Building Resilient Pathways by Enhancing Operational Reliability and Connectivity in Intermodal Transportation Systems

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Traffic Operation and Connectivity Challenges for Intermodal Connectors

- Intermodal connectors—critical links that facilitate the movement of goods and passengers between various transportation modes—achieving resiliency in traffic operations and connectivity is particularly essential.
- Intermodal connectors form the **first and last mile** of movement, bridging the gap between main highways and transportation hubs like ports, rail terminals, and airports.
- However, this pivotal role comes with unique challenges that often test the resiliency of these connectors and demand targeted solutions to ensure **operational reliability and robust connectivity**.

Traffic Operation Challenges for Intermodal Connectors

- One of the foremost challenges in ensuring resiliency on intermodal connectors is managing the heavy and often complex traffic operations that occur on these corridors.
- Unlike typical road segments, intermodal connectors frequently handle high volumes of both freight and passenger vehicles, often leading to congestion that can hinder efficient movement.
- These connectors are frequently located in densely populated urban areas, where they serve as conduits not only for trucks moving goods but also for passenger vehicles and transit routes.
- This dual-purpose nature make worse congestion, especially during peak hours
- The mixed nature of traffic—combining large freight trucks with smaller passenger vehicles—creates significant operational complexity.
- Large trucks require more space, have longer stopping distances, and are slower to accelerate, which can lead to bottlenecks and increase the risk of collisions.
- The operation challenge is also heightened at intersections and merging points along the connector routes, where the risk of accidents and operational delays increases.
- For these reasons, ensuring resiliency in traffic operations on intermodal connectors calls for solutions that can accommodate the varying needs of different vehicle types and manage traffic flows in real-time to prevent disruptions.

Connectivity Challenges for Intermodal Connectors

- Connectivity is another critical side of transportation resiliency for intermodal connectors, as these routes must reliably link multiple transportation modes to ensure continuous transitions.
- In many cases, these connectors are the only routes linking critical infrastructure, meaning any disruption in connectivity can separate access between transit points and the wider transportation network.
- The physical and digital infrastructure required to support these innovations is often limited on intermodal connectors, as these corridors were not originally designed for modern demands.
- Aging infrastructure, including narrow lanes, outdated bridges, and insufficient signage, makes it challenging for these connectors to adapt to new requirements.
- Additionally, connectivity challenges are compounded by limited space for upgrades in urban areas, where these connectors are commonly located.
- If an intermodal connector is disrupted, there is often no readily available alternative that can handle the same volume and types of traffic

CASE STUDY

FREIGHT INTERMODAL CONNECTORS (FICs) in Tennessee

- USDOT(Bureau of Transportation Statistics) https://rosap.ntl.bts.gov/view/dot/56268
- https://trid.trb.org/view/1858351
- **TRR:** https://journals.sagepub.com/doi/abs/10.1177/0361198119834906?journalCode=trra

Intermodal Connectors

- My presentation examines how the findings from the "Intermodal Connectors" study I conducted in Tennessee for TDOT few years ago that provide insights into the highlighted challenges, the findings that can be used for developing a resilient, robust transportation system for the future of mobility, specifically with intermodal connectors as a case study.
- This study evaluated Freight Intermodal Connectors (FICs) in Tennessee to identify deficiencies related to **congestion/capacity, safety, travel time reliability and environmental needs**.

- This study performed multimodal inventory check and evaluated some of critical freight connectors in Tennessee by identifying improvement needs with respect to
  - Safety
  - Risk Assessment
  - Operations (Capacity)
  - Environmental (Emissions)
  - Access and Connectivity
- Operations Analysis identified deficiencies and issues along selected FICs based on:
  - Level of Service (LOS) at Intersections
  - Access and connectivity
  - Queue storage lengths being exceeded
  - Delay at intersections
  - Bottlenecks
  - Traffic signal progression
  - Adequate capacity (LOS)
  - Turning radii at intersections
  - Travel time reliability

FREIGHT INTERMODAL CONNECTORS (FICs)

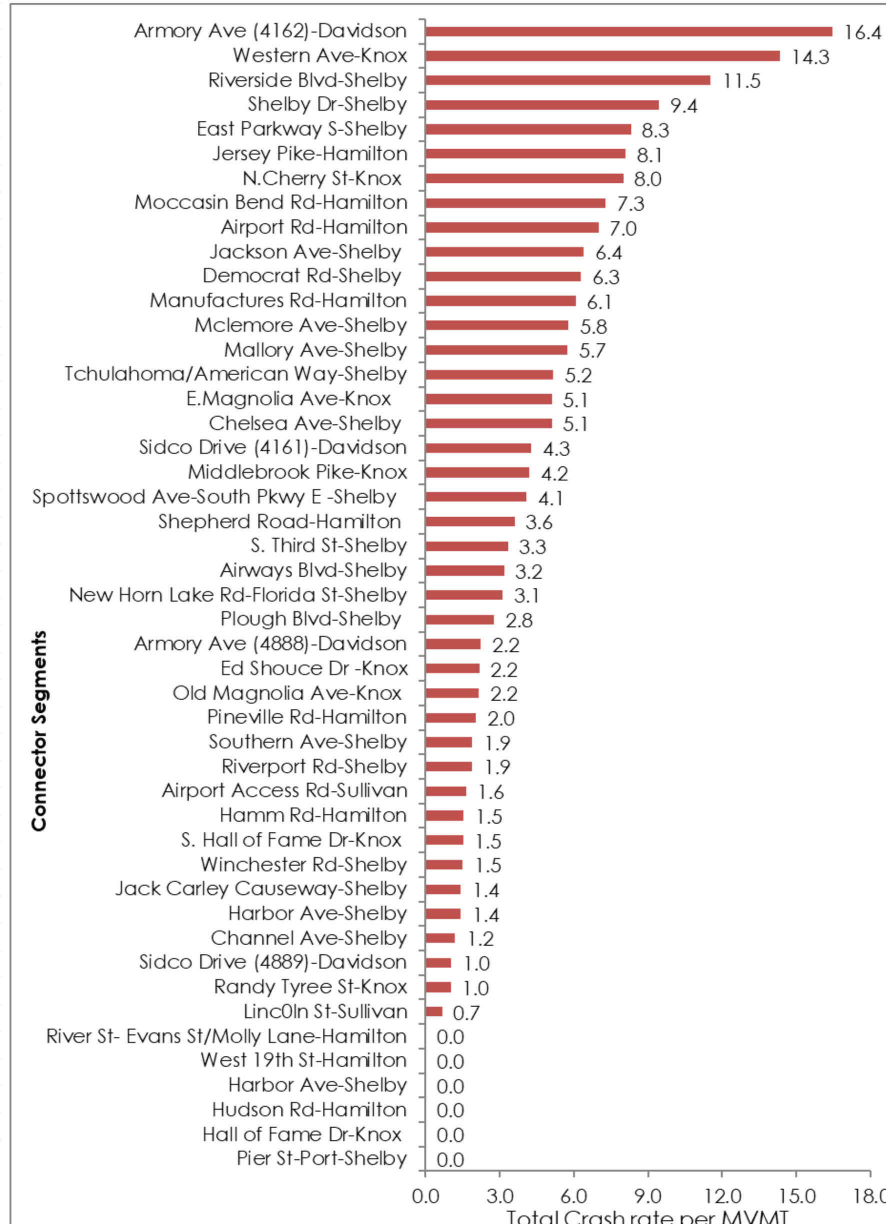
- FICs which are also known as **“First mile/last mile roadways”** are connector facilities that link freight-intensive land uses to main freight routes.
- They are generally the shortest portion of a freight trip; however, often times they are the most difficult to complete.
- First-mile, last-mile connections, especially in well-populated urban areas, may experience issues such as traffic congestion, safety, freight-incompatible roadway geometry, and configurations resulting in delays to moving freight.

