TECHNICAL MEMORANDUM

Congestion Pie Chart for Different Sources of Congestion

Task 3: Develop Performance Assessment and Evaluation Analytical Tools

SUMA
Support for Urban Mobility Analysis

A technical memorandum to

Support for Urban Mobility Analysis (SUMA)
FHWA Pooled Fund Study

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August 2021

Submitted by the

Texas A&M Transportation Institute

Executive Summary

Traffic congestion – both recurring and non-recurring – is caused by a variety of factors and sources. Recurring congestion stems from capacity constraints, bottlenecks, signalization, access points, etc. Non-recurring congestion is caused by disruptions, such as traffic incidents, weather, road construction and maintenance, and/or special events. On an aggregated level across all nationwide roadways, non-recurring congestion accounts for more delay than recurring congestion. However, local and regional estimates for contributions from different sources of congestion can vary considerably from national estimates, from freeways to arterial corridors, and from urban to rural areas. Therefore, there is a push for more granular understanding of the estimates of contributions from different sources of congestion to the overall "congestion pie."

Empirical estimates of congestion by source are useful to guide the decision-making and program design processes of transportation agencies, state and national departments of transportation (DOTs), and to identify which areas of improvement should be emphasized. This synthesis identifies extant literature and research on causes of congestion, compiles information from local, regional and national level estimates, and summarizes these estimates to be used to update sketch-planning tools such as the Future Improvement Examination Implementation (FIXiT) tool. Available estimates from a variety of empirical studies performed at the local, state and national levels, as well as research based on simulation study are reviewed and collated to cover a reasonable range of scenarios and use-cases on both uninterrupted facilities (freeways) and interrupted facilities (arterial streets).

This technical memorandum discusses observations and findings from the resources reviewed, identifies ways in which these findings can be used in sketch-planning tool FIXiT, and notes future opportunities. The key findings of this technical memorandum are listed below, and more discussion is provided in the body of the memo.

Key Points

- FHWA's nationwide estimates are by far the most cited and used reference for congestion estimates by a majority of regional and state agencies in their planning efforts.
- Classified by the type of congestion (recurring vs non-recurring) on a nationwide level, around 45% of congestion is caused by recurring sources (bottlenecks and suboptimal signal timing), and the remaining 55% is caused by non-recurring sources.
- The nationwide estimates can be a good starting point, but a local, granular, more empirical approach can lend more context-sensitivity to planning efforts keeping in mind that local and regional estimates for contributions from different sources of congestion can vary considerably from national estimates, from freeways to arterial corridors, and from urban to rural areas.
- Recurring sources of congestion contribute higher in urban areas compared to rural areas, while traffic incidents and work zones contribute a higher proportion to total congestion in rural areas. Moreover, arterial segments typically exhibit a higher contribution of recurring congestion compared to freeway segments. This can be because of presence of signals, suboptimal signal timing, access points, etc., on arterial segments.
- A few state DOTs, local agencies and independent research efforts have examined these estimates for their own regions and corridors, and more efforts are underway to be able to extend such analyses to a more granular (segment, corridor) level and wider use.

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Introduction and Background

Traffic congestion – broadly categorized into two types, recurring and non-recurring – stems from a variety of sources. Previous work has shown that congestion is the result of the following seven root causes, often interacting with one another *(1)*.

1. **Physical Bottlenecks ("Capacity")** – Capacity is the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves).
2. **Traffic Incidents** – Events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents.
3. **Work Zones** – Construction activities on the roadway that result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction or elimination of shoulders, and even temporary roadway closures.
4. **Weather** – Environmental conditions can lead to changes in driver behavior and ability that affect traffic flow.
5. **Traffic Control Devices** – Intermittent disruption of traffic flow by control devices such as railroad grade crossings and sub-optimally timed signals also contribute to congestion and travel time variability.
6. **Special Events** – A special case of demand fluctuations whereby traffic flow in the vicinity of the event is radically different from "typical" patterns. Special events occasionally cause "surges" in traffic demand that overwhelm the system during short periods of peak demand.
7. **Fluctuations in Normal Traffic** – Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also results in variable (i.e., unreliable) travel times.

On average, and as a whole across the United States, non-recurring congestion accounts for more delay than recurring congestion *(2)*. Non-recurring congestion is caused by disruptions, such as traffic incidents, weather, road construction and maintenance, and/or special events. This is particularly true in areas with smaller population sizes which do not experience a lot of recurring congestion.

However, local and regional estimates for contributions from different sources of congestion can vary considerably from national estimates, from freeways to arterial corridors, and from urban to rural areas. Regional and national estimates of congestion by source are useful to guide the decision-making and program design processes of transportation agencies, state and national departments of transportation (DOTs), and to identify which areas of improvement should be emphasized.

The objective of this synthesis is to identify extant literature and research on causes of congestion, compile information from local, regional and national level estimates, and summarize these estimates to be used to update sketch-planning tools such as the Future Improvement Examination Implementation (FIXiT) tool.

Available estimates from a variety of empirical studies performed at the local, state and national levels, as well as research based on simulation study have been reviewed and compiled to cover a reasonable range of scenarios and use-cases on both uninterrupted facilities (freeways) and interrupted facilities (arterial streets).

Findings

This section summarizes the data sources, types of facilities studied, and estimates for causes of congestion for the different relevant resources reviewed for this synthesis.

FHWA Office of Operations

Federal Highway Administration's (FHWA) national estimates for the causes of congestion are by far the most cited resource for most regional and state agencies in their planning efforts. National estimates of congestion by source are useful to guide FHWA's program and to identify areas of emphasis *(1,2)*.

Figure 1 shows these national estimates for urban areas. However, local conditions vary widely – developing methods for estimating congestion sources on individual highways is useful to transportation engineers and planners trying to decide how to devise the most relevant mitigation strategies. FHWA is currently researching this issue and is developing a methodology to allow transportation professionals to estimate the sources' contribution to total congestion using local data.

