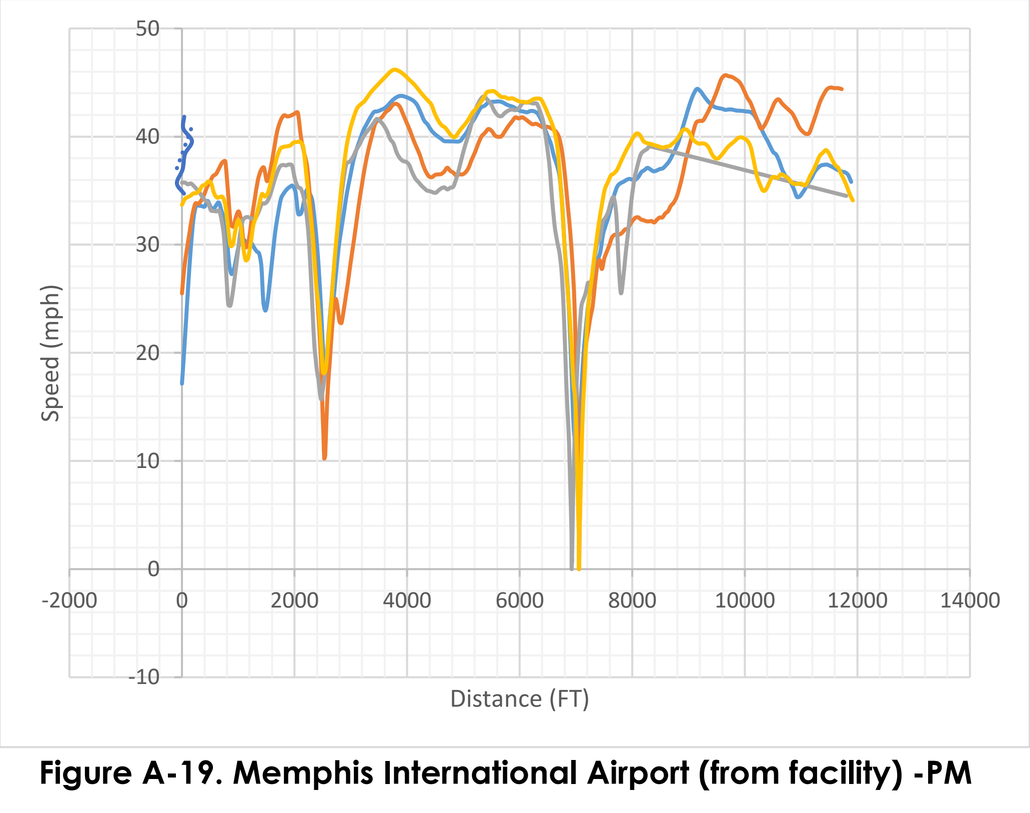


Figure A-19. Memphis International Airport (from facility) -PM

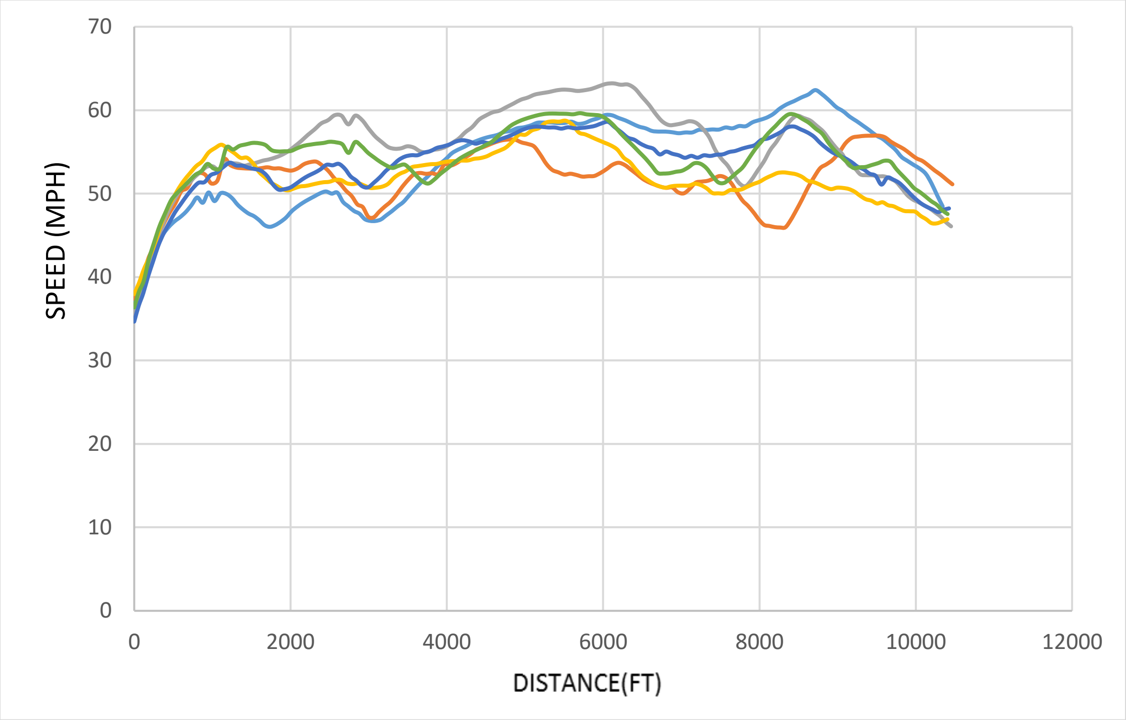


Figure A-20. Memphis International Airport (toward the facility) AM

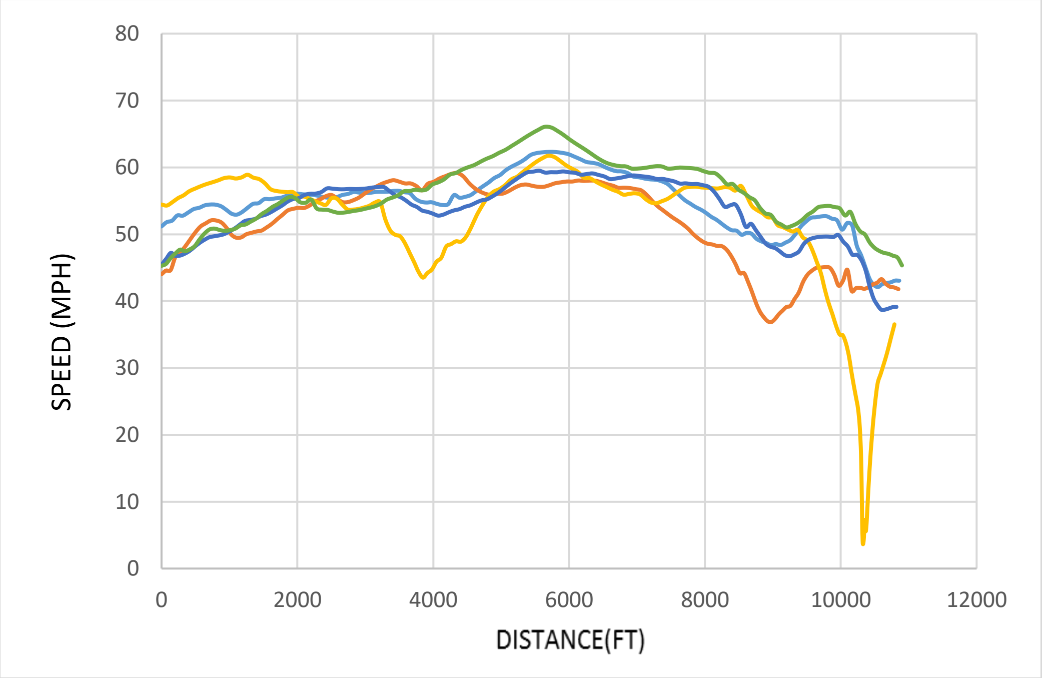


Figure A-21. Memphis International Airport (from the facility) AM

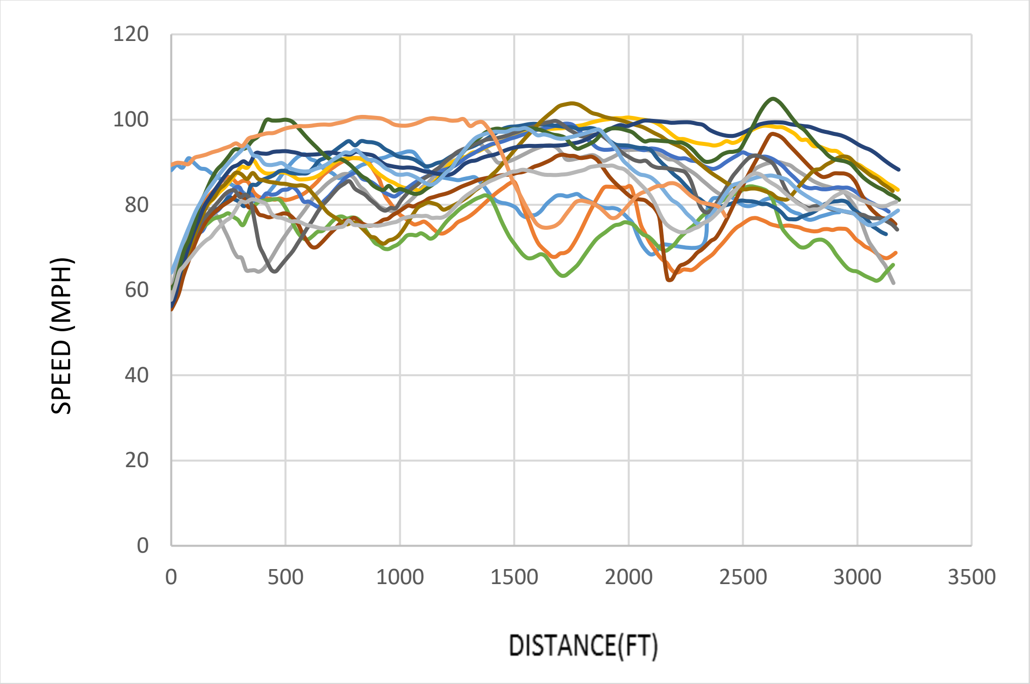