County	Airport	Intercity Bus Terminal	Port Terminal	Truck/ Pipeline Terminal	Truck/ Rail Facility	Total
Davidson	0	1	0	0	1	**2**
Hamilton	1	1	4	1	0	**7**
Knox	0	1	0	1	0	**2**
Shelby	2	1	1	0	6	**10**
Sullivan	1	0	0	0	1	**2**
Total	**4**	**4**	**5**	**2**	**8**	**23**

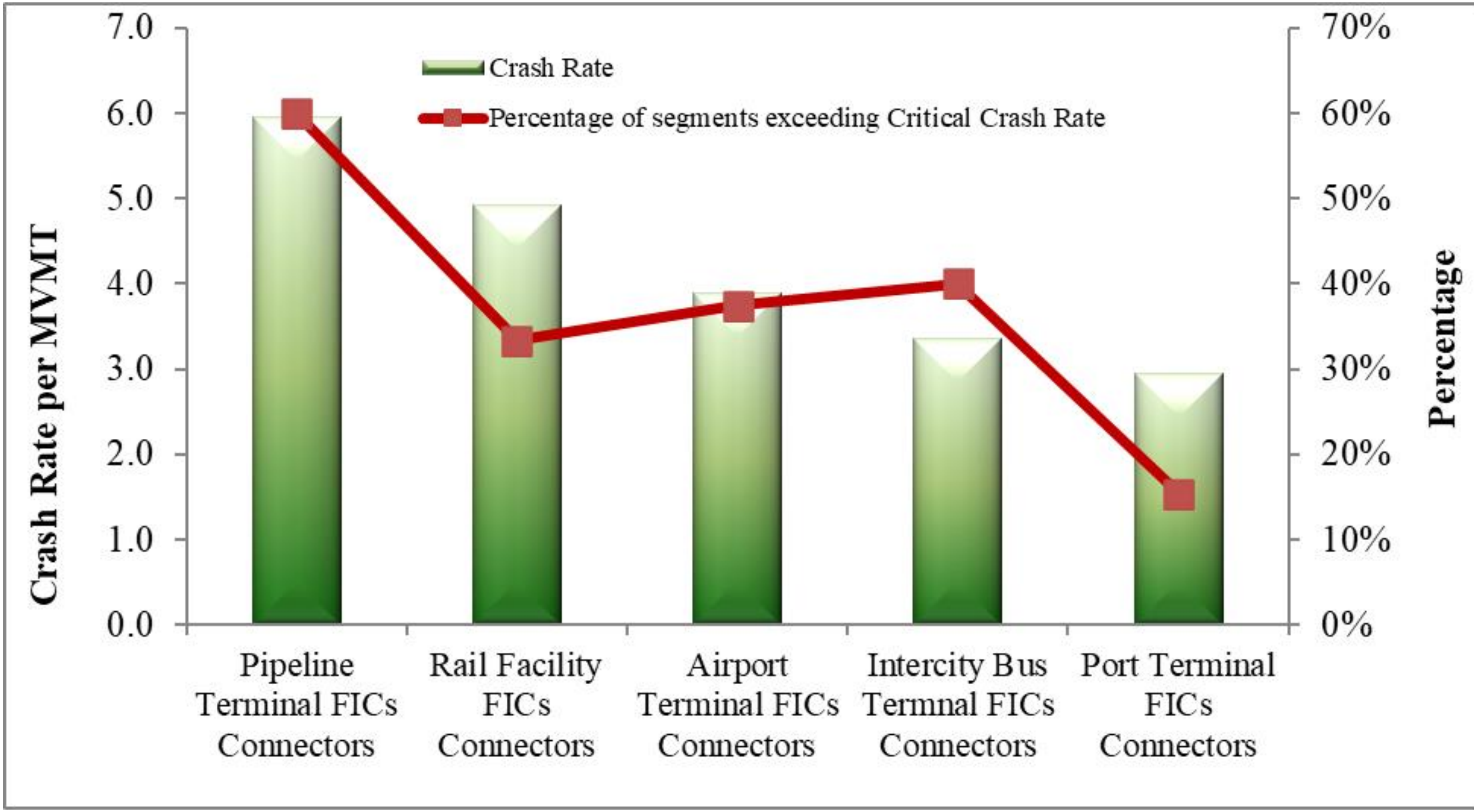
Facility Type	Type	No.	Connector Description	Miles	Id
Chattanooga Metropolitan Airport	Airport	1	Shepherd Road (Airport Connector) Between SR-153 And Airport Road	0.7	TN2A
Colonial & Plantation Pipeline Co. - Knx	Truck/Pipeline Terminal	1	Middlebrook Pike (SR-169), Ed Shouse Drive, Western Ave From Terminal Entrance To I-75	1.3	TN11L
Colonial Pipeline - Chattanooga	Truck/Pipeline Terminal	1	Jersey Pike From Enterprise Park Drive To SR-153	0.5	TN1L
CSX Corporation - Kingsport	Truck/Rail Facility	1	Linc0ln Street From John B. Dennis Highway (SR-93) To Facility Entrance	0.8	TN10R
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	1	Southern Avenue From Lamar Ave. (SR-4) To East Parkway (SR-277)	0.8	TN13R
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	2	East Parkway (SR-277) From Lamar Ave. (SR-4) To Southern Avenue	0.8	TN13R
Forrest Yards - Memphis Norfolk Southern	Truck/Rail Facility	3	Spottswood Avenue From Airways (SR-277) To Forrest Yard	0.3	TN13R
Greyhound Bus Terminal - Chattanooga	Intercity Bus Terminal	1	West 4th Street And Chestnut Street From I-124 To West 5th Street	0.3	TN8B
Greyhound Bus Terminal - Knoxville	Intercity Bus Terminal	1	Cherry Street And Magnolia Avenue (SR-1) From I-40 To Central Street	2.3	TN12B
Greyhound Bus Terminal - Memphis	Intercity Bus Terminal	1	Union Avenue (SR-3) Between Danny Thomas Blvd (SR-1) And 4th Street	0.2	TN20B
Greyhound Bus Transp Center - Nashville	Intercity Bus Terminal	1	Demonbreun Between I-40 And 8th Avenue South (SR-1)	0.4	TN21B
J.I.T. Terminals - Chattanooga	Port Terminal	1	Manufactures Road From SR-29 To Terminal Entrance	0.2	TN4P
Johnston Yards - Memphis Illinois Centra	Truck/Rail Facility	1	Mallory Avenue And Riverport Road Between I-55 And Rail Yard	1.5	TN19R
Leewood Yards - Memphis CSX	Truck/Rail Facility	1	Jackson Avenue (SR-14) And Chelsea Avenue Between I-40 And Warford Street	2.5	TN17R
Memphis International Airport	Airport	1	Tchulahoma And Democrat Rd Between Lamar Ave (SR-4) And Airways Blvd	2.4	TN15A
Memphis International Airport	Airport	2	Plough Blvd Between I-240 And The Airport Entrance	2	TN15A
Mid-South Terminals	Port Terminal	1	Hudson Rd. To Pineville Rd. To Moccasin Bend Rd. To Hamm Rd. To S. R. 29	2.8	TN3P
President's Island - Memphis	Port Terminal	1	Mclemore Av, Riverside Blvd, Jack Carley Causeway, Harbor Av, Channel Av, Jetty St Btw I-55 & Port	5.3	TN14P
Radnor Yards - Nashville CSX	Truck/Rail Facility	1	Armory Ave And Sidco Drive Between I-65 And Harding Place (SR-255)	2	TN22R
Southern Foundry Supply - Chattanooga	Port Terminal	1	West 19th Street From Riverfront Parkway (SR-58) To The Port Entrance	0.3	TN6P
Tennessee Yards - Memphis Burlington Nor	Truck/Rail Facility	1	Shelby Drive Between Lamar Avenue (SR-4) And The Tennessee Yard	0.6	TN18R
Tri-Cities Regional Airport - Kingsport	Airport	1	Airport Access Road (SR-357) From I-81 To Airport Entrance	3.1	TN9A
Vulcan Materials Company -Chattanooga	Port Terminal	1	River Street From Evans Street To Riverfront Parkway (SR-58)	0.1	TN5P
Total				31.2	

