Connecticut Statewide Freight Plan Update

Appendix D – Truck Bottleneck Analysis

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1. TRUCK BOTTLENECK ANALYSIS METHODOLOGY

CDM Smith is supporting Connecticut Department of Transportation (CTDOT) in the development of Baseline Performance Period Report [23 CFR 490.107(b)(1)(ii)(E)] as part of the truck freight bottleneck analysis for the Connecticut Statewide Freight Plan Update.

This technical memorandum describes the methodology and analysis of truck freight bottlenecks as well as the methodology and calculation of freight performance measures for the State of Connecticut.

Truck freight bottlenecks are mainly caused by:

1) Congestion – Slow average truck travel speeds due to congestion, often at daily or seasonal peaks causes recurrent and non-recurrent bottlenecks:

   a. Recurrent bottlenecks occur at predictable times and locations when traffic demand at peak periods exceeds a road's capacity.

   b. Non-recurrent bottlenecks occur when temporary incidents like crashes, special events, bad weather, or work zones can reduce road capacity, increase travel demand or in extreme cases necessitate re-routing or a complete halt to all travel.

2) Truck restrictions – Infrastructure restrictions that delay trucks by forcing them to take longer routes, carry smaller loads or move at different travel times.[1]

A bottleneck for truck freight is "a segment of roadway identified by the United States Department of Transportation (USDOT) as having constraints that cause a significant impact on freight mobility and reliability."[2] Truck freight bottlenecks occur either when trucks are delayed by slow speeds due to general traffic congestion or where restrictions limit truck travel. **Figure 1** shows a taxonomy for truck freight bottlenecks. This analysis is based on congestion-based bottlenecks; it excludes bottlenecks caused by truck restrictions and non-recurring congestion.

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[1] Truck Freight Bottleneck Reporting Guidebook, July 2018, FHWA-HOP-18-070
[2] 23 CFR 490.101

Figure 1: Taxonomy for Truck Freight Bottlenecks
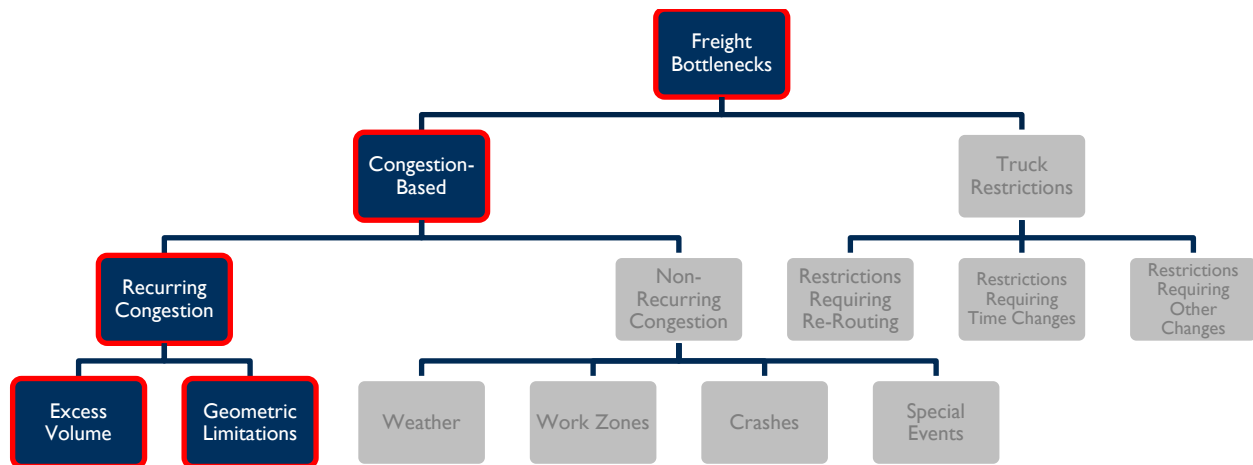
Source: Truck Freight Bottleneck Reporting Guidebook, July 2018, FHWA-HOP-18-070

Bottlenecks characterized by significant reductions in average truck speeds can be either recurrent or non-recurrent. Their severity is a function of how many trucks are affected, how significantly truck speeds are reduced, how long the congestion exists, and how often it reoccurs. According to the Federal Highway Administration's (FHWA) Localized Bottleneck Reduction Program materials,[3] recurrent congestion occurs when traffic over-demand at peak periods routinely exceeds a road's capacity, defined primarily by the number of lanes and the travel speed for which they were designed. The foremost examples are the familiar peak morning and afternoon weekday commute hours, but recurrent congestion may also occur around midday, seasonally or at factory shift-change hours. In addition to lane or speed limitations, recurrent congestion bottlenecks can be caused or exacerbated by other limitations in physical roadway characteristics that particularly affect truck travel speeds.

The truck freight bottleneck identification and analysis framework performed for this study is divided into six main steps which are detailed in the following sections.

2. STEP 1: SELECT ROADS FOR ANALYSIS

Truck freight bottleneck reporting applies, at a minimum, to the Interstate System. But given that the truck freight bottleneck reporting process should be integrated with the State Freight Plan bottleneck analysis and must include any highway bottlenecks identified in the National Strategic Freight Plan,[4] the bottleneck analyses may also include other roadways that the State determines to be vital to the goods movement. In this analysis, the 2019 National Performance Management Research Data Set (NPMRDS) Traffic Message Channel (TMC) network for Connecticut was downloaded, then conflated to the

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[3] https://ops.fhwa.dot.gov/bn/lbr.htm
[4] Per 23 CFR 490.107(b)(1)(ii)(E)

CTDOT Linear Referencing System (LRS), and used for route selection. **Figure 2** shows the roads selected for the freight bottleneck analysis.