Figure A-22. Memphis International Airport (to the facility) PM

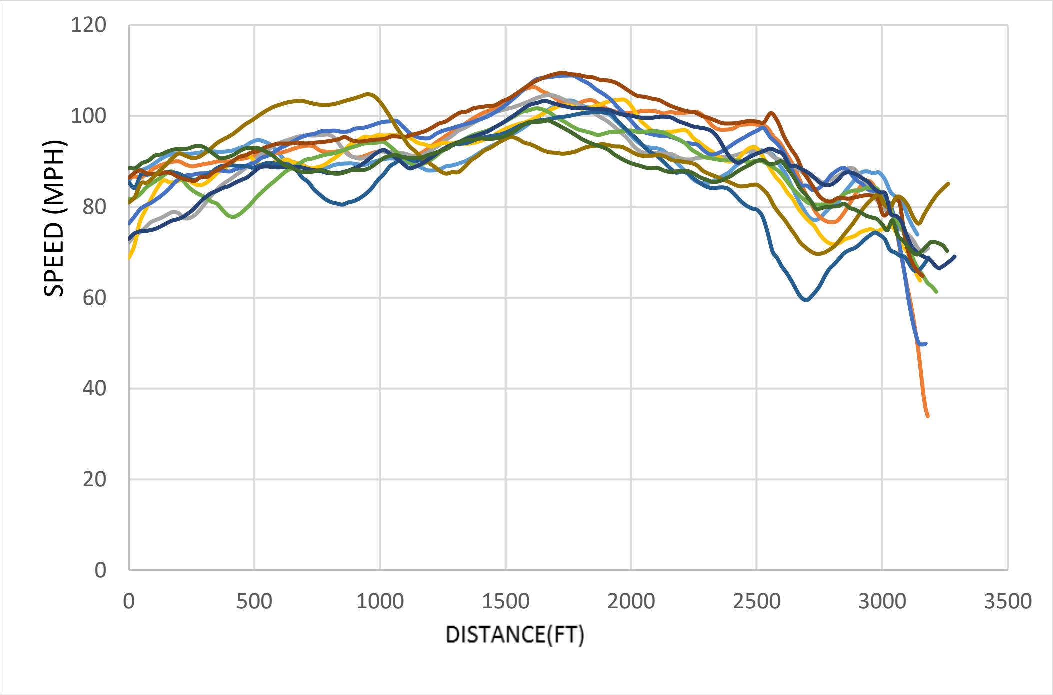


Figure A-23. Memphis International Airport (from the facility) PM

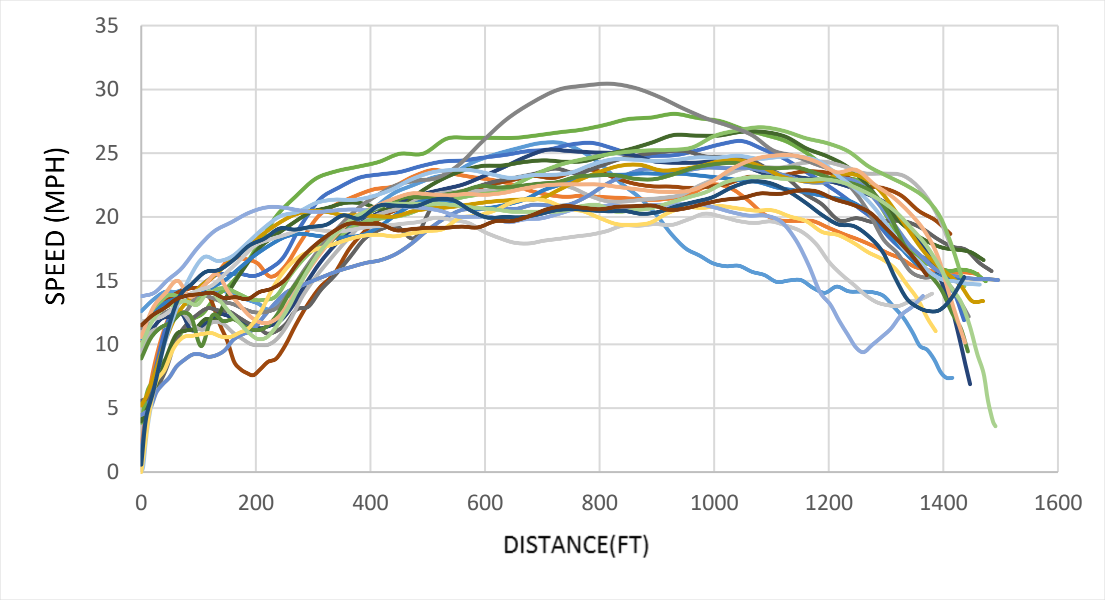


Figure A-24. Southern Foundry Supply-Chattanooga AM

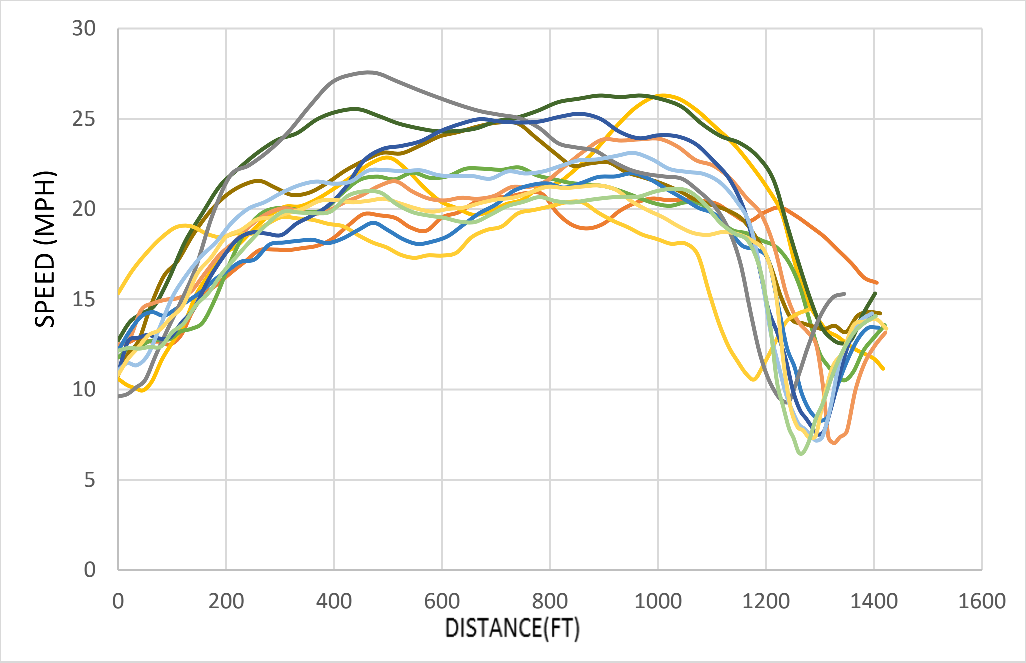


Figure A-25. Southern Foundry Supply-Chattanooga PM