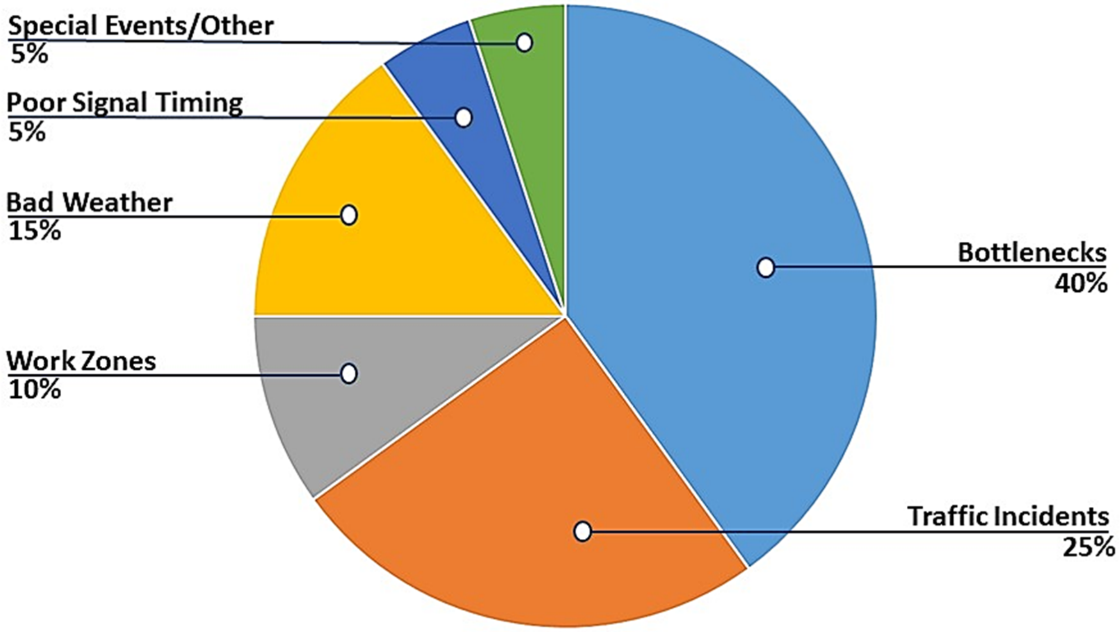


Figure 1: National Summary of the Sources of Congestion for Urban Areas *(1)*

Divided by the type of congestion (recurring vs non-recurring), around 45% of congestion is caused by recurring sources (bottlenecks and poor signal timing), and the remaining 55% is caused by non-recurring sources. This is shown in Figure 2.

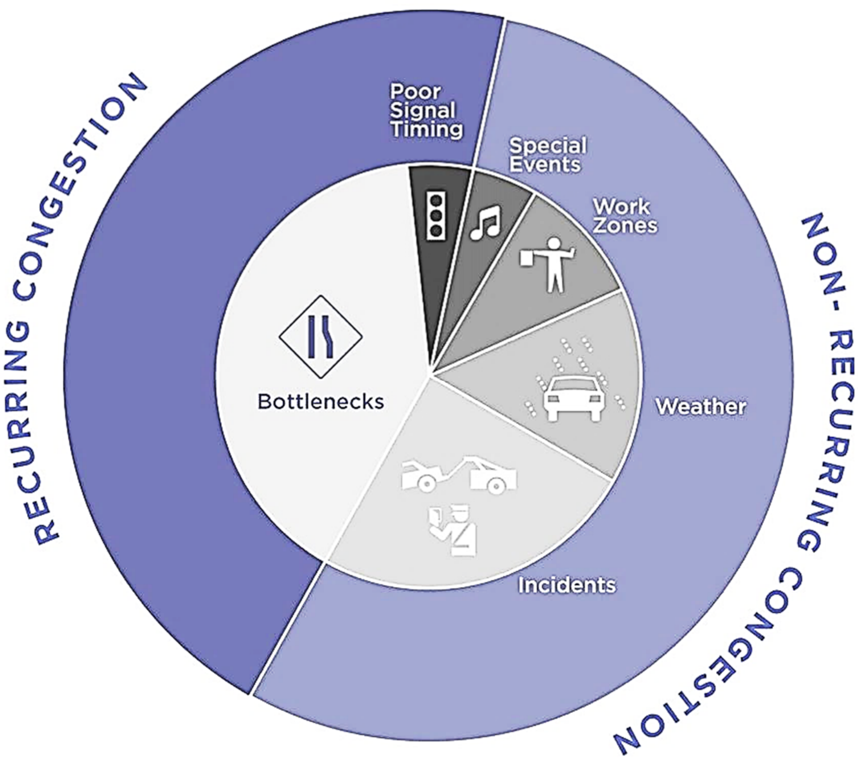


Figure 2: Summary of the Sources of Congestion Classified by Type of Recurrence *(2)*

Figure 3 shows the national estimates for rural areas. Traffic incidents and work zones contribute a much higher percentage to the rural congestion pie compared to the same for urban areas.