Figure 2: Selected Roads for Analysis
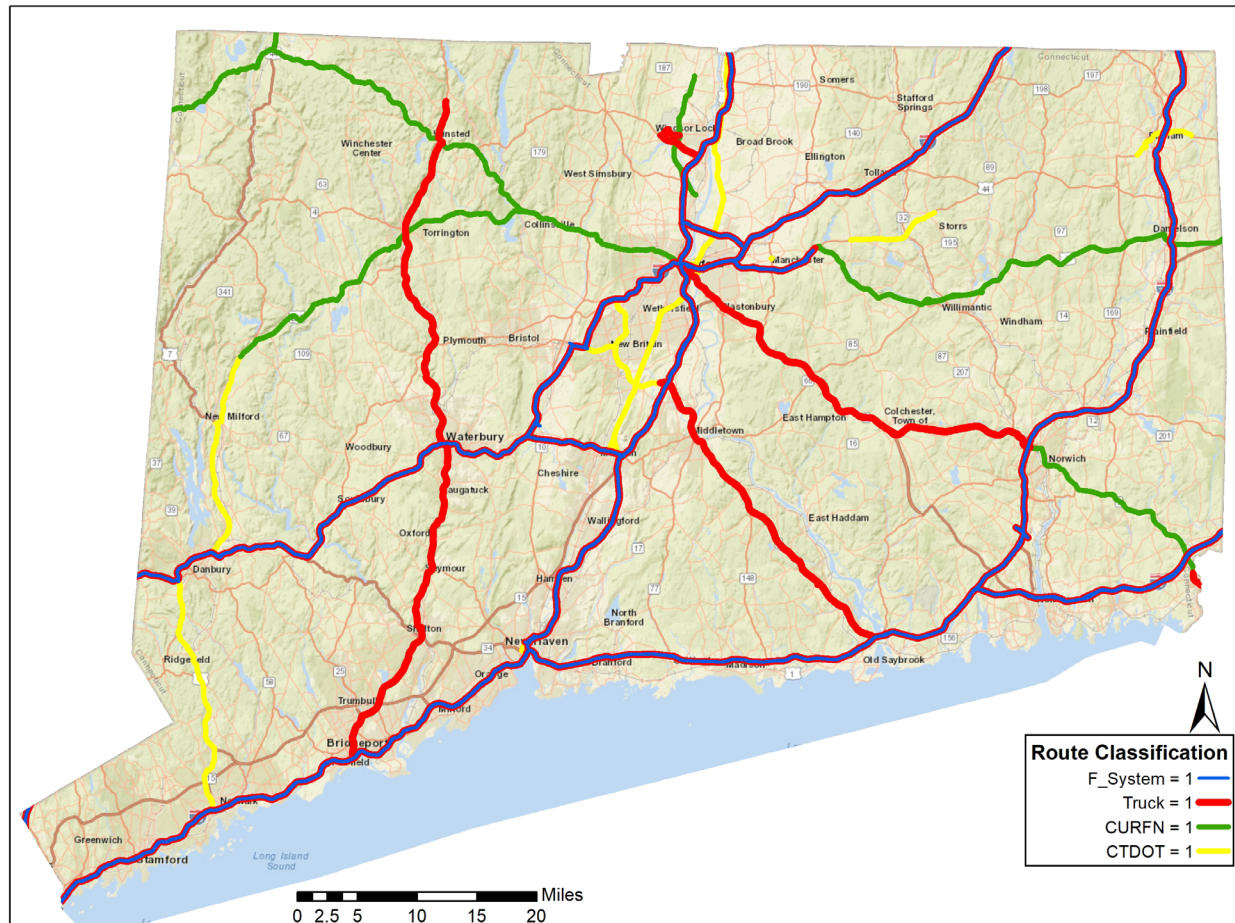
Source: CTDOT

The first criteria for the selection of roads were the Interstate system which are selected using the attribute F_System =1, that indicates the Interstate system. The second criteria, belonging to the National Highway System (NHS) and Interstates indicated as Truck = 1. For the third criteria, the raw 2019 TMC data was merged with Critical Rural and Urban Freight Corridor network (CURFN) data in ArcGIS software and an attribute was created to indicate those CURFN roadways which are marked as CURFN = 1. The last criteria are additional routes identified in collaboration with CTDOT.

The 2019 TMC network data were checked for TMCs that do not have a route assigned. Such TMCs were assigned a route based on spatial location of the TMC and visualization with Open Street Map/Google Maps using ArcGIS software. For example, if a TMC was located on I-95 but it was not assigned the appropriate route name or number, it was manually assigned a route name and number based on spatial location and visualization.

The TMC data includes the single and combined truck average annual daily traffic (AADT) and the Truck AADT was calculated by adding the two numbers for each TMC. After every TMC was assigned a route, it was exported to a spreadsheet where the first step was to calculate the harmonic mean of the truck

AADT for each route. Next, using the histogram function within the 'Data Analysis' toolbox in Microsoft Excel (available as an Add-in), the frequency and distribution of the harmonic mean truck AADT was calculated and plotted for both study roads as well as for all the roads. The representation of the study roads was then calculated to find what percentage of the study roads is representation from all the roads. **Table 1** shows the study road representation and **Figure 3** shows the frequency and cumulative percentages of the study roads and all roads.

Table 1: Study Roads Representation

Bin	All Roads		Study Roads		Representation
	Frequency	Cumulative %	Frequency	Cumulative %	
500	51	25.76%	1	2.78%	2%
1000	58	55.05%	4	13.89%	7%
1500	48	79.29%	4	25.00%	8%
2000	14	86.36%	5	38.89%	36%
2500	4	88.38%	2	44.44%	50%
4000	3	91.41%	3	52.78%	100%
4500	1	91.92%	1	55.56%	100%
5000	1	92.42%	1	58.33%	100%
6000	1	92.93%	1	61.11%	100%
6500	2	93.94%	2	66.67%	100%
7500	1	94.44%	1	69.44%	100%
8000	2	95.45%	2	75.00%	100%
10500	1	95.96%	1	77.78%	100%
13000	1	96.46%	1	80.56%	100%
16000	1	96.97%	1	83.33%	100%
20500	3	98.48%	3	91.67%	100%
21500	3	100.00%	3	100.00%	100%