Safety Analysis

Connector Segment	Fatal & Injury crash rate	Total crash rate	Total Crash rate (No Ramp Related)	Total Cra rate (Ran Related O
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 shouce 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



Safety Scores

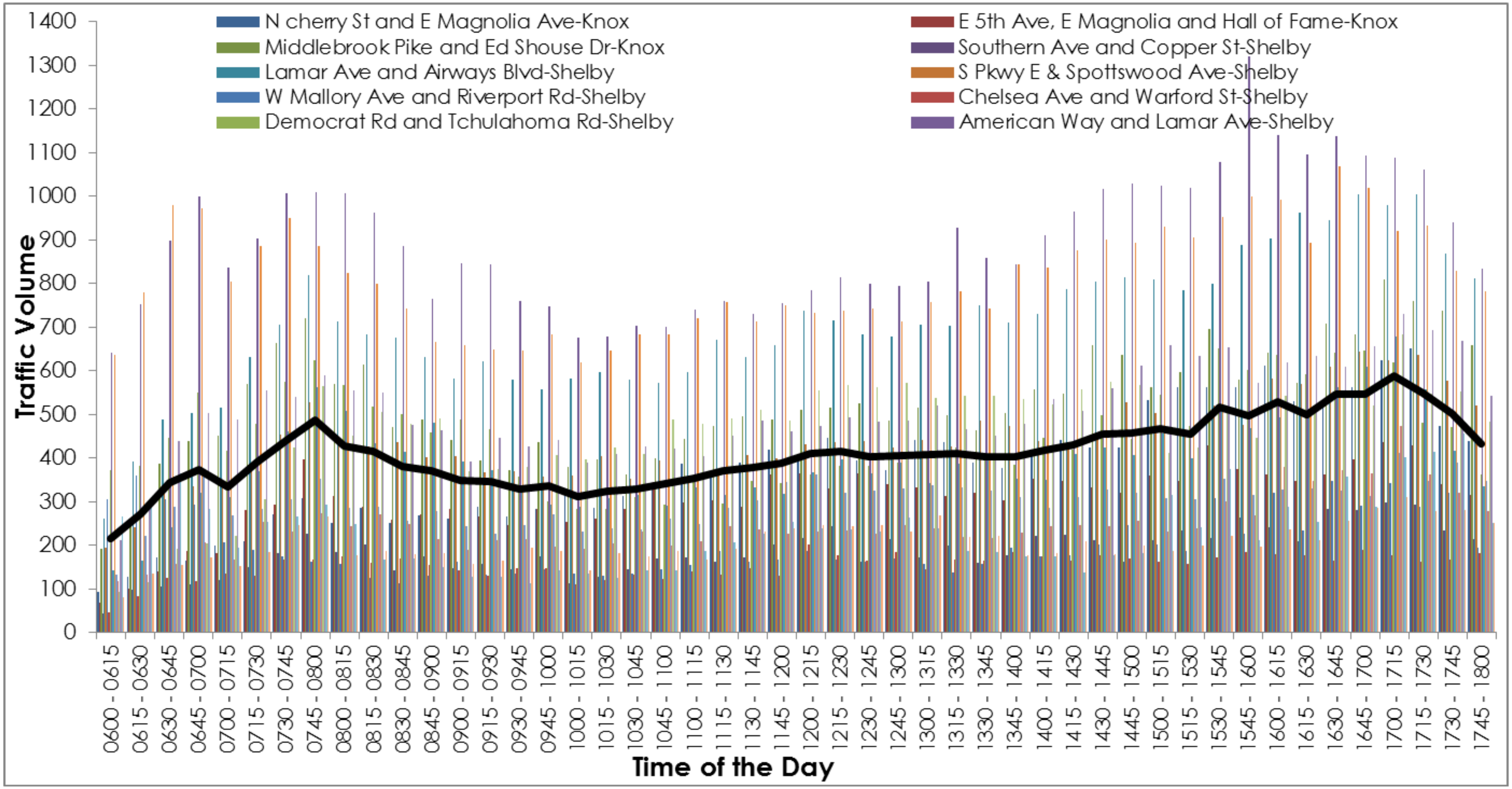


Impacts of Different Factors to Safety in terms of Crash Frequency

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 TWLTL*	-0.981	-3.890
Presence of Outside Shoulder	-0.467	-1.580
Presence of Curb and Gutter	0.102	0.370
Constant	1.666	3.840
Length	Offset	