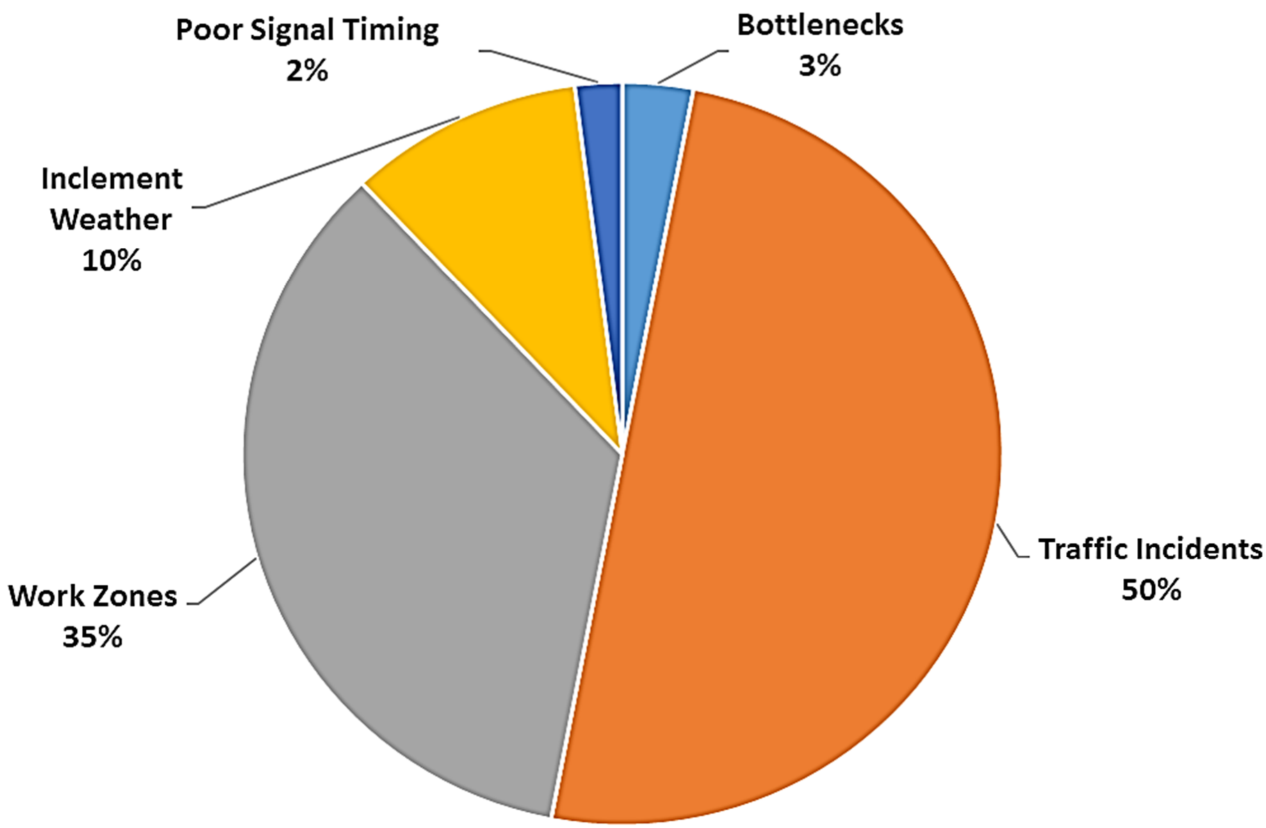


Figure 3: National Summary of the Sources of Congestion for Rural Areas *(1)*

Pennsylvania Department of Transportation

The PennDOT Traffic Systems and Performance Unit created a Pennsylvania-specific version of the congestion pie chart with a tool that could be used to generate pie charts for different regions, districts and corridors *(3)*. A primary focus area of the 4th Edition of the PennDOT TSMO (Transportation System Management & Operations) Performance Report is to introduce a data-driven Pennsylvania-specific congestion pie chart. The congestion pie chart shown in Figure 4 is provided from the statewide perspective, but the congestion pie chart tool provides capability to build a corridor congestion profile down to PennDOT district, county and roadway levels.

PennDOT's congestion pie chart was developed by utilizing traffic speed data for year 2018 provided by INRIX's flow incident API. While INRIX's exact methodology for conditions that produce a flow incident is proprietary, the general guidelines are that a traffic incident begins when traffic speeds drop below 65% of reference (free-flow) speed for at least 2 minutes, and that a flow incident ends when speeds have returned to greater than 70% of reference speed. For all data sources except Road Weather Information System (RWIS), a cause was correlated to a congestion incident if the cause occurred within 30 minutes of the congestion and within a mile of the congestion event. If no cause of congestion could be determined from department sources, crowed-sourced data from Waze was used to attempt to determine a cause, using the same 1 mile, 30-minute buffer parameters. Weather data from RWIS was correlated if it was indicated by the nearest RWIS station to the congestion event, with a maximum distance of 15 miles.

In some cases, multiple potential causes were identified for a single congestion incident. At this time, no special analysis was done to determine a primary cause, or to assign percentages of congestion across the multiple causes. For analysis purposes, congestion that correlated to multiple causes, DOT data or crowd-sourced, were classified using the following priority:

1. Crash
2. Roadwork
3. Weather

To generate the pie chart, all congestion events were assigned an impact score. The impact score of a congestion event = (event duration) x (length of queue) x (speed drop). The total area wide impact score was aggregated for each cause of congestion. The congestion pie chart as presented in Figure 4 represents a breakdown of the contribution of each cause of congestion to the total area wide congestion impact score. For example, roadwork contributes 26 percent of the statewide congestion impact score in Pennsylvania.

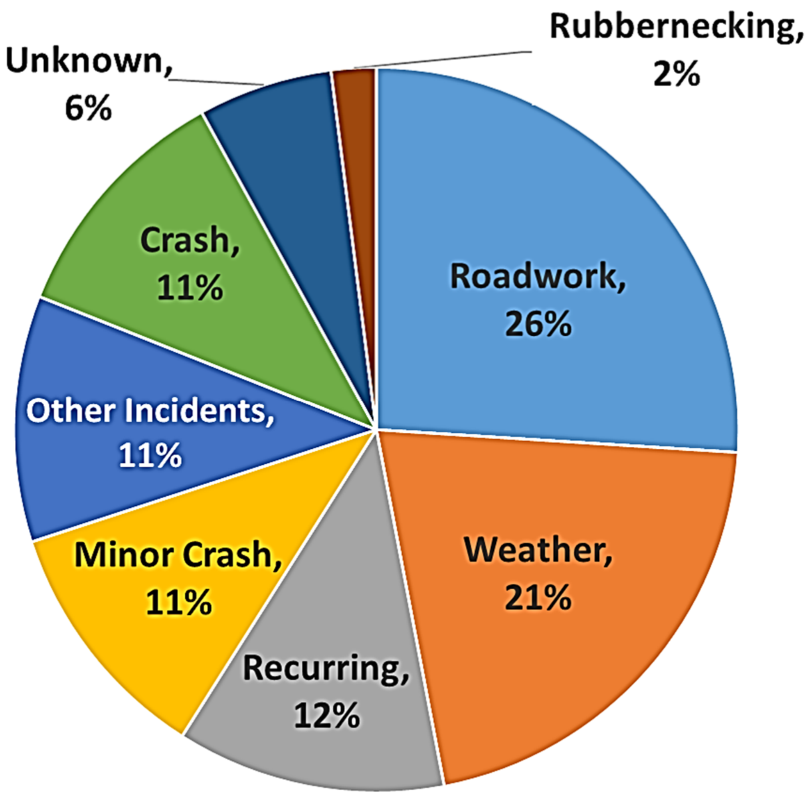


Figure 4: Pennsylvania Statewide Congestion Pie Chart for Year 2018

Table 1 provides the definitions of and the sources used to collect data for the different causes of congestion shown in Figure 4.