Figure 3: Frequency and Distribution of Harmonic Mean Truck AADT
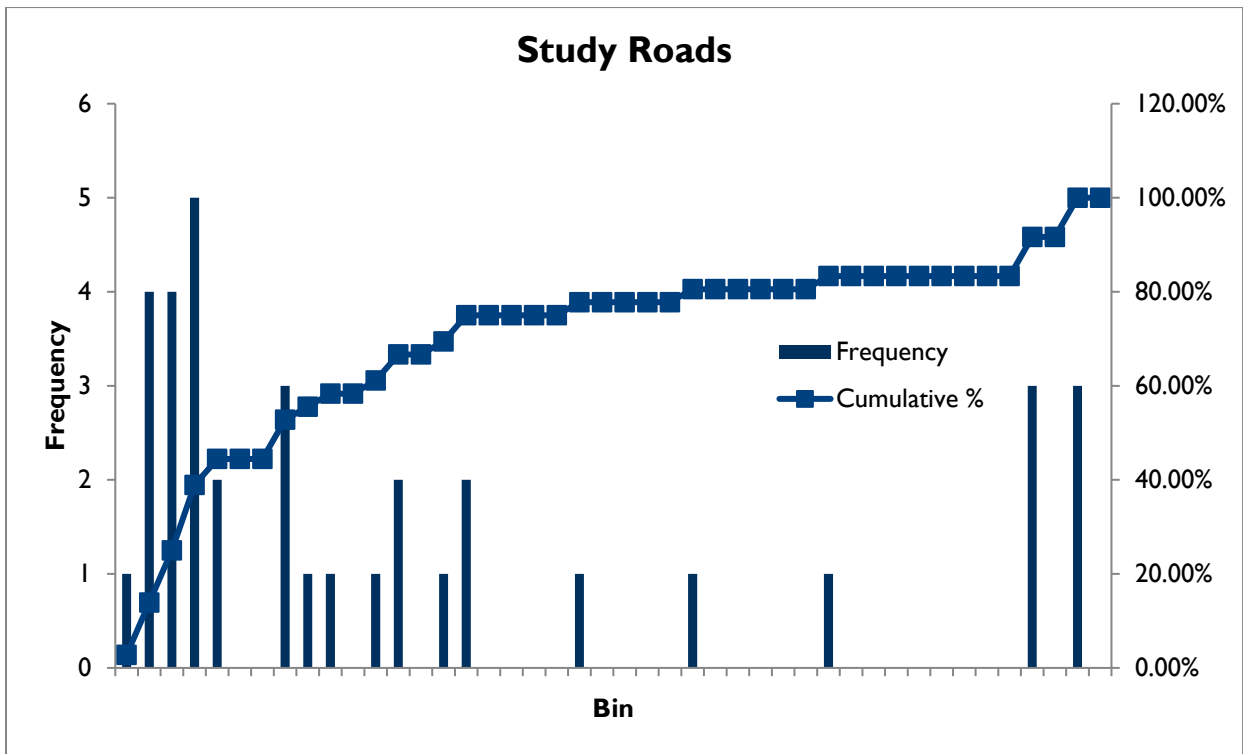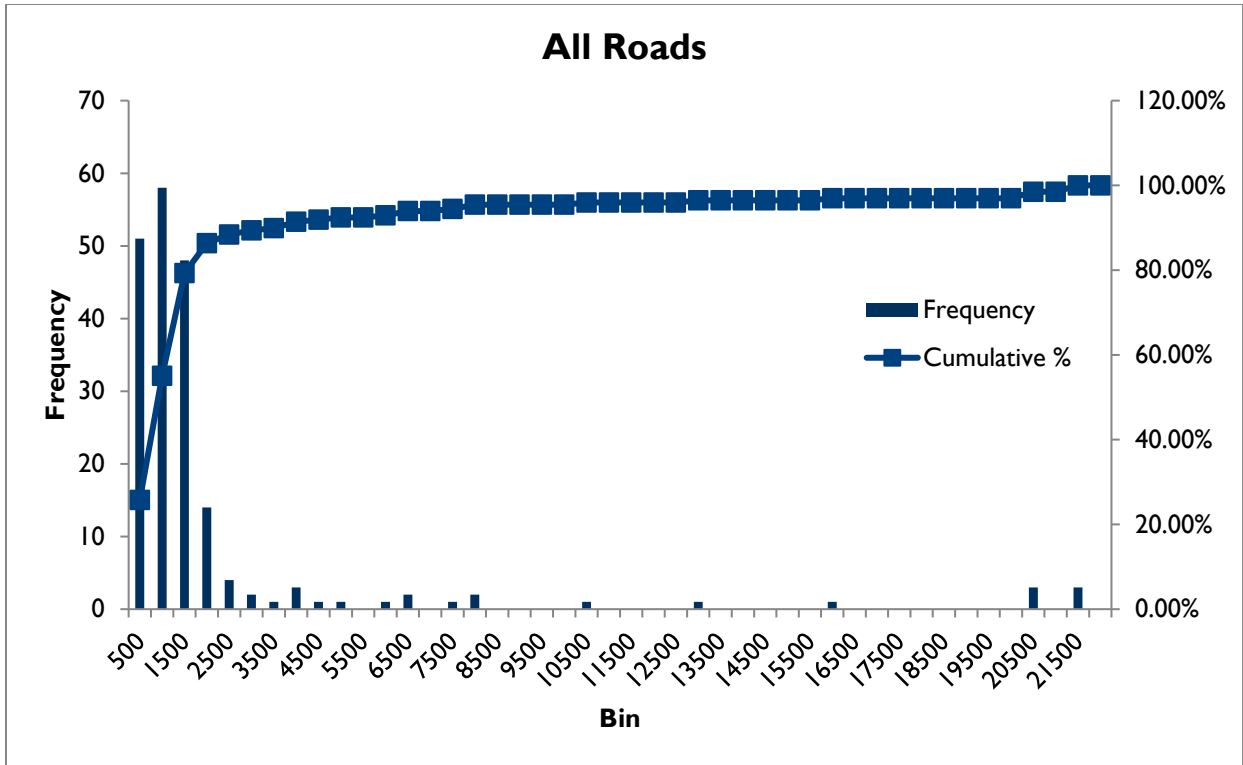
3. STEP 2: GATHER DATA FOR ANALYSIS

The FHWA encourages states to use truck travel time data as a core element for bottleneck identification; a data-driven approach helps expedite bottleneck identification by automating scanning of roadway system segments while also providing an objective basis for selecting bottlenecks.

This analysis used 2019 NPMRDS data for the State of Connecticut. The FHWA sponsors production of the NPMRDS, which contains archived speed and travel time information for all road segments on the National Highway System (NHS), including intermodal connectors, and additional roadways near 26 key border crossings with Canada (20 crossings) and Mexico (6 crossings). The NPMRDS provides information about average travel times reported at five-minute increments for roadway segments and includes data broken out by passenger vehicles, freight trucks, and combined traffic. The NPMRDS road segments are based on the TMC network, which is the industry standard for depicting road segments in navigation and mapping applications. The new NPMRDS includes AADT and AADTT conflated from the Highway Performance Monitoring System (HPMS).

# 4. STEP 3: SCREEN FOR TRUCK FREIGHT BOTTLENECKS

Truck speed data sets like NPMRDS make data-driven approaches for identifying congestion-related truck bottlenecks an efficient and accurate solution for speedy screening on a statewide scale to identify serious bottlenecks. Screening results can serve as a starting point for both detailed site-specific analysis of selected bottlenecks and engagement with stakeholders that will help to fine-tune an eventual list of bottlenecks.

In this study, first, the congested condition was checked for each TMC by means of the chosen metric called Truck Travel Time Index (TTTI) which is the ratio of the observed truck travel time to free flow travel time. The threshold for uninterrupted facility (defined as F_System = 1 or 2) was set at TTTI ≥ 1.33 and the threshold for interrupted facility (defined as F_System = 3, 4 or 5) was set at TTTI ≥ 2.50. The second metric was chosen to check for recurring congestion, and it is called Truck Speed Standard Normal Deviate (TSSND) which is the index of variation of the speed from the average speed in terms of standard deviation. The threshold chosen was TSSND > -1.50.

The first step of the calculation was performed by developing a programmable script in RStudio. The script is provided in the Appendix section of the memo (R Script for Truck Bottleneck Analysis). The script was used to read the large NPMRDS speed data available for the State of Connecticut. The data was then filtered for only the study roads and also the removal of the missing data. Next, the free flow travel time was calculated by dividing the length of the TMC by the reference speed. Next, TTTI for each TMC was calculated by dividing the truck travel time by the free flow travel time. In addition, the average speed and the speed standard deviation were also calculated. In the next step, TSSND values were calculated, and 'recurring' and 'congested' columns were created using the thresholds defined above. Finally, the calculated data was grouped by TMC ID and hour and was summarized for Max TTTI, Mean TTTI, TTTI Standard deviation, probability of recurring, and recurring TTTI. The final summarized data was then written out in an Excel spreadsheet.

From the summarized Excel spreadsheet, the maximum value of the recurring congestion TTTI was calculated for each TMC and imported into ArcGIS where this value for the study TMCs was joined into the raw TMC data. **Figure 4** shows the recurring congestion bottlenecks defined by the thresholds as displayed in the map.