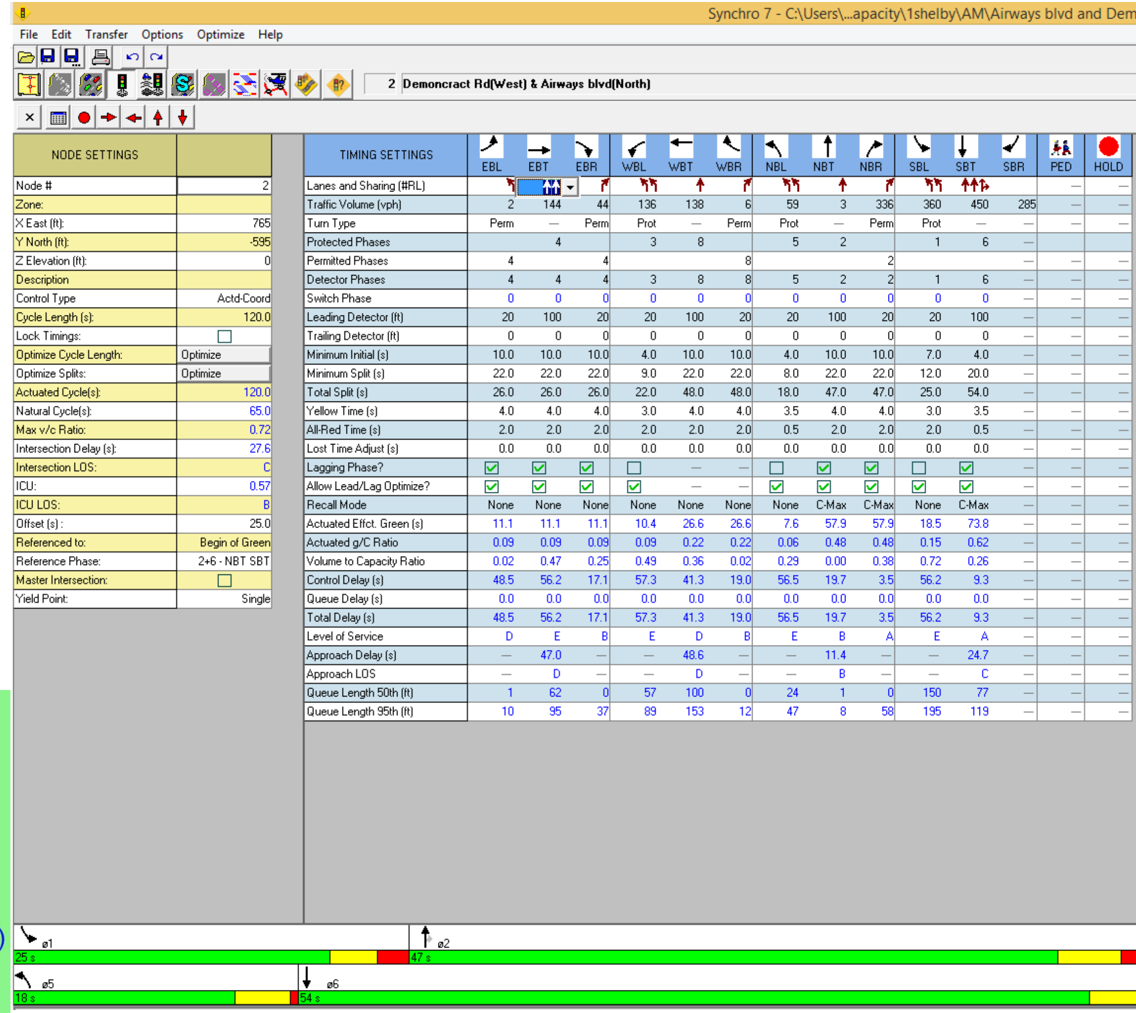
OPERATIONAL AND CAPACITY EVALUATION

Distribution of Intersection Volumes by Time of the Day



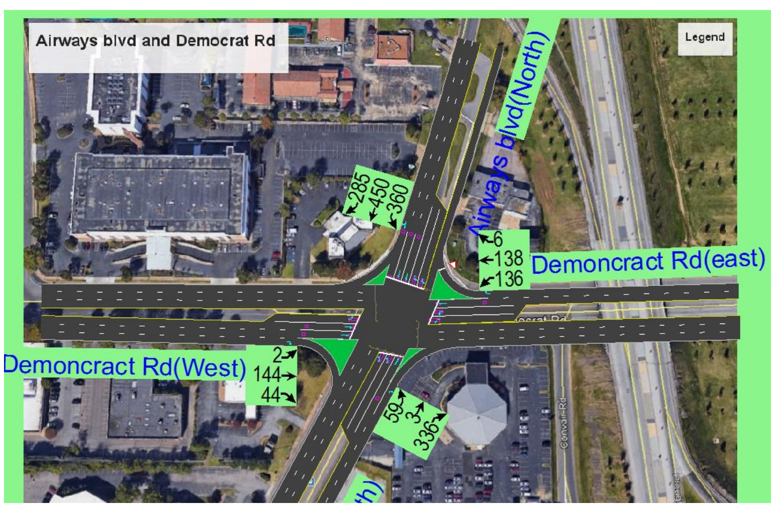
Operational Analysis of Intersections

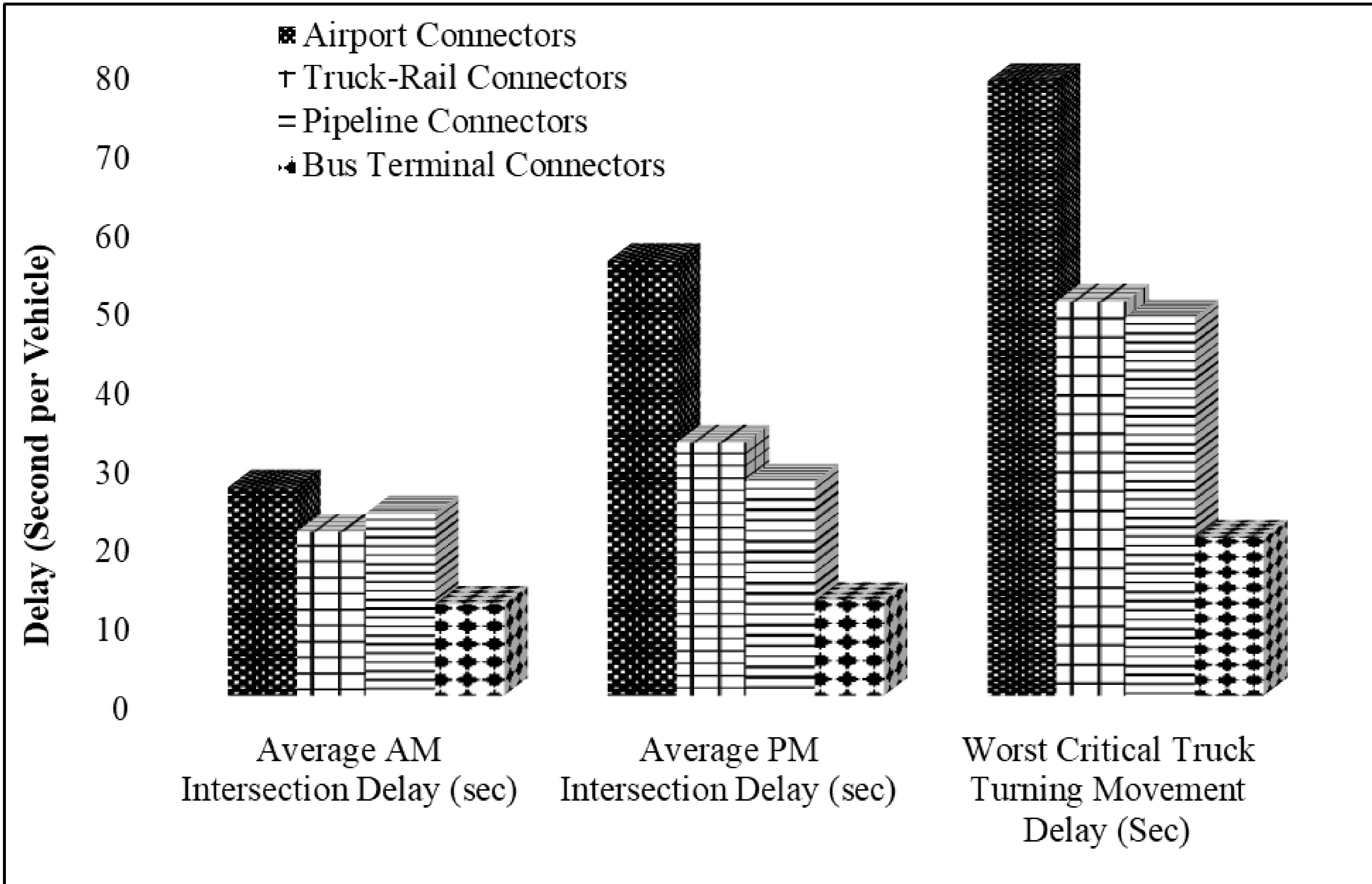
- Synchro was used for the intersection capacity analysis
- **Analysis followed procedures in H**ighway Capacity Manual (HCM)



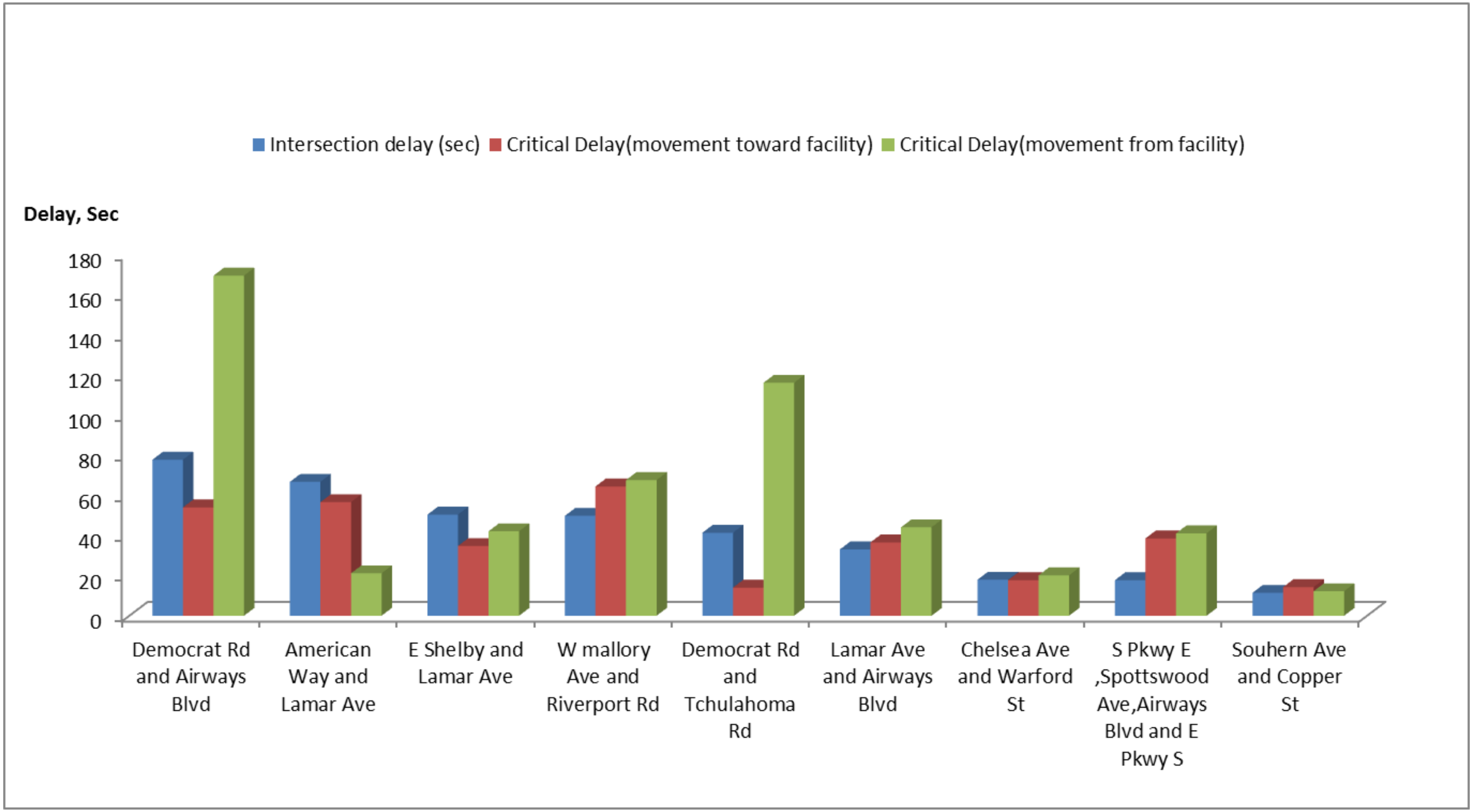
NODE SETTINGS	
Node #	2
Zone:	
X East (ft):	765
Y North (ft):	-595
Z Elevation (ft):	0
Description	
Control Type	Actd-Coord
Cycle Length (s):	120.0
Lock Timings:	☐
Optimize Cycle Length:	Optimize
Optimize Splits:	Optimize
Actuated Cycle(s):	120.0
Natural Cycle(s):	65.0
Max v/c Ratio:	0.72
Intersection Delay (s):	27.6
Intersection LOS:	C
ICU:	0.57
ICU LOS:	B
Offset (s):	25.0
Referenced to:	Begin of Green
Reference Phase:	2+6 - NBT SBT
Master Intersection:	☐
Yield Point:	Single