Table 1: Definitions and Data Sources for Different Causes of Congestion *(3)*

Cause of Congestion	Source/Definition
Roadwork	Road Condition Reporting System (RCRS) Roadwork, Maintenance Database, or Waze Roadwork event
Weather	Inclement weather (Heavy rain, any kind of snow, and/or snow covered, icy, or wet with temperature below freezing) roads conditions from Roadway Weather Information System (RWIS) or Waze weather event
Recurring	Congestion where speed drop is no more than 10% greater than the historical average speed
Minor Crash	Non-reportable crash from RCRS or Waze
Other Incident	Non-crash traffic hazard from Waze (i.e. disabled/car stopped on shoulder, hazard on roadway)
Crash	Reportable crash from the Crash Reporting System (CRS)
Unknown	Cause could not be identified with current data sources
Rubbernecking	Any previously identified congestion pie chart incident cause is linked to one side of the road, and no incident is correlated to the other side of the road in the same area, but still experiences a speed drop above historical norm

For Pennsylvania, Philadelphia (District 6) and Pittsburgh (District 11) constitute the primary urban areas. The recurring delay contribution in these regions is higher than overall statewide numbers and the highest among all regions, as shown in the charts in Figure 5.

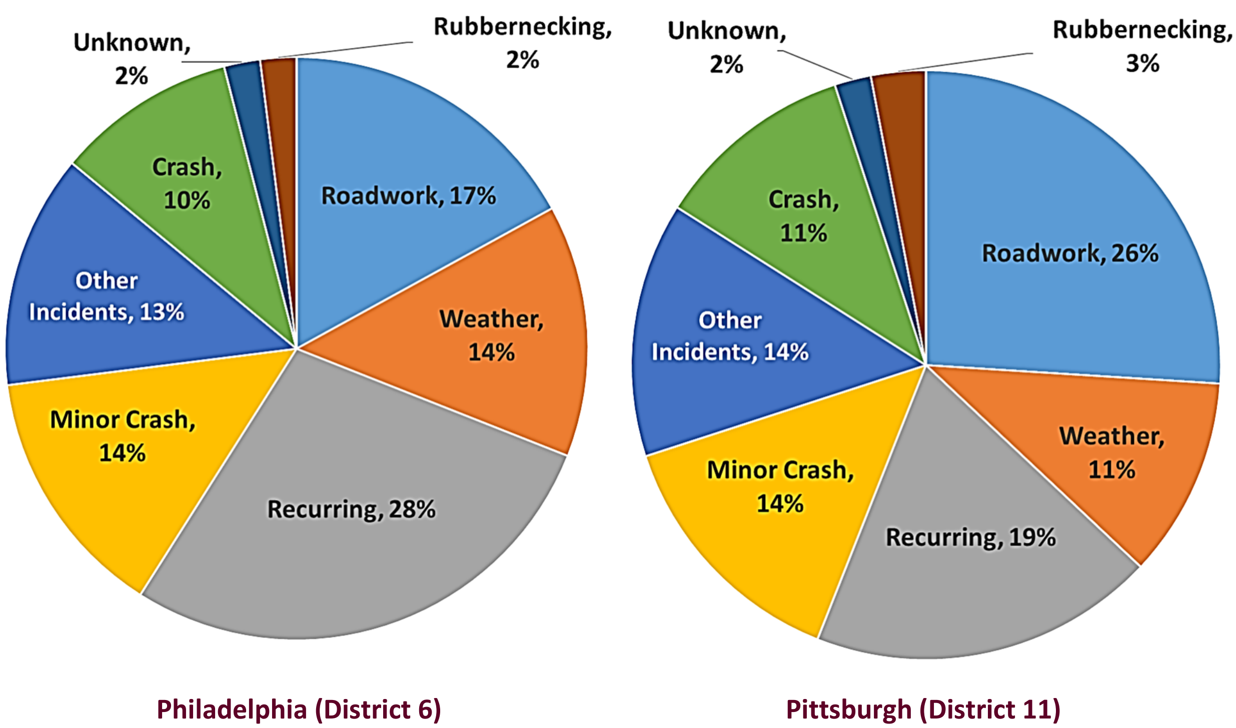


Figure 5: Congestion Pie Charts for Urban Areas in Pennsylvania

PennDOT's congestion pie chart tool can be utilized by PennDOT traffic operations personnel and planning partners to better understand the nature of congestion specific to their area of interest. Knowing the predominant causes of congestion provide the input to choose effective programs and strategies that deal with that particular concern. The analysis tool allows users to generate a congestion pie chart for the entire state, district(s), county(s), specific roadway, or roadway/county combinations (corridor). Future enhancements are in the works to allow smaller segments of roadways to be analyzed, and to further investigate the impact of multiple congestion causes on safety and severity of the incident timeline.

The Eastern Transportation Coalition

Under the TDADS (Transportation Disruption and Disaster Statistics) program, The Eastern Transportation Coalition (formerly the I-95 corridor coalition), with University of Maryland CATT Lab, developed a project to turn the hypothetical understanding of the causes of disruptions on the nation's transportation system into a tool - using real data - that can access, analyze and visualize network disruptions and disasters using nationally available data *(4)*. The data covered the entire National Highway System (NHS) from August 2018 to July 2019. Any event where the operating speeds dropped below 60 percent of the reference speeds was classified as a disruption. Analysis was performed for all individual states separately to evaluate regional factors and create interactive, easily-accessible tool in the hands of decision makers. Results for nation-wide analysis are shown in Figure 6. The percentages in these national statistics indicate the proportion of total user delay cost caused by each source of disruption (congestion).