Figure 4: Recurring Congestion Bottlenecks
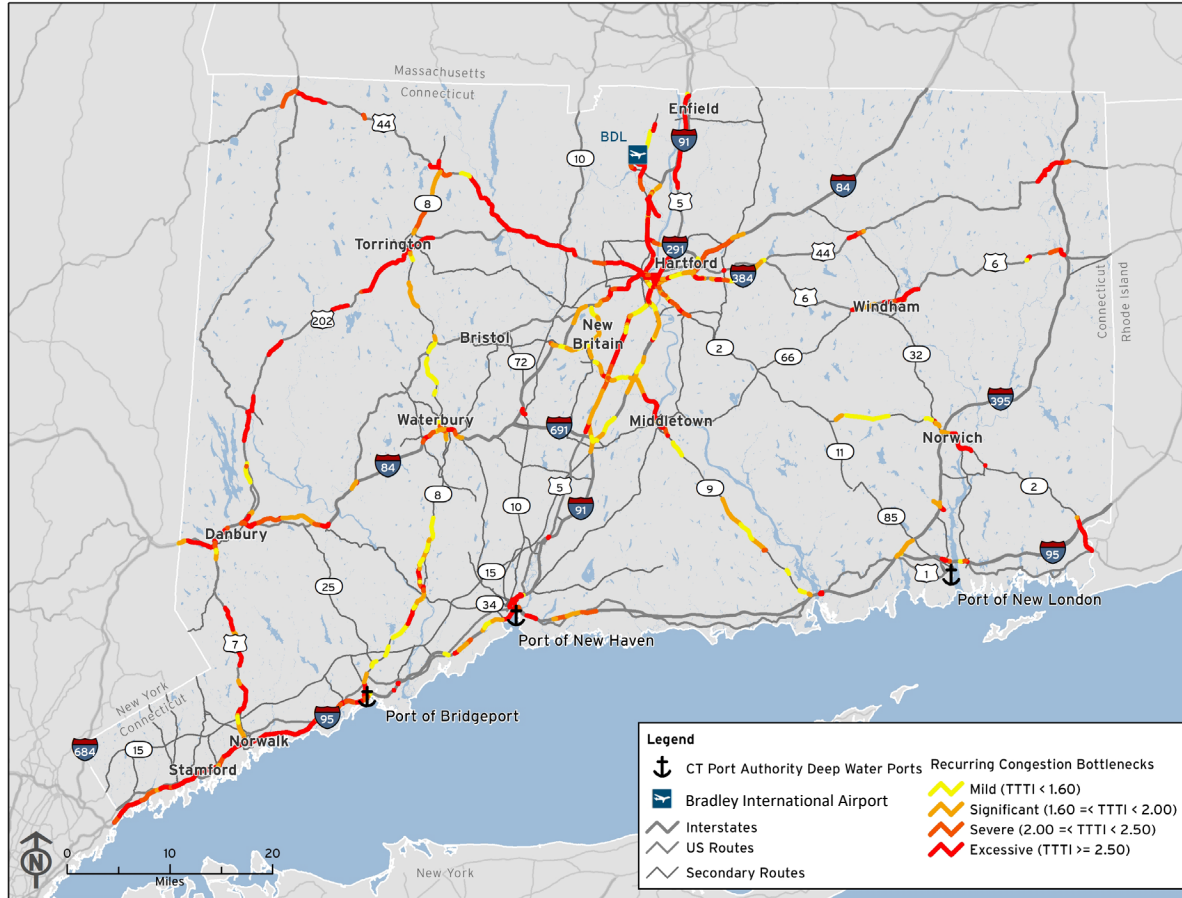
The next step was to identify the segments for these study TMCs. Segments were assigned based on the existing corridors in the Open Street Map. Such route segments help identify the extent of recurring congestion. **Table 2** shows a sample of the recurring congestion showing the routes, the extent, and the recurring congestion summary values.

Table 2: Recurring Congestion by Route

| Route | Limits or Location | | TMC ID | Time | Recurring Congestion | | | | |
	From	To			Max. TTTI	Mean TTTI	SD TTTI	Probability	Expected Mean TTTI
I-95	CT-136 at I-95		120N13112	8:00 AM	3.91	3.08	1.17	1.00	3.08
				9:00 AM	1.43	1.38	0.06	1.00	1.38
				5:00 PM	2.87	2.17	0.98	1.00	2.17
				8:00 PM	3.07	2.25	1.16	1.00	2.25
			120P13112	3:00 AM	1.60	1.47	0.16	1.00	1.47
				3:00 PM	2.50	1.92	0.83	1.00	1.92
	US-1 at I-95 NB Exit 51		120N12591	2:00 AM	7.57	3.32	2.04	1.00	3.32
	US-1 at I-95 SB Exit 83		120+12604	12:00 AM	17.00	5.24	4.08	1.00	5.24
				1:00 AM	17.00	8.20	5.12	1.00	8.20
				2:00 AM	11.33	5.97	3.83	1.00	5.97
				6:00 AM	2.83	2.33	0.49	1.00	2.33
				7:00 AM	13.60	5.86	3.98	1.00	5.86
				9:00 AM	22.66	8.87	8.29	1.00	8.87
				1:00 PM	17.00	5.20	5.85	1.00	5.20
				2:00 PM	17.00	3.75	4.73	0.82	3.07
				3:00 PM	7.55	2.72	2.18	0.86	2.34
				4:00 PM	11.33	4.20	4.77	1.00	4.20
				8:00 PM	2.27	1.93	0.43	1.00	1.93
				9:00 PM	17.00	8.87	6.63	1.00	8.87
				10:00 PM	4.25	2.67	1.20	1.00	2.67
				11:00 PM	17.00	5.13	6.69	1.00	5.13
LINDEN AVE	Main St	King St	120N56864	7:00 AM	6.27	5.50	0.69	1.00	5.50
				10:00 AM	6.90	5.12	1.69	1.00	5.12
				1:00 PM	17.25	7.90	6.32	1.00	7.90
				2:00 PM	5.31	5.12	0.27	1.00	5.12
				4:00 PM	5.75	3.95	1.64	1.00	3.95
				5:00 PM	17.25	8.88	7.33	1.00	8.88

5. STEP 4: VALIDATE BOTTLENECKS IDENTIFIED BY DATA

Validation of screening helps to ensure that agencies' final bottleneck lists accurately reflect a region or state's most significant highway bottlenecks for freight trucks. A presentation was provided to seek stakeholder's validation of locations.

6. STEP 5: EVALUATE BOTTLENECK CAUSES

Understanding bottleneck causes is still a challenging process that potentially demands a combination of travel time data analysis, scrutiny of roadway characteristics, field assessment, and discussions with affected road users. Because knowledge of bottleneck causes is inherently part of the process for development of appropriate solutions, FHWA encourages all agencies to examine the underlying causes of bottlenecks as much as possible as part of their compliance activities. Key techniques for understanding bottleneck causes include data visualizations, indicator analysis and location research. A number of bottlenecks were located in the previous section which will be evaluated based on the excess volume and roadway geometry.

Excess Volume (Volume Bottlenecks)

In order to evaluate bottlenecks for this study with respect to excess volumes, vehicle to capacity (V/C) ratio was calculated for each TMC having recurring congestion. The volume is calculated based on the following assumptions:

- Assume D = 0.5 (directional split)

- Hourly adjustment factors are used from Highway Capacity Manual (Exhibit 17-5) as shown in the Appendix.

- The hourly adjustment factor for each TMC was calculated based on the hour of recurring congestion and functional classification system as follows:

F_System	Functional Class
1	Interstate
2	Principal Arterial-Other Freeways and expressways
3	Principal Arterial-Other
4	Minor Arterial
5	Major Collector
6	Minor Collector
7	Local

- If the field, 'number of thru lanes' in the TMC data is zero, it was assumed that the TMC will have 2 lanes per direction.

The capacity was calculated based on the Highway Economic Requirements System (HERS) capacity procedures. The HERS procedure follows the HCM procedure verbatim, with adjustments for lane width, lateral clearance, interchange density, heavy trucks, and the peak-hour factor. The equation below shows the calculation for freeway capacity:

$$Capacity = \frac{(2{,}200 + 10 \times (\min(70, FFS) - 50))}{1 + \%HV/100} \times Lanes$$

Where: FFS = free flow speed

       %HV = percent of heavy vehicles (decimal), with heavy vehicles consisting of trucks with more than four tires, buses, and recreational vehicles Multilane Highways

       Lanes = Number of through lanes in the direction of travel from NPMRDS dataset

The free flow speed for each TMC segment was already provided in the NPMRDS dataset and therefore did not need to be calculated separately.