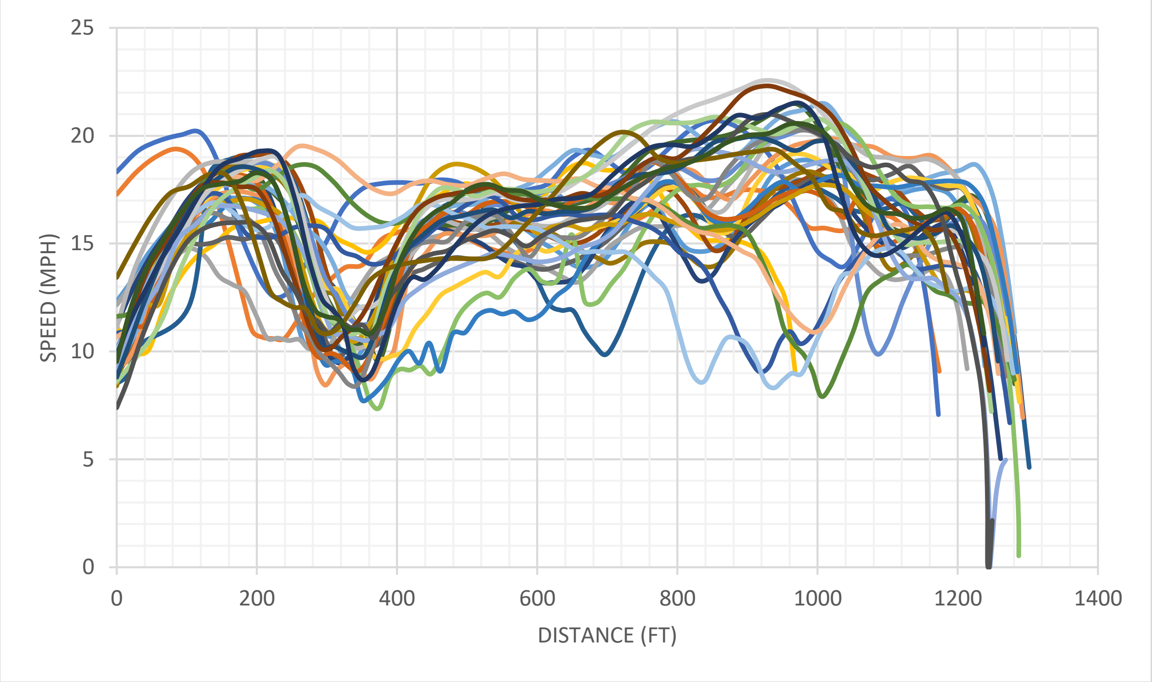


Figure A-26. Vulcan Materials Company-Chattanooga AM

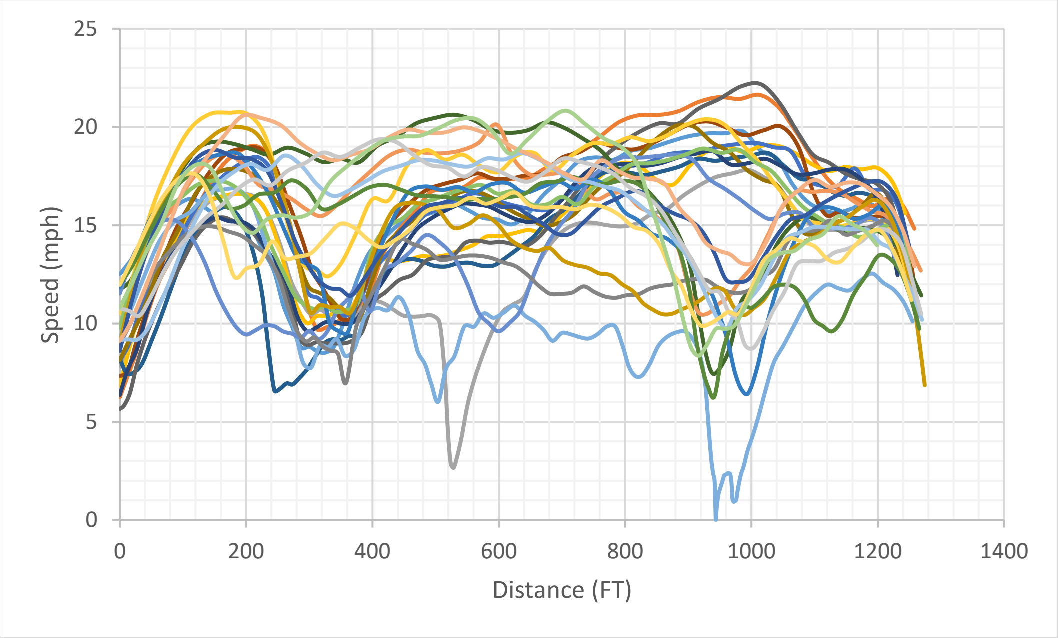
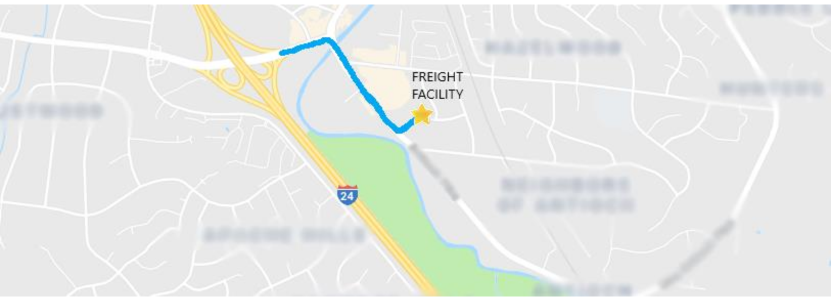


Figure A-27. Vulcan Materials Company-Chattanooga PM

APPENDIX B: TRUCK DRIVER SURVEY

Truck Driver Survey: Evaluation of Freight Intermodal Connectors