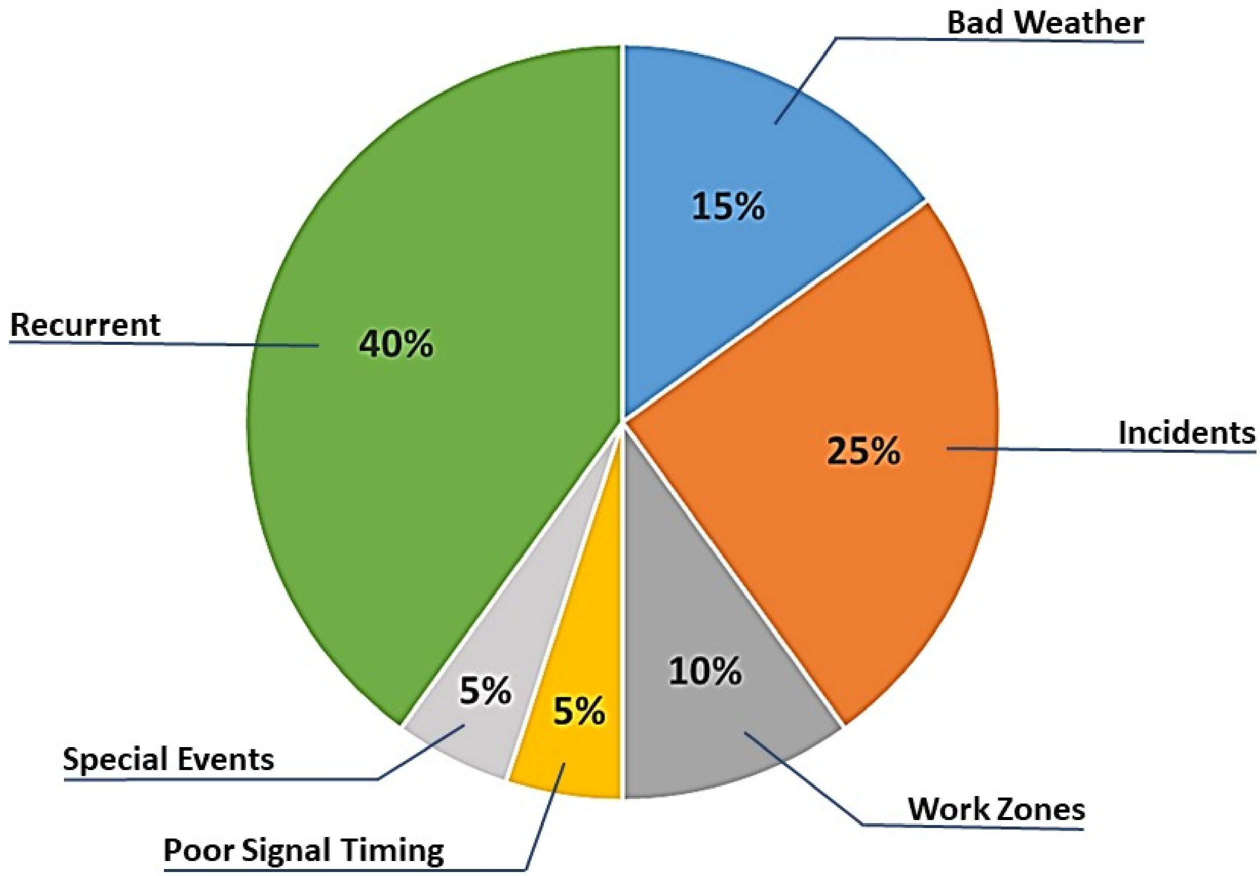


Figure 6: Pie Chart for User Delay Cost by Cause of Disruption on National Highway System *(4)*

The tool interface allows more granular analysis and visualization for the user or decision maker. For example, more disaggregate break-up (distribution) of user delay cost by state, month and source of congestion is possible with the tool.

Florida Case Study on Congestion Pie Charts for Arterial Roadways

Soltani-Sobh et al. *(5)* focused on arterial corridors to examine the contributions from different sources of congestion to create congestion pie charts which demonstrate the proportion of average experienced delay components. A linear regression model was developed to decompose the observed delay into various factors. The linear model was chosen based on the assumption that each of the explanatory variables contributes linearly to the delay. Three separate linear regression models for AM peak, Mid-day, and PM peak were developed using 15-minute aggregated travel times on a section of Broward Boulevard in Fort Lauderdale, FL, for 4 months (Sep-Dec) in 2014. Figure 7 shows the contributions of the various causal factors considered to the *average congestion* (delay) for different periods of the day.

In order to demonstrate the relative effect of various factors on delay, a set of normalized pie charts were developed by considering each factor's maximum value instead of using the average value. As shown in Figure 8, the normalized pie charts disregard the effect of factors' frequency, and demonstrate the magnitude of various factors' effects on delay, and the change in average delay due to variation of the factors. The variations for these less frequent factors statistically affect delay variations, and if any of these factors occurs, delay changes considerably. However, the contributions of these factors to *average delay* are not considerable. It is because of the fact that frequencies of these events (over time at various segments) are relatively small.