After calculation of volume and capacity, V/C ratio was calculated for each TMC, and demand was flagged as a probable cause for bottlenecks if: V/C ratio >= 0.75.

Geometric Bottlenecks

To evaluate truck bottlenecks due to roadway geometry, the HPMS dataset was extracted for each TMC and joined using the 'Spatial Join' tool in ArcGIS using the method of 'Closest GEODESIC'.

Curvature

It was assumed that the number of lanes were evenly distributed between directions and lane fractions were rounded to whole lanes. The congestion criteria for curvature were selected as – if the TMC segment contained portions with curvature higher than 3.5 degrees.

Grades

The congestion criteria for grades were selected as – if the TMC segment contained portions with grade higher than 2.5 percent.

Traffic Control

The number of signals (NUMBER_SIG) and stop signs (STOP_SIGNS) for each TMC was also extracted from the HPMS dataset. This was further verified by visual inspection of ArcGIS Imagery. If the TMC had a traffic control measure such as stop signs or signalized/non-signalized intersections, it was marked for traffic control. The traffic control criteria were therefore assumed to be the presence of any traffic control measure on the TMC segment.

7. STEP 6: PRIORITIZE BOTTLENECKS

Prioritizing bottlenecks can help focus freight planning efforts on the highest and best use of limited resources. It is a component of performance-based planning and programming practices that seek to prioritize funding needs across multiple competing objectives. Developing a prioritized list of freight

bottlenecks can also help in measuring progress toward addressing bottlenecks in performance reporting. In this study, the bottlenecks were ranked based on the estimates of 'Total Delay'. Like the calculation of volume, the calculation of delay also assumes directional split to be 50% (D = 0.5) and hourly adjustment factors are used from the HCM as shown in the Appendix. The delay is calculated only for those TMCs which are highly likely (RC_TTTI > 1) to have recurring congestion. Delay is calculated in seconds by subtracting the free flow travel time from the congested travel time. **Table 3** summarizes delay (converted to hours) in 2019 by bottleneck cause and route type. A majority of the truck delay occurs on Connecticut's Interstate highways, followed by NHS routes.

Table 3: Delay by Cause and Route Type (2019, in Hours)

|	Interstate	NHS Routes	CURFN	CTDOT Designated
Traffic Control	2,684	218	1,493	27
Demand	2,987	16	-	-
Combination of Causes*	466	21	82	-
Grades	54	26	1	-
Curvature	16	33	1	-
Unknown	6,737	797	442	8
Total	**12,945**	**1,112**	**2,018**	**35**

Source: CTDOT, National Performance Management Research Data Set, and CDM Smith analysis
*Combination of any two or more causes from traffic control, demand, grades, and curvature causes

The delay that could not be diagnosed based on available data can be diagnosed if other data could be available such as pavement type, access control, shoulder width, presence of high occupancy vehicles (HOV), toll road or auxiliary lanes, media and shoulder type and presence of any obstacles. These attributes may be able to explain some of the delay that are otherwise flagged as unknown. FHWA defines a truck bottleneck as a combination of three features: the type of constraint, the type of roadway, and the type of freight route. Knowing the freight route such as if it is Urban, Intercity, Truck Access or Intermodal connector can also help to identify some of the reasons for potential delays.

Figure 5 shows the TMC segments with various levels of delay. Based on this map, the top 10 segments with high delay include I-95 segments in Fairfield, Norwalk and Stamford, I-91 segments near Humphreys Street, New Haven, Hartford and from Day hill road to Jennings Road and I-84 near East Hartford and from I-291 to Deming Street. Segments with top delays also include US-1 at I-95 intersection at Fairfield, CT-15/CT-5 between Newington and Berlin (Merritt Burlington turnpike) and also includes two local streets, South State Street at Stamford, and State Street at New Haven.

Figure 5: TMC Segments with Various Levels of Delay
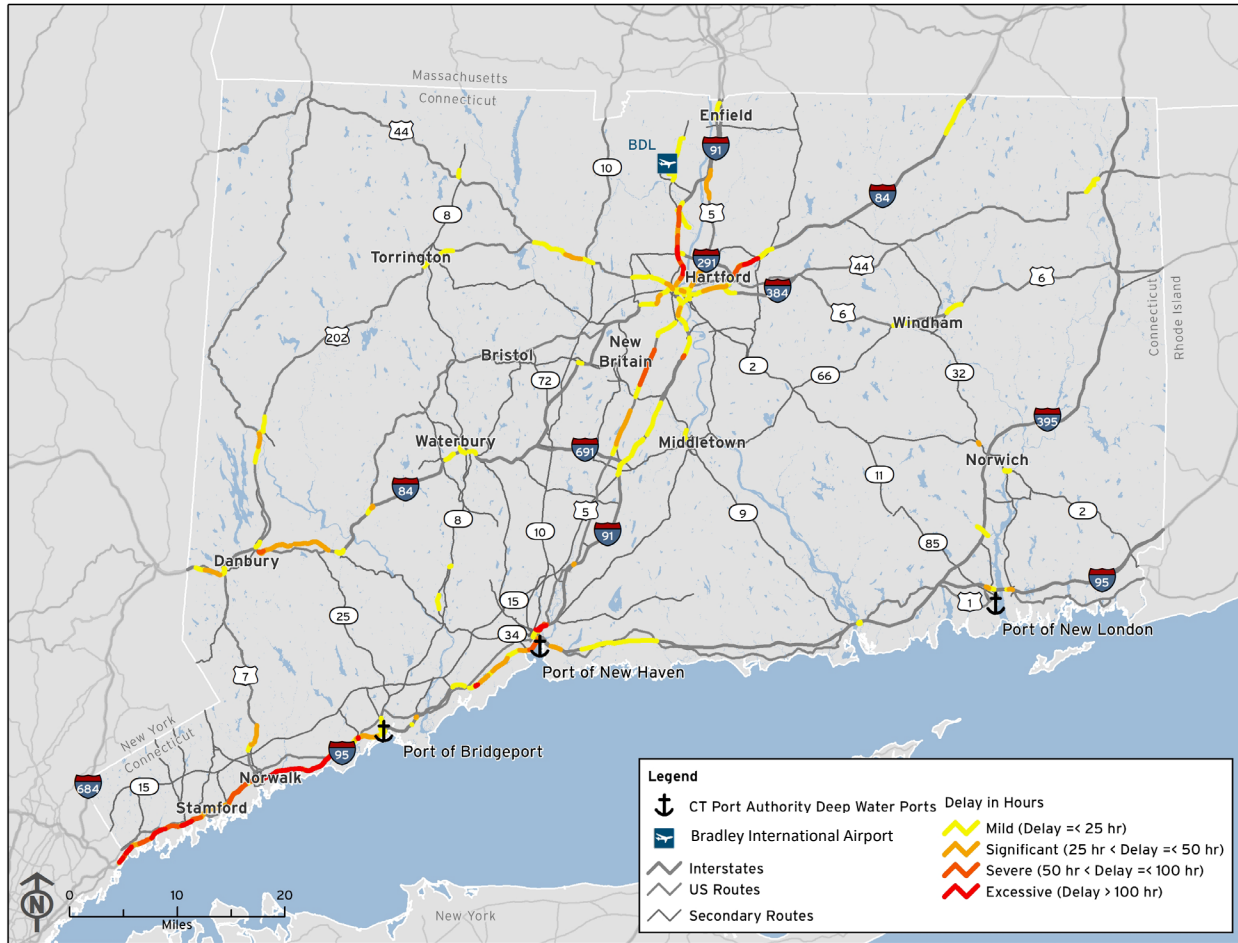
Source: CTDOT, National Performance Management Research Data Set, and CDM Smith analysis

Based on the figure above, the top ten segments with high delay are listed in **Table 4** and shown on **Figure 6**.