TIMING SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	PED	HOLD
Lanes and Sharing (#RL)													—	—
Traffic Volume (vph)	2	144	44	136	138	6	59	3	336	360	450	285	—	—
Turn Type	Perm	—	Perm	Prot	—	Perm	Prot	—	Perm	Prot	—	—	—	—
Protected Phases		4		3	8		5	2		1	6	—		
Permitted Phases	4		4			8			2			—	—	—
Detector Phases	4	4	4	3	8	8	5	2	2	1	6	—	—	—
Switch Phase	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Leading Detector (ft)	20	100	20	20	100	20	20	100	20	20	100	—	—	—
Trailing Detector (ft)	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Minimum Initial (s)	10.0	10.0	10.0	4.0	10.0	10.0	4.0	10.0	10.0	7.0	4.0	—	—	—
Minimum Split (s)	22.0	22.0	22.0	9.0	22.0	22.0	8.0	22.0	22.0	12.0	20.0	—	—	—
Total Split (s)	26.0	26.0	26.0	22.0	48.0	48.0	18.0	47.0	47.0	25.0	54.0	—	—	—
Yellow Time (s)	4.0	4.0	4.0	3.0	4.0	4.0	3.5	4.0	4.0	3.0	3.5	—	—	—
All-Red Time (s)	2.0	2.0	2.0	2.0	2.0	2.0	0.5	2.0	2.0	2.0	0.5	—	—	—
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—
Lagging Phase?	☑	☑	☑	☐	—	—	☐	☑	☑	☐	☑	—	—	—
Allow Lead/Lag Optimize?	☑	☑	☑	☑	—	—	☑	☑	☑	☑	☑	—	—	—
Recall Mode	None	None	None	None	None	None	None	C-Max	C-Max	None	C-Max	—	—	—
Actuated Effct. Green (s)	11.1	11.1	11.1	10.4	26.6	26.6	7.6	57.9	57.9	18.5	73.8	—	—	—
Actuated g/C Ratio	0.09	0.09	0.09	0.09	0.22	0.22	0.06	0.48	0.48	0.15	0.62	—	—	—
Volume to Capacity Ratio	0.02	0.47	0.25	0.49	0.36	0.02	0.29	0.00	0.38	0.72	0.26	—	—	—
Control Delay (s)	48.5	56.2	17.1	57.3	41.3	19.0	56.5	19.7	3.5	56.2	9.3	—	—	—
Queue Delay (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—
Total Delay (s)	48.5	56.2	17.1	57.3	41.3	19.0	56.5	19.7	3.5	56.2	9.3	—	—	—
Level of Service	D	E	B	E	D	B	E	B	A	E	A	—	—	—
Approach Delay (s)	—	47.0	—	—	48.6	—	—	11.4	—	—	24.7	—	—	—
Approach LOS	—	D	—	—	D	—	—	B	—	—	C	—	—	—
Queue Length 50th (ft)	1	62	0	57	100	0	24	1	0	150	77	—	—	—
Queue Length 95th (ft)	10	95	37	89	153	12	47	8	58	195	119	—	—	—



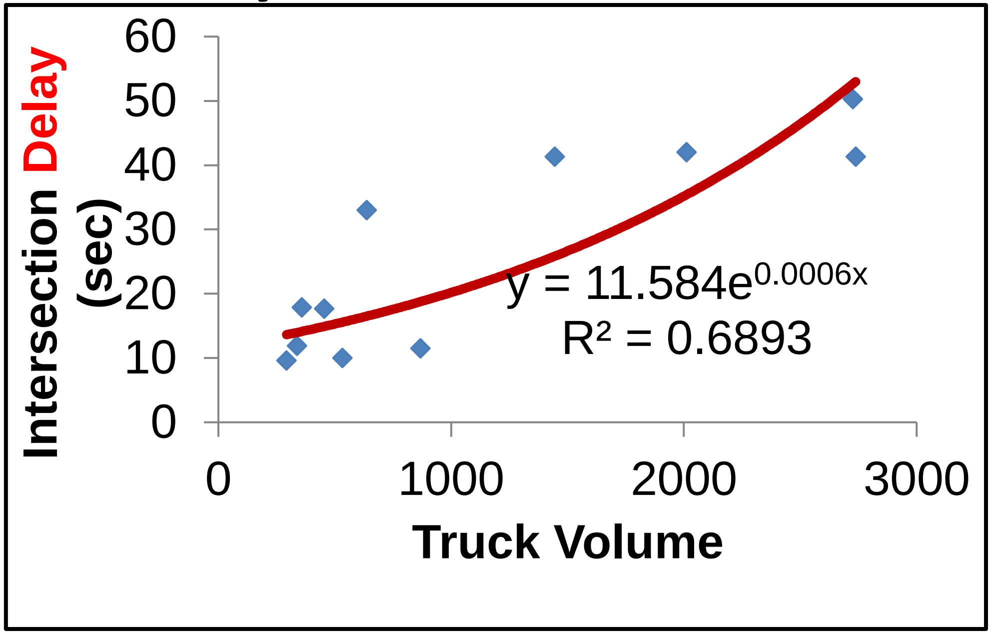

Airport Connectors
Truck-Rail Connectors
Pipeline Connectors
Bus Terminal Connectors
Delay (Second per Vehicle)
0
10
20
30
40
50
60
70
80
Average AM Intersection Delay (sec)
Average PM Intersection Delay (sec)
Worst Critical Truck Turning Movement Delay (Sec)