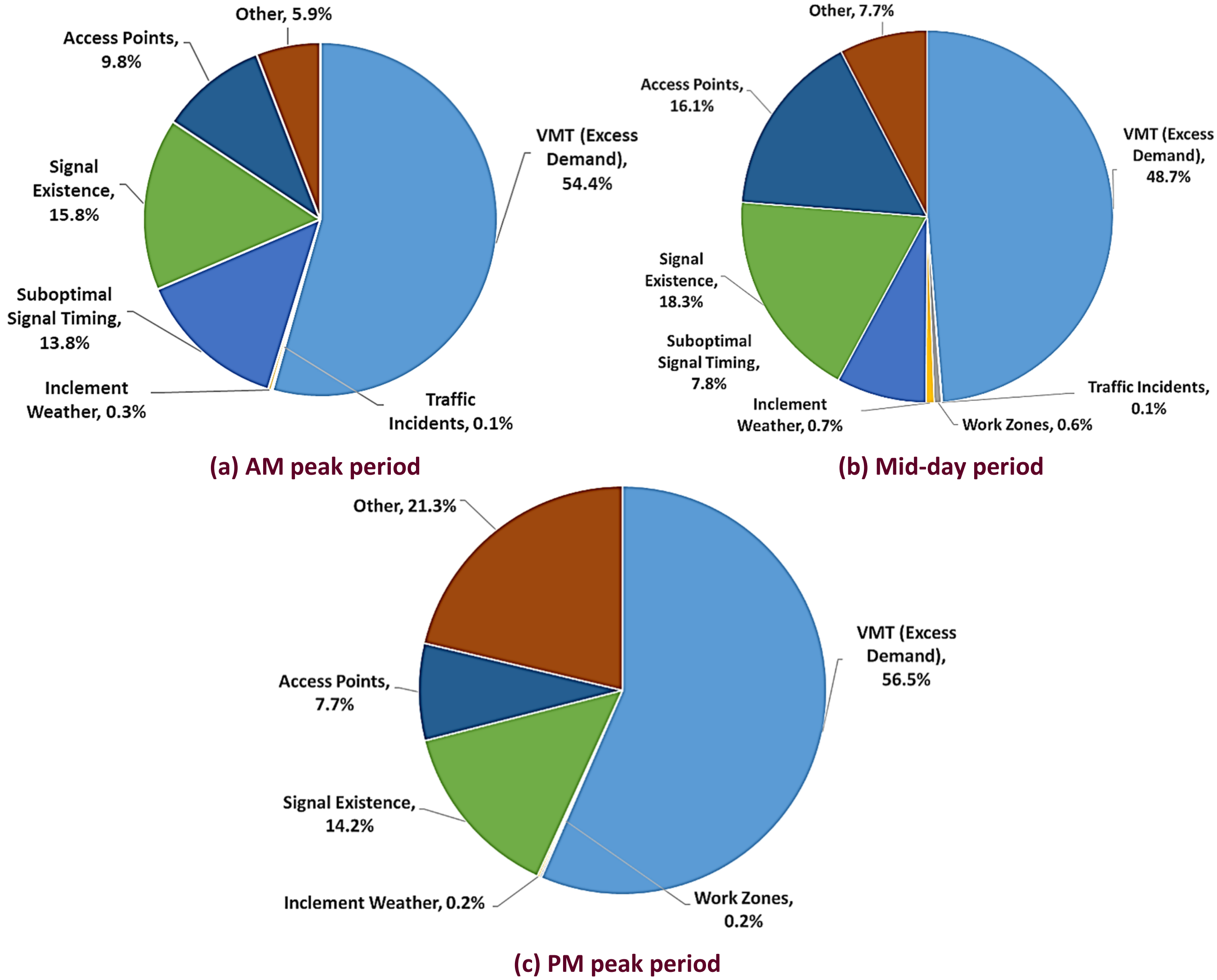
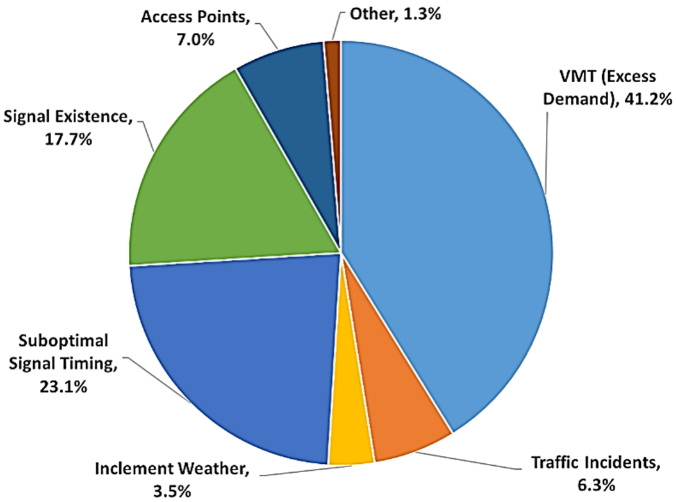
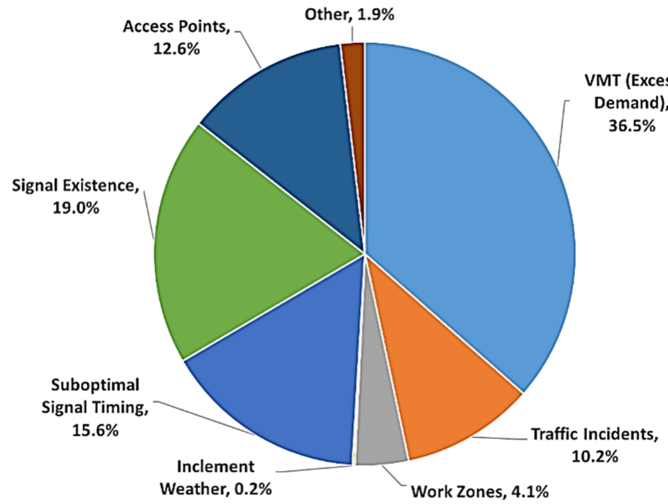


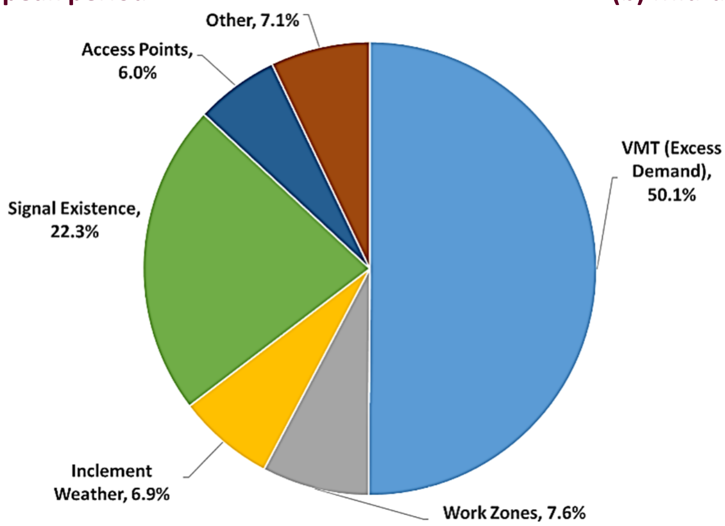
Figure 7: Congestion Pie Charts for Different Periods of the Day on an Arterial Street



(a) AM peak period



(b) Mid-day period



(c) PM peak period

Figure 8: Normalized Congestion Pie Charts for Different Periods of the Day on an Arterial Street

California Case Study on the Congestion Pie for Freeway Segments

Kwon and Varaiya *(6)* explored three primary causes of congestion on a freeway section:

i. the delay caused by collisions (crashes);
ii. the potential reduction in delay at bottlenecks that ideal ramp metering can achieve; and
iii. the remaining delay, due mainly to excess demand, but also to all other causes, and including non-collision incidents, lane closures, and weather.