Table 4: Top Ten Segments with High Delay

Map ID	Segment	From	To	Causes of Delay
A	I-95 (Fairfield)	Mill Hill Rd	Sherwood Island Connector	Demand
B	I-95 (Norwalk)	Sherwood Island Connector	Exit 13	Demand
C	I-95 (Stamford)	Lafayette St	Sachem Rd	Demand, Traffic Control
D	I-91 (New Haven)	Orange St	East St	Demand
E	I-91 (Hartford)	Day Hill Rd	Jennings Rd	Unknown
F	I-84 (East Hartford)	I-291	Deming St	Unknown
G	US-1 (I-95 intersection at Fairfield)	Stephens Ln	Johnson Dr	Demand, Traffic Control
H	CT-15/CT-5 (B/W Newington and Berlin)	Deming Rd	Prospect St	Traffic Control

Map ID	Segment	From	To	Causes of Delay
I	South State Street, Stamford	Exit 7	Elm St	Demand, Traffic Control
J	State Street (Route 5), New Haven	Bradley St	Willow St	Traffic Control

Source: CTDOT, National Performance Management Research Data Set, and CDM Smith analysis

Figure 6: Top Ten Bottlenecks with High Delay
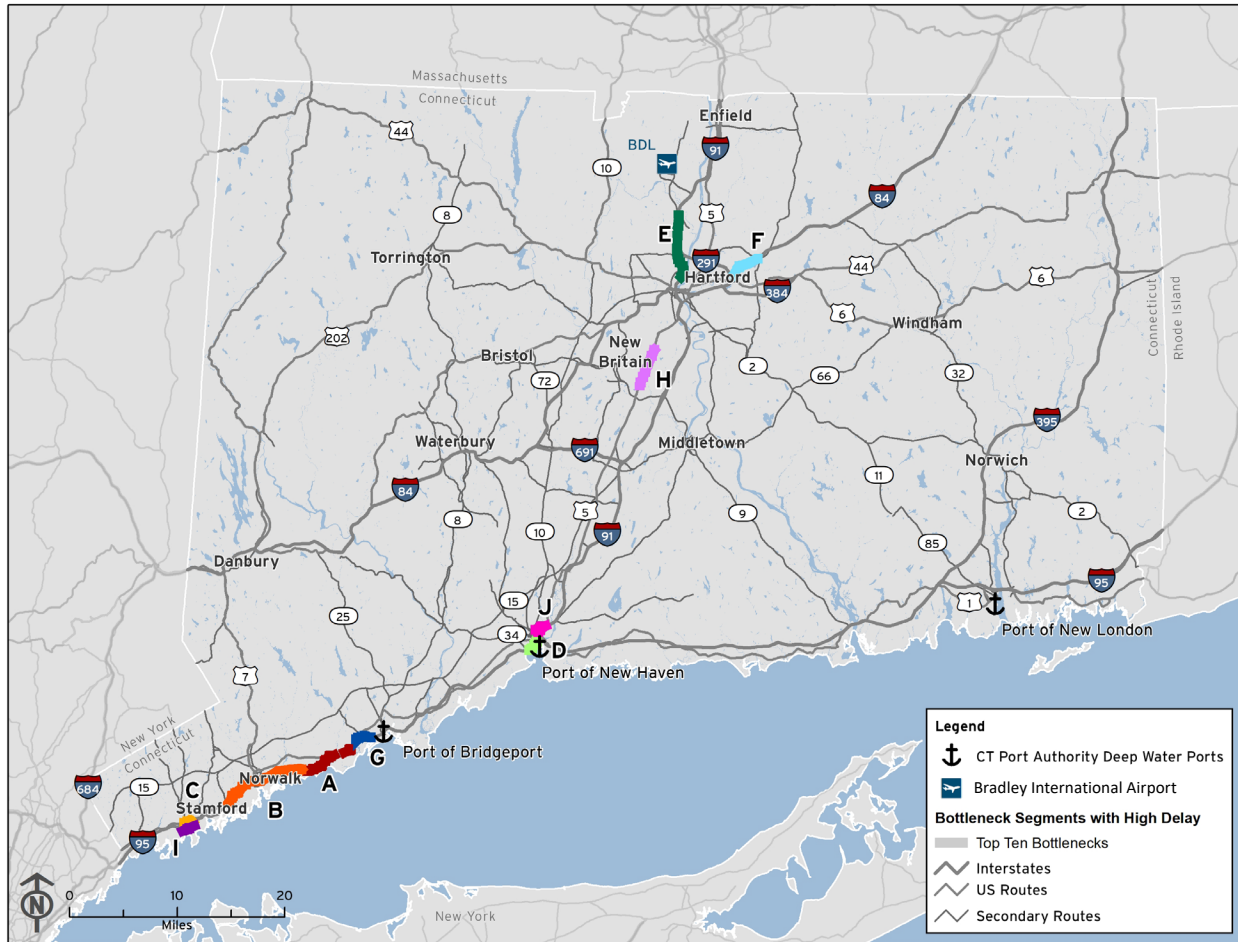
Source: CTDOT, National Performance Management Research Data Set, and CDM Smith analysis

The American Transportation Research Institute (ATRI), develop a list of top 100 truck bottlenecks every year. ATRI's methodology to identify bottlenecks is not the same as the FHWA methodology used in this analysis, but are considered here as another input for truck bottlenecks in the state. Based on the top 100 truck bottlenecks of 2022 published by American Transportation Research Institute (ATRI)[5], there are six truck bottlenecks identified in Connecticut:

- Hartford, CT: I-84 at I-91

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[5] https://truckingresearch.org/2022/02/08/top-100-truck-bottlenecks-2022/

- Stamford, CT: I-95
- Waterbury, CT: I-84 at SR 8
- Norwalk, CT: I-95
- Bridgeport, CT: I-95 at SR 8/SR 25
- New Haven, CT: I-95 at I-91

All of these bottleneck locations published by ATRI are captured based on the various levels of delay as shown in **Figure 5**, however not all of the ATRI bottlenecks are identified in the top 10 bottleneck list. This bottleneck analysis combined with ATRI's locations identified in Connecticut corroborates CTDOT's emphasis on the need for congestion relief and the need for improved sections of I-95 and I-84.

8. FREIGHT PERFORMANCE MEASURES METHODOLOGY

As part of this analysis, two additional measures were calculated to address the statewide freight performance measure. A programmable script was developed to calculate these measures in RStudio environment which is provided in the Appendix below (R Script for Freight Performance Measures Calculation).