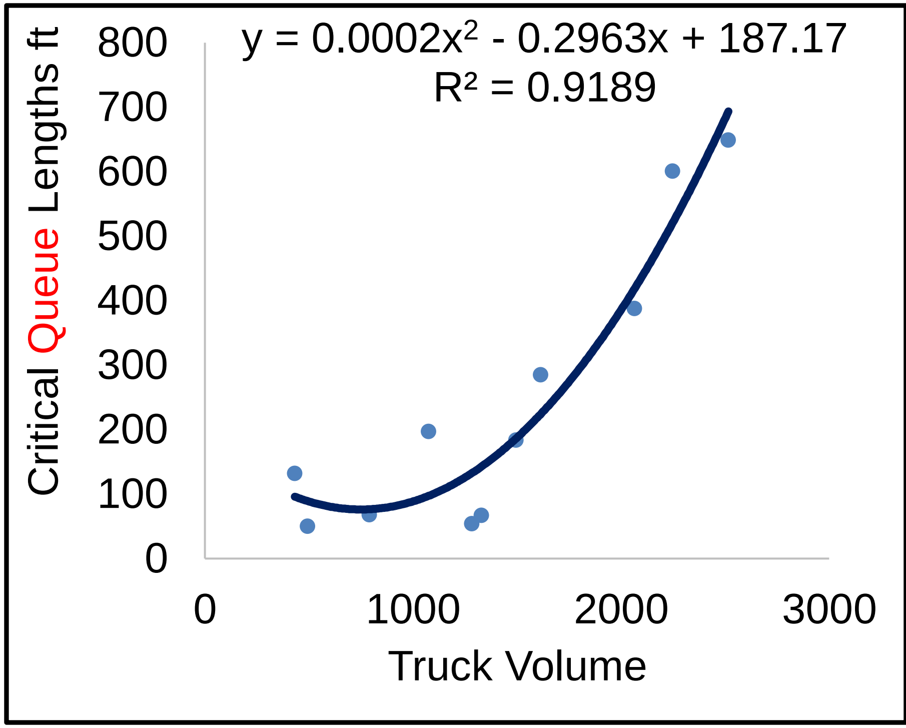
AM & PM Critical Approach Queue Lengths



Intersection delay (sec)
Critical Delay(movement toward facility)
Critical Delay(movement from facility)
Delay, Sec
180
160
140
120
100
80
60
40
20
0
Democrat Rd and Airways Blvd
American Way and Lamar Ave
E Shelby and Lamar Ave
W mallory Ave and Riverport Rd
Democrat Rd and Tchulahoma Rd
Lamar Ave and Airways Blvd
Chelsea Ave and Warford St
S Pkwy E ,Spottswood Ave,Airways Blvd and E Pkwy S
Souhern Ave and Copper St