Applied to a 22.5-mile section of I-15N in San Diego, the method used by this study found that collisions, potential reduction by ideal ramp metering, and excess demand, respectively, account for 31%, 46%, and 23% of the total daily delay, as shown in Figure 9. The research notes that ideal ramp metering may overestimate the gain, because it assumes that ramps do not have storage limits. Nevertheless, the large gain (46%) signals the great potential to mitigate congestion by ramp metering.

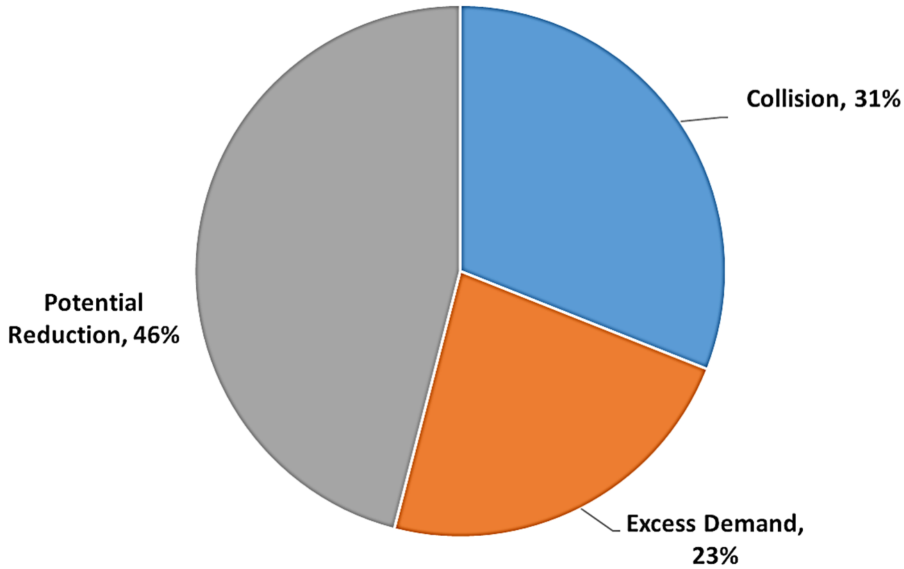


Figure 9: Delay Pie Chart for Freeway Segment *(6)*

Varaiya *(7)* explored the distribution of total vehicle hours of travel (VHT) during peak periods on freeway facilities using 5 years' worth of data from the PeMS (Performance Monitoring System) database for California highways. This distribution is shown in Figure 10.

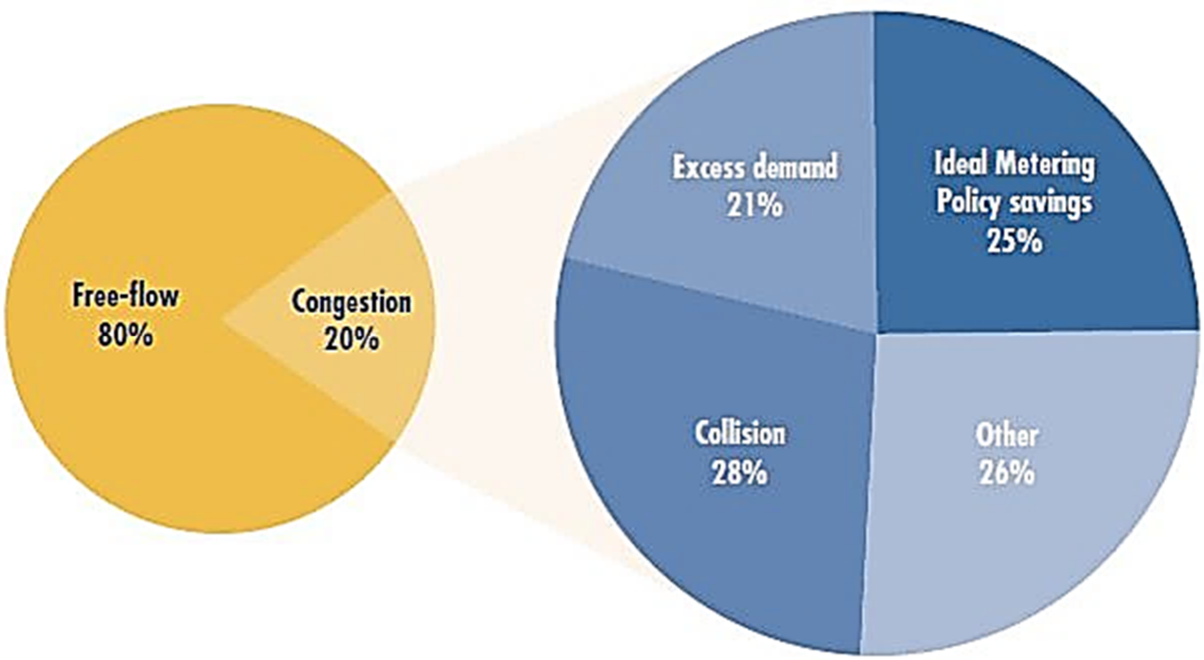
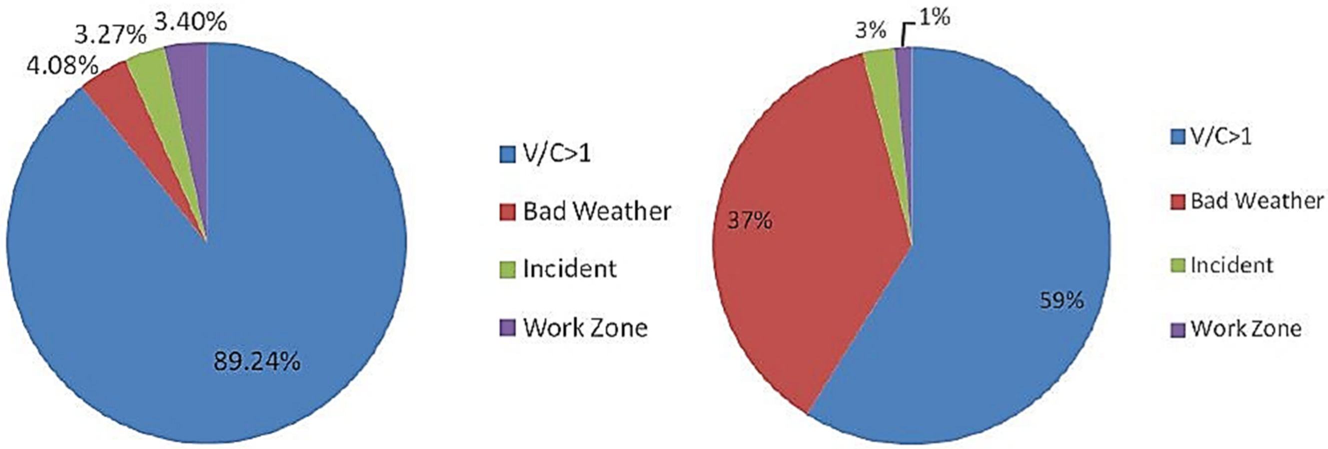