9. TRUCK TRAVEL TIME RELIABILITY (TTTR) METRIC

- Only reporting segments on the Interstate system are used in the calculation of the Freight Reliability metrics (where F_system = 1)

- Create a new data element that takes on the value of truck travel time if truck travel time is not null or not zero, and the travel time of combined trucks and passenger cars if truck travel time is null or zero

- For each reporting segment (e.g., TMC) and Freight Reliability time period (Freight_Period) combination, compute the 50th and 95th percentile travel times

- Compute the Truck Travel Time Reliability (TTTR) metric as the 95th percentile travel time divided by the 50th percentile travel time for each of the five time periods for each reporting segment. Round the TTTR metric to the nearest hundredth

Table 5 shows the truck TTTR metric for a sample of the study TMCs.

Table 5: Sample TTTR values by TMC

TMC	Period	50th Percentile	95th Percentile	TTTR
120-04143	10-4 Weekdays	27.08	36.82	1.36
120-04143	4-8 Weekdays	27.53	32.499	1.18

TMC	Period	50th Percentile	95th Percentile	TTTR
120-04143	6-10 Weekdays	27.36	34.7185	1.27
120-04143	Overnight	26.98	31.4725	1.17
120-04143	Weekend	27.43	41.5925	1.52
120-04144	10-4 Weekdays	111.195	117.0185	1.05
120-04144	4-8 Weekdays	112.72	121.828	1.08
120-04144	6-10 Weekdays	111.86	119.8555	1.07
120-04144	Overnight	111.46	121.768	1.09
120-04144	Weekend	112.36	122.102	1.09
120-04145	10-4 Weekdays	4.14	4.45	1.07
120-04145	4-8 Weekdays	4.22	4.679	1.11
120-04145	6-10 Weekdays	4.22	4.5985	1.09
120-04145	Overnight	4.13	4.6	1.11
120-04145	Weekend	4.18	4.63	1.11
120-04146	10-4 Weekdays	70.98	77.157	1.09
120-04146	4-8 Weekdays	72.45	81.747	1.13
120-04146	6-10 Weekdays	73.5	87.2265	1.19
120-04146	Overnight	70.1	77.859	1.11
120-04146	Weekend	71.745	80.111	1.12
120-04148	10-4 Weekdays	83.44	109.0185	1.31
120-04148	4-8 Weekdays	86.48	115.323	1.33
120-04148	6-10 Weekdays	88.735	116.552	1.31
120-04148	Overnight	81.38	90.124	1.11
120-04148	Weekend	84.82	118.0095	1.39

10. FREIGHT RELIABILITY (FR) MEASURE

- For each reporting segment, the TTTR metric with the highest value of the five TTTR metrics is selected as the "maximum TTTR"

- The Freight Reliability Measure is then calculated as a weighted average of the maximum TTTR by reporting segment length

The FR measure for the study area is 1.85.

11. APPENDIX

R Script for Truck Bottleneck Analysis

```
# Load required libraries

library(readr)

library(dplyr)

library(psych)

library(lubridate)


# Get working directory

folder <- getwd()


# Create output folder and read input folder

dir.create("./Output", showWarnings = FALSE, recursive = TRUE)

dataFolder <- paste0(folder, "/Input")

outFolder <- paste0(folder, "/Output")


# Read travel time data

NPMRDSdata <-  read_csv(paste0(dataFolder, "/CT_Hourly_Truck.csv"),

                col_types = cols( average_speed = col_skip(),

                data_density = col_skip(),

                measurement_tstamp = col_datetime(format = "%Y-%m-%d %H:%M:%S")),

                locale = locale(tz="America/New_York"))


# Read Tmc data

F1TMC <- read_csv(paste0(dataFolder, "/TMC_Identification_AllRoads.csv"))

# F1TMC <- read_csv(paste0(dataFolder, "/Tmcs_newhaven_I-84.csv"))
```

```
F1TMC <- F1TMC %>%

 filter(STUDY_AREA==1)
```

```
# filter to study Tmcs

NPMRDSdata_CT_TMC <- NPMRDSdata %>%

 filter(NPMRDSdata$tmc_code %in% F1TMC$Tmc)
```

```
# Filter all missing values

NPMRDSdata_CT_TMC_omit <- na.omit(NPMRDSdata_CT_TMC)
```

```
# Add Time Stamp only for aggregation

NPMRDSdata_CT_TMC_omit$Time <- format(NPMRDSdata_CT_TMC_omit$measurement_tstamp,
format="%H:%M:%S")

NPMRDSdata_CT_TMC_omit$Date <- format(NPMRDSdata_CT_TMC_omit$measurement_tstamp,
'%Y-%m-%d')
```

```
# Join attributes to calculate FFTT

F1TMC <- F1TMC %>%

 select(Tmc, Miles, F_System)

NPMRDSdata_CT_TMC_omit_join <- left_join(NPMRDSdata_CT_TMC_omit, F1TMC, by=
c("tmc_code"="Tmc"))
```

```
# Calculate FFTT in seconds

NPMRDSdata_CT_TMC_omit_join$FFTT <-
round(NPMRDSdata_CT_TMC_omit_join$Miles/NPMRDSdata_CT_TMC_omit_join$reference_speed
*60*60, digits = 2)
```

```
# Calculate TTTI

NPMRDSdata_CT_TMC_omit_join$TTTI <-
round(NPMRDSdata_CT_TMC_omit_join$travel_time_seconds/NPMRDSdata_CT_TMC_omit_join$F
FTT, digits = 2)
```

```
# Get Average speed

NPMRDSdata_Summary <- aggregate(speed ~ Time + tmc_code, NPMRDSdata_CT_TMC_omit_join,
mean)

names(NPMRDSdata_Summary)[names(NPMRDSdata_Summary)=="speed"] <- "Speed_Avg"
```

```
# Get speed standard deviation

NPMRDSdata_Summary$Speed_SD <- aggregate(speed ~ Time + tmc_code,
NPMRDSdata_CT_TMC_omit_join, sd)$speed
```

```
# Join summary to data

NPMRDSdata_CT_TMC_omit_join_summ <- NPMRDSdata_CT_TMC_omit_join %>%

  left_join(NPMRDSdata_Summary, by = c("tmc_code"="tmc_code", "Time"="Time"))
```

```
# Create recurring/congested columns

NPMRDSdata_summ_final <- NPMRDSdata_CT_TMC_omit_join_summ %>%

  mutate(Congested=if_else(F_System %in% c(1,2) & TTTI >= 1.33,1,

               if_else(F_System %in% c(3,4,5) & TTTI >= 2.5,1,0)))

NPMRDSdata_summ_final <- NPMRDSdata_summ_final %>%

  mutate(TSSND=case_when(Congested == 1 ~ round((speed-Speed_Avg)/Speed_SD, digits = 2)))

NPMRDSdata_summ_final <- NPMRDSdata_summ_final %>%

  mutate(Recurring=case_when(TSSND > -1.5 ~ 1,

               TSSND <= -1.5 ~ 0))
```

```
# omit missing values

NPMRDSdata_summ_final_omit <- na.omit(NPMRDSdata_summ_final)


# Summarize results

NPMRDS_data_output <- NPMRDSdata_summ_final_omit %>%
  group_by(tmc_code, Time) %>%
  summarise(Max_TTTI = round(max(TTTI), digits = 2),
        Mean_TTTI = round(mean(TTTI), digits = 2),
        SD_TTTI = round(sd(TTTI), digits = 2),
        Prob_REC = round(mean(Recurring), digits = 2)) %>%
  mutate(RC_TTTI = round(Mean_TTTI*Prob_REC, digits = 2))


# Filter all missing values

# NPMRDS_data_output <- na.omit(NPMRDS_data_output)


# Write final output

write.csv(NPMRDS_data_output, paste0(outFolder, "/263760_bottleneck_analysis_results.csv"),
row.names = FALSE)
```