This questionnaire seeks to evaluate Freight Intermodal Connectors (FICs) in Tennessee from the stakeholders' (truck drivers') perspective. FICs, which are also known as "first mile/last mile connectors," are roadway segments that link freight logistics hubs or freight-intensive land uses to main freight routes. They are public, short mile roads that connect intermodal terminals to the National Highway Systems' (NHS) mainline routes (primarily interstates and arterials).



Please select the road segment(s) along the FICs in Tennessee that you frequently use:

Memphis:	Jack Carley Causeway	☐	Riverport Rd	☐	Spottswood Ave	☐
	Democrat Rd	☐	Chelsea Ave	☐	East Shelby Dr	☐
	Southern Ave	☐	West Mallory Ave	☐	New Horn Lake Rd	☐
	Plough Blvd	☐				
Chattanooga:	Jersey Pike	☐	Airport Rd	☐	Shepherd Rd	☐
	Manufacturers Rd	☐	Moccasin Bend Rd	☐	West 19th Street	☐
	River St	☐				
Knoxville:	East Magnolia Ave	☐	Middlebrook Pike	☐		
Kingsport:	Airport Access Rd	☐	Lincoln Street	☐		
Smyrna:	Sam Ridley Pkwy W	☐	Lee Victory Pkwy	☐		
Clarksville:	Hwy 76	☐	Guthrie Hwy	☐		
Portland:	Hwy 52 W	☐	Ronnie Mc Dowell Pkwy	☐		
Nashville:	Sidco Dr	☐				
Other:						