Correlation between Traffic Volume and Delays and Queues at FICs Intersections

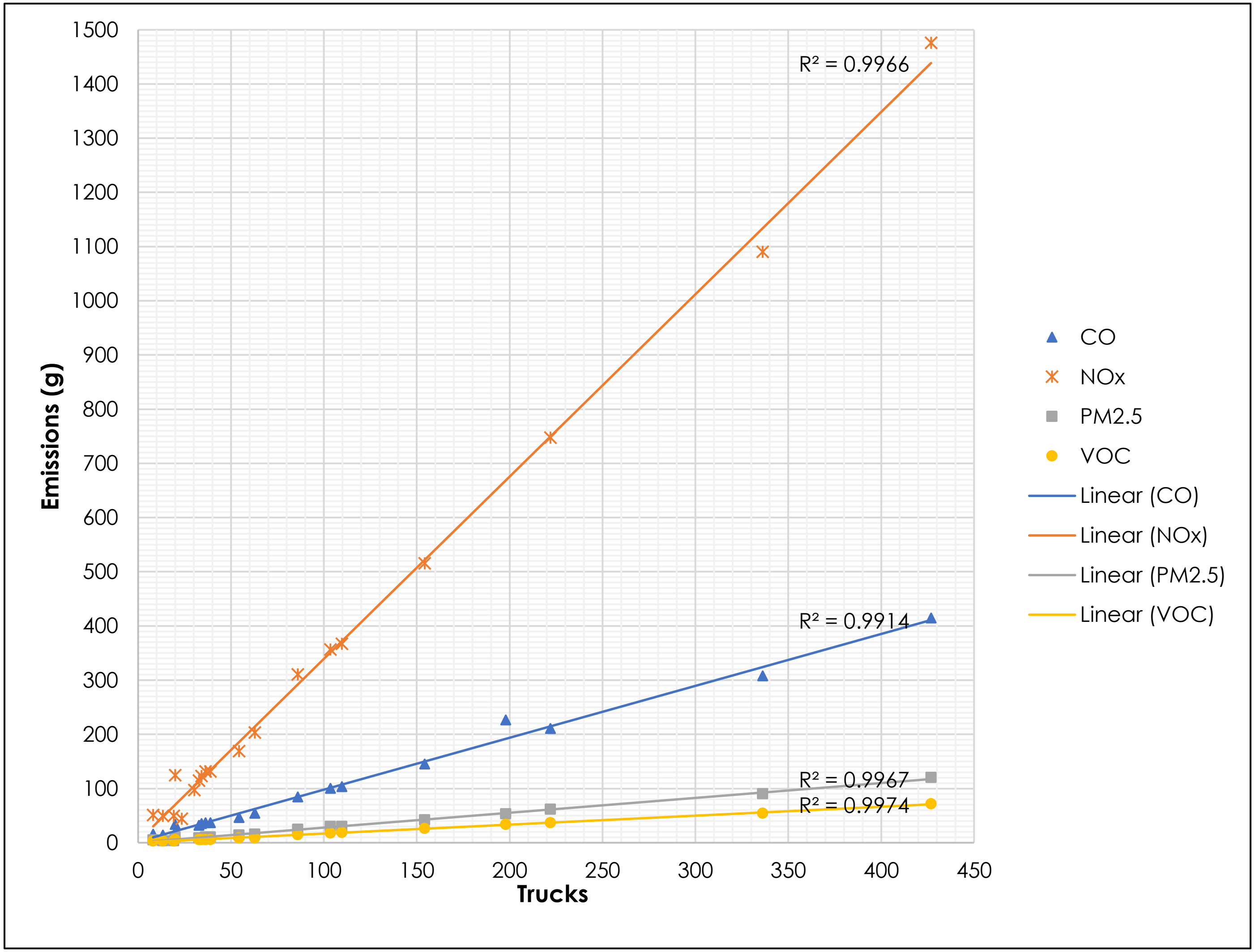


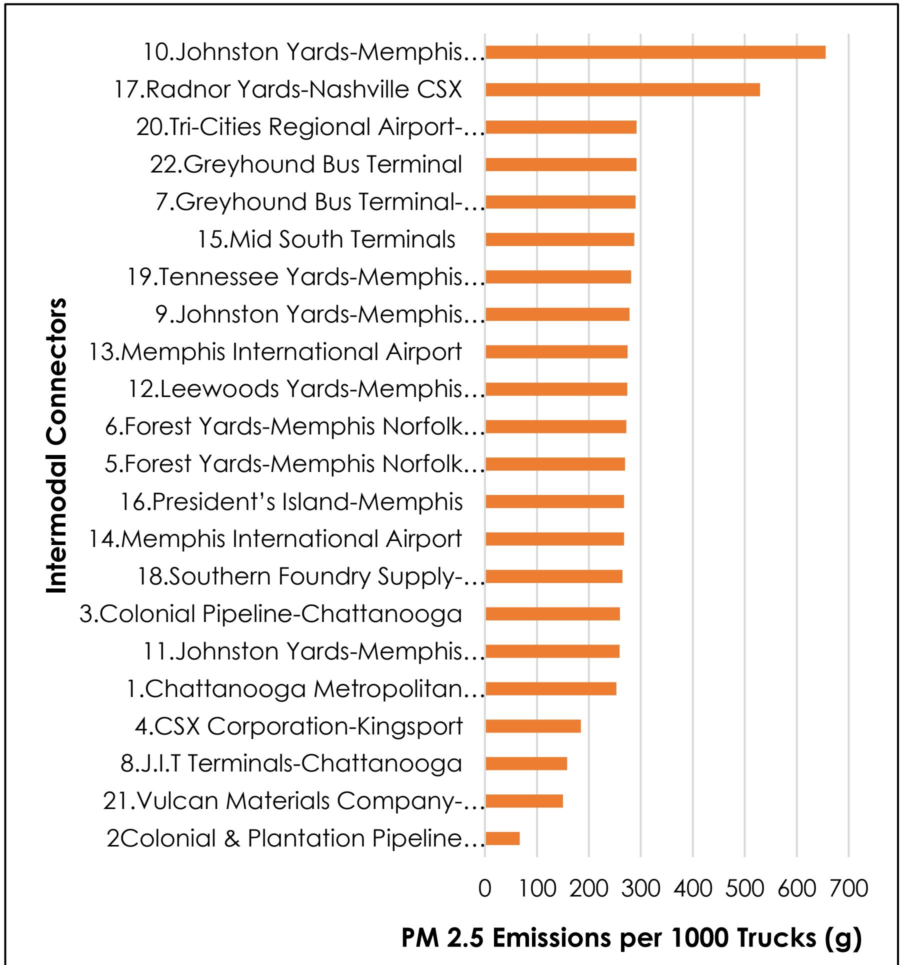


Emissions Evaluation

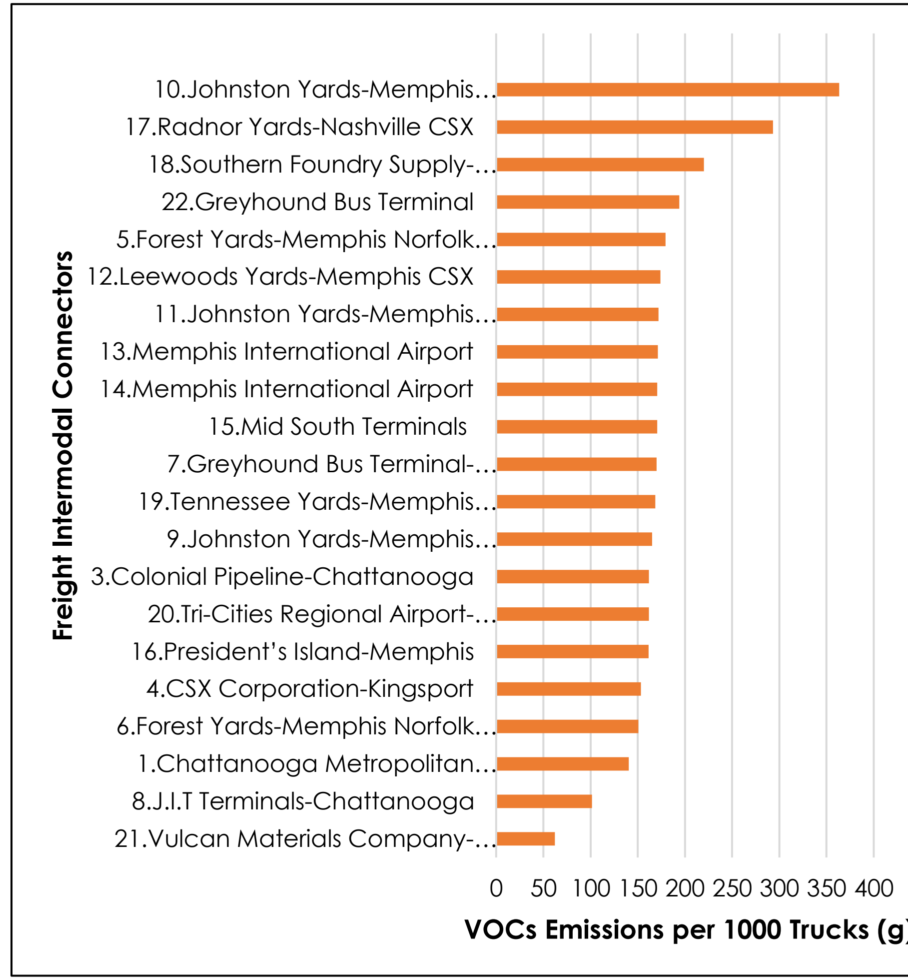
- ❑ The study uses EPA mobile source emissions model, MOVES2014a (MOVES) to estimate truck emissions along the FIC segments on a second-by-second basis in combination with VISSIM simulation software.
- ❑ The MOVES model estimations is compared/combined with estimates from VISSIM microscopic traffic simulation model to obtain accurate emission results.
- ❑ The VISSIM/MOVES model is used to determine freight transportation emissions factors for VOCs, NOx, P.M 2.5 and CO along the FICs.