R Script for Freight Performance Measures Calculation

```
# Prepare and Calculate TTTR and FR


# NOTE: Please unzip the data in the 'Data' folder and rename it as "CT_NPMRDS_Truck_Hourly"


library(readr)

library(dplyr)

library(psych)
```

```
library(lubridate)

library(tidyverse)


folder <- setwd("..")

folder <- getwd()

dir.create(file.path(folder, "Output"), showWarnings = FALSE)

dataFolder <- paste0(folder, "/Data/Hourly/2019 Truck/CT_2019_hourly (1)")

outFolder <- paste0(folder, "/Output")


NPMRDSdata <-  read_csv(paste0(dataFolder,"/CT_NPMRDS_Truck_Hourly.csv"),

                        col_types = cols( average_speed = col_skip(),

                        data_density = col_skip(),

                        measurement_tstamp = col_datetime(format = "%Y-%m-%d %H:%M:%S")),

                        locale = locale(tz="America/New_York"))


segDefinition <- read_csv(paste0(dataFolder,"/TMC_Identification.csv"),

                        col_types = cols_only(miles = col_guess(),

                        tmc = col_guess(),

                        f_system = col_guess()))


#join length and f_System

NPMRDSdata_CT_TMC <- left_join(NPMRDSdata, segDefinition, by= c("tmc_code"="tmc"))


#filter all missing and zero values and F_system=1

NPMRDSdata_CT_TMC <- na.omit(NPMRDSdata_CT_TMC)

NPMRDSdata_CT_TMC <- NPMRDSdata_CT_TMC %>%

  filter(travel_time_seconds!=0,
```

```
    f_system==1)
```

#Add Time Stamp for Aggregation and percentile calculation

NPMRDSdata_CT_TMC$Time <- format(NPMRDSdata_CT_TMC$measurement_tstamp, format="%H:%M:%S")

NPMRDSdata_CT_TMC$Date <- format(NPMRDSdata_CT_TMC$measurement_tstamp, '%Y-%m-%d')

NPMRDSdata_CT_TMC <- NPMRDSdata_CT_TMC %>%

  mutate(Weekday=wday(Date)) %>%

  mutate(wkday=if_else(Weekday %in% c(1,7),"Weekend","Weekday")) %>%

  mutate(Hour=hour(measurement_tstamp)) %>%

  mutate(Period=case_when(Hour >= 6 & Hour < 10 & wkday=="Weekday" ~ "6-10 Weekdays",

                Hour >= 10 & Hour < 16 & wkday=="Weekday" ~ "10-4 Weekdays",

                Hour >= 16 & Hour < 20 & wkday=="Weekday" ~ "4-8 Weekdays",

                Hour >= 6 & Hour < 20 & wkday=="Weekend" ~ "Weekend",

                TRUE ~ "Overnight"))

#calculate travel time percentiles and TTTR

NPMRDSdata_CT_TMC_Summ <- NPMRDSdata_CT_TMC %>%

  group_by(tmc_code, Period) %>%

  summarise(P_50th=quantile(travel_time_seconds, 0.5),

      P_95th=quantile(travel_time_seconds, 0.95)) %>%

  mutate(TTTR=round(P_95th/P_50th, digits = 2))

#calculate FR

NPMRDSdata_CT_TMC_FR <- NPMRDSdata_CT_TMC_Summ %>%

  group_by(tmc_code) %>%

  summarise(maxTTTR=max(TTTR)) %>%

```
  left_join(segDefinition, by= c("tmc_code"="tmc")) %>%

  select(-f_system) %>%

  mutate(sumMaxTTTR=maxTTTR*miles)
```

```
FR <-
round(sum(NPMRDSdata_CT_TMC_FR$sumMaxTTTR)/sum(NPMRDSdata_CT_TMC_FR$miles),digits
= 2)
```

```
print(paste0("Freight Reliability value is = ", FR))
```

```
write.csv(NPMRDSdata_CT_TMC_Summ, paste0(outFolder, "/Summary_table_TTTR.csv"), row.names
= FALSE)
```

```
write.table(FR, paste0(outFolder, "/Freight_Reliability.txt"), row.names = FALSE, quote = FALSE,
col.names = FALSE)
```

Default Hour-of-Day Demand Ratios (ADT/AADT)

Hour Starting	Expressway			Principal Arterial			Minor Arterial		
	Weekday	Weekend	Weekly Average	Weekday	Weekend	Weekly Average	Weekday	Weekend	Weekly Average
00:00:00	0.010	0.023	0.013	0.010	0.010	0.010	0.010	0.010	0.010
01:00:00	0.006	0.015	0.008	0.006	0.006	0.006	0.006	0.006	0.006
02:00:00	0.004	0.008	0.005	0.005	0.005	0.005	0.004	0.004	0.004
03:00:00	0.004	0.005	0.004	0.005	0.005	0.005	0.002	0.002	0.002
04:00:00	0.007	0.005	0.006	0.009	0.009	0.009	0.002	0.002	0.002
05:00:00	0.025	0.009	0.021	0.030	0.030	0.030	0.007	0.007	0.007
06:00:00	0.058	0.016	0.047	0.054	0.054	0.054	0.023	0.023	0.023
07:00:00	0.077	0.023	0.063	0.071	0.071	0.071	0.067	0.067	0.067
08:00:00	0.053	0.036	0.048	0.058	0.058	0.058	0.066	0.066	0.066
09:00:00	0.037	0.045	0.039	0.047	0.047	0.047	0.054	0.054	0.054
10:00:00	0.037	0.057	0.042	0.046	0.046	0.046	0.051	0.051	0.051
11:00:00	0.042	0.066	0.048	0.050	0.050	0.050	0.056	0.056	0.056
12:00:00	0.045	0.076	0.053	0.053	0.053	0.053	0.071	0.071	0.071
13:00:00	0.045	0.073	0.052	0.054	0.054	0.054	0.066	0.066	0.066
14:00:00	0.057	0.074	0.062	0.063	0.063	0.063	0.060	0.060	0.060
15:00:00	0.073	0.075	0.074	0.069	0.069	0.069	0.062	0.062	0.062
16:00:00	0.087	0.075	0.084	0.072	0.072	0.072	0.063	0.063	0.063
17:00:00	0.090	0.071	0.085	0.077	0.077	0.077	0.075	0.075	0.075
18:00:00	0.068	0.063	0.067	0.062	0.062	0.062	0.07	0.070	0.070
19:00:00	0.049	0.051	0.050	0.044	0.044	0.044	0.053	0.053	0.053
20:00:00	0.040	0.043	0.041	0.035	0.035	0.035	0.044	0.044	0.044
21:00:00	0.037	0.037	0.037	0.033	0.033	0.033	0.035	0.035	0.035
22:00:00	0.029	0.032	0.030	0.026	0.026	0.026	0.033	0.033	0.033
23:00:00	0.019	0.023	0.020	0.021	0.021	0.021	0.019	0.019	0.019

Source: The National Academics of Sciences, Engineering, Medicine. Highway Capacity Manual: A Guide for Multimodal Mobility Analysis. Transportation Research Board, 2016.