The following questions are in relation to the road segment(s) identified above:

1. Signage or striping concerns along the segment/corridor? **Yes** ☐ or **No** ☐
2. Roadway or shoulder width issues along the segment/corridor? **Yes** ☐ or **No** ☐
3. Adequate turning radii at some of the intersection(s)? **Yes** ☐ or **No** ☐
4. Train impediment issues along the segment/corridor? **Yes** ☐ or **No** ☐
5. Vertical clearance or weight restrictions? **Yes** ☐ or **No** ☐

6. Intersection turning movement issues? **Yes** ☐ or **No** ☐

7. Traffic accidents/safety concerns along the segment/corridor? **Yes** ☐ or **No** ☐

8. Recurring congestion along the segment/corridor? **Yes** ☐ or **No** ☐

9. Issues related to interacting with other vehicles, pedestrians, cyclists, and conflicting land uses along the segment/corridor? **Yes** ☐ or **No** ☐

10. To move freight more efficiently how important are the following transportation factors?

	Critical	**Important**	**Neutral**	**Unimportant**
• Infrastructure condition	☐	☐	☐	☐
• On-time delivery	☐	☐	☐	☐
• Direct/indirect cost of congestion	☐	☐	☐	☐
• Bottlenecks	☐	☐	☐	☐
• Safety and security	☐	☐	☐	☐
• Signage	☐	☐	☐	☐

11. How would you rate the transportation infrastructure along the Freight Intermodal Connectors?

	Inadequate	**Poorly Maintained**	**Average**	**Well Maintained**
• Signage and road markings	☐	☐	☐	☐
• Road geometrics	☐	☐	☐	☐
• Pavement conditions	☐	☐	☐	☐
• Traffic signals and timing	☐	☐	☐	☐
• Roadway connectivity	☐	☐	☐	☐
• Roadway capacity	☐	☐	☐	☐
• Interstate/highway accessibility	☐	☐	☐	☐
• Street lighting	☐	☐	☐	☐
• Safety features	☐	☐	☐	☐

12. How often do you encounter the following barriers that affect freight transportation?

	Never	**Rarely**	**Often**	**Always**
• Bridge/tunnel restrictions for freight	☐	☐	☐	☐
• Access to freight facility (turning lane)	☐	☐	☐	☐
• Congestion due to freight trucks	☐	☐	☐	☐
• Congestion due to crashes on the road segment	☐	☐	☐	☐
• Traffic congestion during Off-peak hours	☐	☐	☐	☐

• Traffic congestion during peak period	☐	☐	☐	☐
• Truck queuing at the terminal gate	☐	☐	☐	☐

13. Pavement conditions of the road segment(s): **Good** ☐ **Fair**☐ **Poor**☐
    - Good condition describes a road pavement that is smooth and does not possess any potholes, bumps, or rough spots.
    - Fair condition describes a road pavement that has a few and minor potholes, bumps, or rough spots, and can generally be described as mostly smooth.
    - Poor condition describes a road pavement characterized by major potholes, bumps, or rough spots.

14. Are any of these features available?

	Present	**Absent**
• Bike lanes along the connectors	☐	☐
• Sidewalks along the connectors	☐	☐
• Pedestrian crossing features	☐	☐

15. In your opinion what causes traffic congestion along this road segment(s)?
    Please respond with one of the following:
    Too many vehicles ☐, **Pedestrians & Cyclists** ☐, **Road Geometry** ☐, **Access Points**☐.

16. Do you experience any negative environmental issues while traveling along the road segment(s) (air pollution, noise)? **Yes** ☐ or **No** ☐

17. Rate the peak hour traffic congestion along the road segment(s)
    Light ☐ **Moderate** ☐ **Heavy** ☐

18. How often do you have to reroute to get to the freight facility?
    Often ☐ **Rarely** ☐ **Never** ☐
19. What is the average travel time from the interstate to freight facility or vice versa?

20. What is the average traveling speed?

21. Any recommendations on improvements?

22. Do you have any other preferred/ alternative routes that help you get to the facility quicker? Or that help navigate from the freight facility to the interstate road?

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