Linear relationship of pollutant emission and truck volume





Ranking by PM 2.5 Emissions per 1000 Trucks



Ranking by VOC Emissions per 1000 Trucks

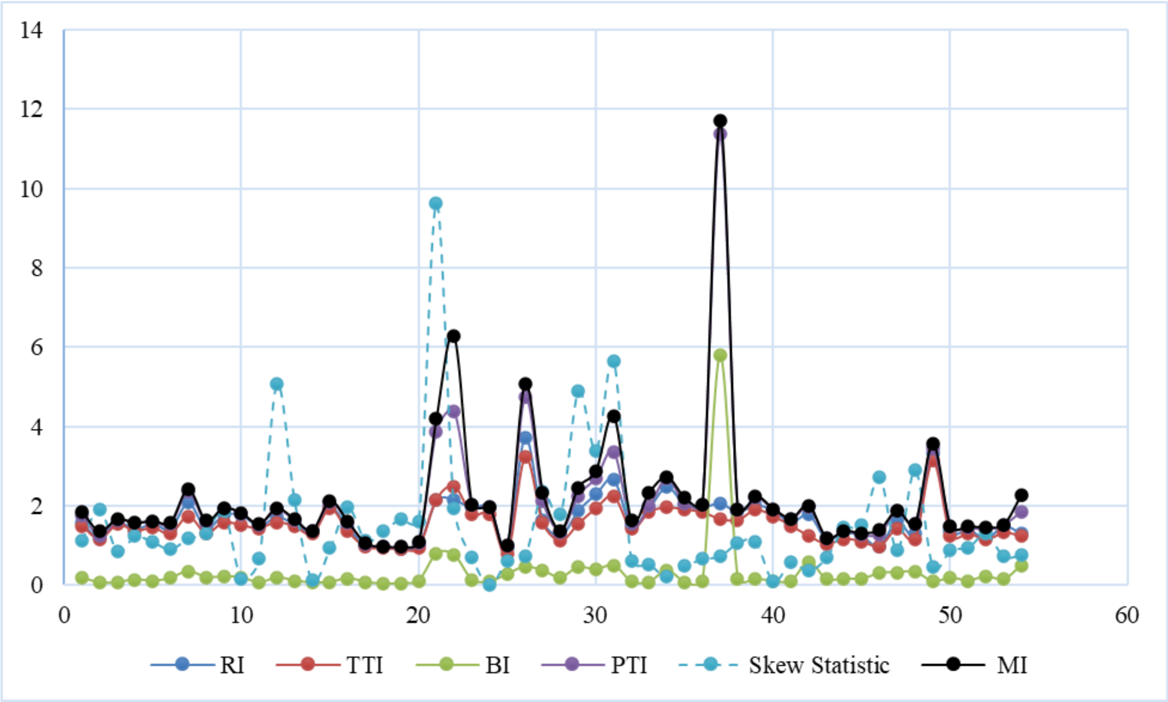
TRAVEL TIME RELIABILITY

Data analysis

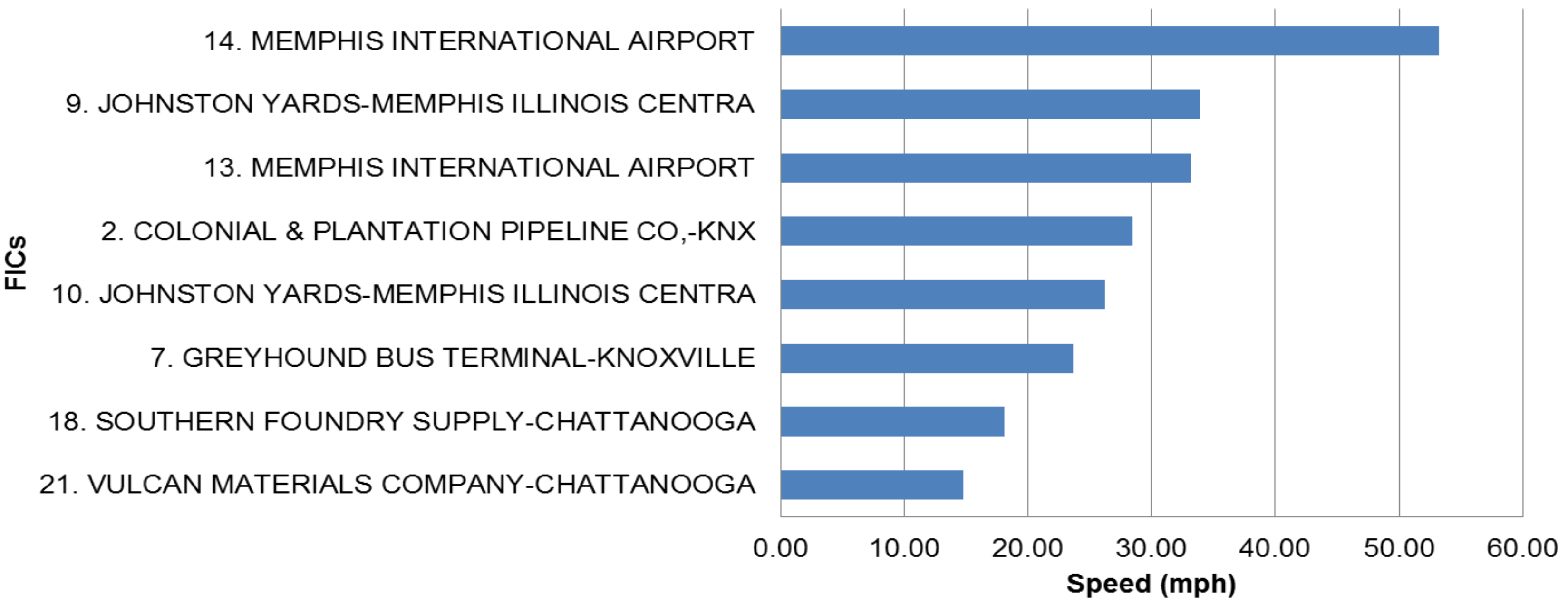
- Speed - distance charts
- Travel times of sections
- Travel time reliability evaluation

Bottlenecks

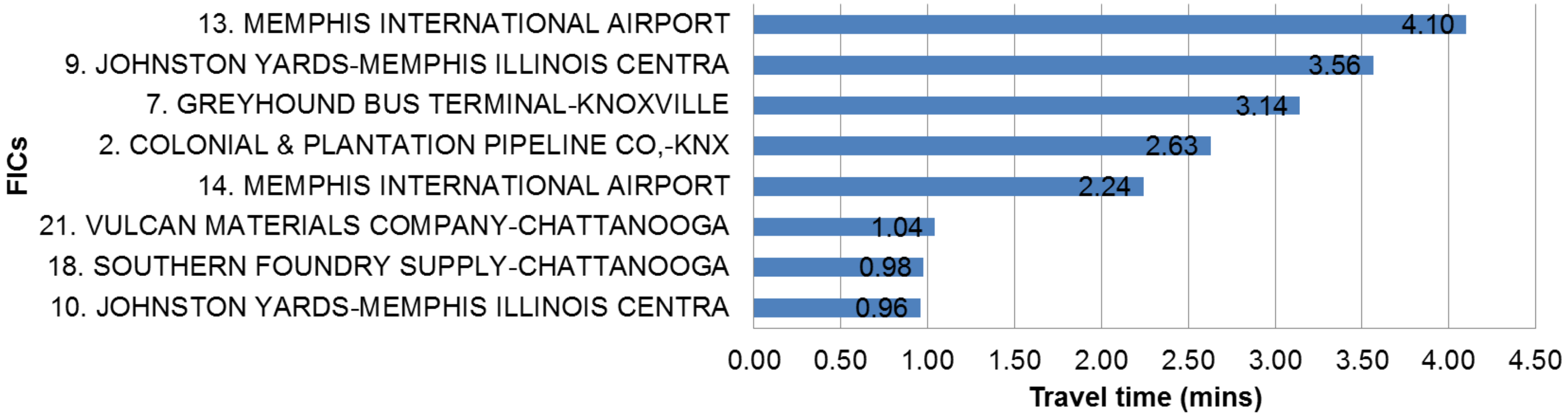
- Travel time delay
- freight cost due to delay
- Ranking the bottlenekcs



Ranking of FIC Average link speed data



FIC Travel time and Average link speed data



Travel Time Reliability

- Using the speed and the distance travel data, travel time reliability was determined by computing the 80th percentile reliability index (RI).
- 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 80th percentile was calculated. Reliability index of each FIC was calculated and table below was used to determine reliability

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

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

Key Findings related to Operational Reliability and Connectivity

- One of the main objectives of the study was to evaluate safety along intermodal connectors.
- Findings revealed that certain types of connectors, particularly those serving pipeline facilities, experienced higher crash rates, while port terminal connectors generally showed lower rates.
- Factors such as the presence of shoulders, signal density, and intersection design were identified as having a significant impact on safety.
- Operational efficiency and connectivity were also central concerns. Intersections at key connectors, such as those to and from Airport, experienced severe peak-hour delays, impacting both the movement of goods and the travel experience for passengers.
- Random delay patterns across connector types further illustrated the need for adaptive solutions that can respond to varied traffic demands.

Key Findings related to Operational Reliability and Connectivity

- Several connectivity challenges that impact the efficiency and reliability of intermodal connectors were identified.
- A major issue identified was limited lane capacity, which creates bottlenecks, particularly on connectors linked to high-traffic facilities like Airport connectors. This limitation constrains the ability of these connectors to handle peak traffic, leading to significant congestion and reducing connectivity with main highway networks.
- Another critical finding was the lack of adequate infrastructure to support multi-modal traffic, with pipeline connectors exhibiting high crash rates due to inadequate design features.
- Peak-hour congestion emerged as a recurrent issue, as connectors experienced heightened delays during specific times, such as evening hours for pipeline connectors and mornings for bus terminals, pointing to the need for enhanced traffic management.
- Many connectors lack redundant pathways, meaning that any disruption can sever access to key transport hubs, making the network vulnerable to incidents.
- Inefficient intersection layouts, contribute to congestion, reducing travel time reliability across these vital corridors

Conclusions

- The Tennessee intermodal connectors study offers a compelling insight into the critical need for enhancing transportation resiliency in mobility systems. This research underscores that the operational reliability and connectivity of intermodal connectors are foundational to a resilient transportation network.
- With rising congestion, frequent bottlenecks, and peak-hour issues across connectors servicing key hubs like airports, ports, and pipelines, the findings reveal an urgent need for innovative infrastructure improvements, adaptive traffic management, and strategic design upgrades.
- Moreover, the environmental impact of heavy truck emissions along these connectors calls for sustainable practices, including the integration of low-emission zones and cleaner energy solutions.
- Building resilience into intermodal systems not only secures the continuity of critical freight and passenger routes but also strengthens the entire transportation ecosystem.
- This study’s findings serve as a call to action for ongoing research and investment to ensure that transportation systems can meet the demands of an evolving, interconnected mobility landscape.

Moving Forward

- Addressing these operational and connectivity challenges on intermodal connectors is essential to enhancing transportation resiliency across the mobility network.
- Solutions must include not only infrastructure enhancements, such as road widening, improved intersections, and real-time traffic monitoring systems, but also policy measures that prioritize resilient planning and design.
- Investments in technology, such as intelligent transportation systems (ITS) that manage traffic dynamically and infrastructure that supports new vehicle types, will be crucial.
- By focusing on both operational efficiency and connectivity, we can ensure that intermodal connectors continue to support reliable, resilient movement for both people and goods in an increasingly interconnected and technology-driven transportation ecosystem.
- Ensuring these connectors are adaptable and equipped with data-driven traffic management tools, intermodal pathways can more effectively handle fluctuations in demand, particularly in high-stakes peak periods.

THANK YOU