Figure 10: Total VHT and Congestion Sources during Peak Periods for California Freeway Facilities *(7)*

Other Case Studies on Congestion Causes and Bottleneck Identification on Freeways and Arterial Segments

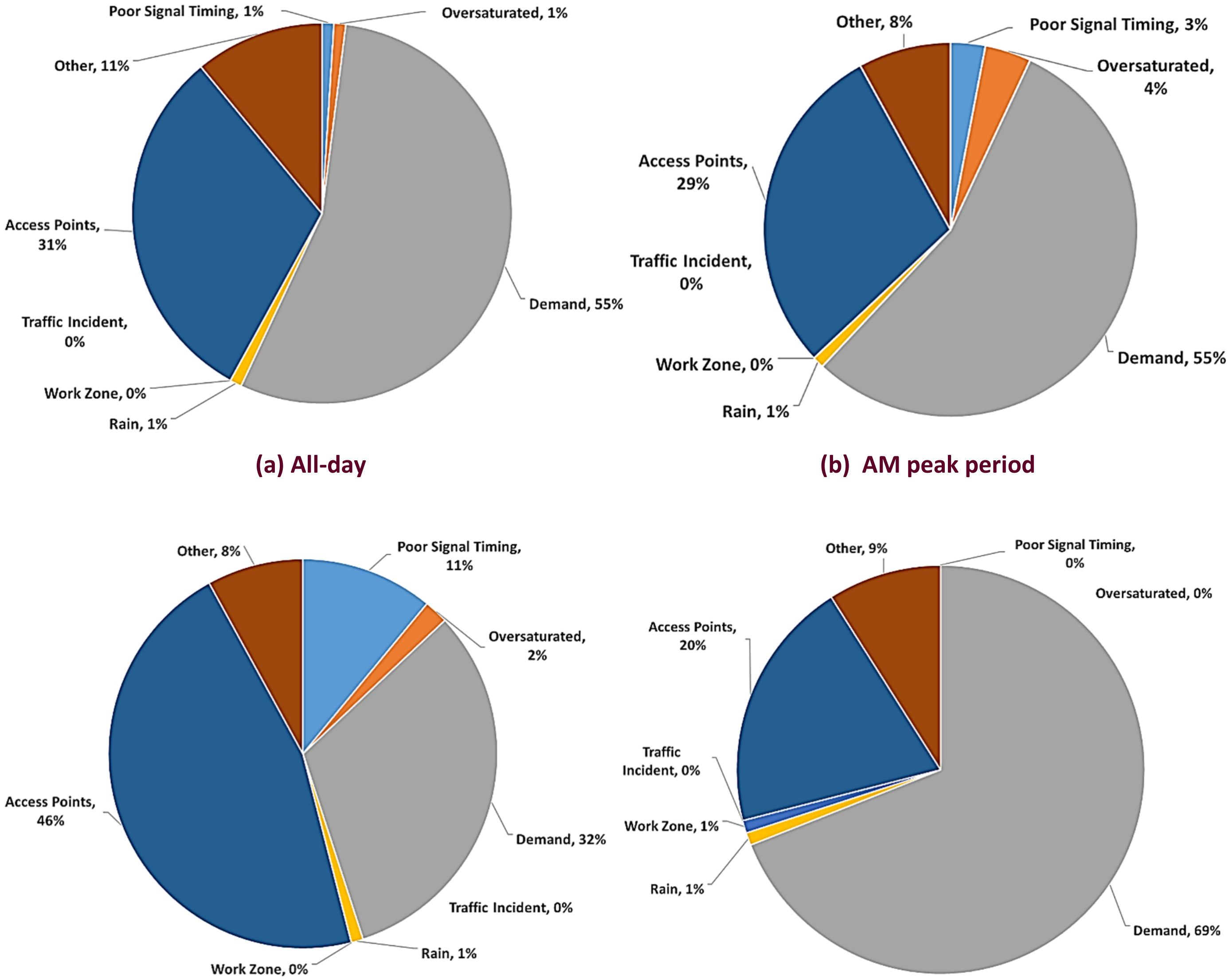
Causes of congestion on freeways and arterial streets were explored and presented during a workshop organized by the Oregon Department of Transportation and sponsored by the Federal Highway Administration *(8)*. Results for two different Freeway facilities in Virginia and California are shown in Figure 11 and period-wise results for arterial facilities in Florida are shown in Figure 12. In case of arterial streets, recurrent sources of congestion consist of poor signal timing, traffic demand and oversaturation (Volume-to-Capacity (V/C) ratio > 1), while non-recurrent sources consist of work zones, incidents, inclement weather and other unanticipated causes of disruption.



(a) I-66 Segment (Virginia) **(b) I-15 Segment (California)**

Figure 11: Congestion Pie Charts for Different Freeway Segments

In summary, road geometry and bad weather conditions contributed a higher portion to the total congestion pie compared to traffic incidents and work zones.



(a) All-day

(b) AM peak period

(c) Mid-day period

(d) PM peak period

Figure 12: Congestion Pie Charts by Periods of Day for Arterial Segments (Florida)

Summary of Findings

Table 2 summarizes the congestion pie estimates for different sources of congestion researched from different resources in this synthesis. It provides a comparative view of the general range of congestion impact of each cause, and how these estimates may vary depending on local, regional and time-of-day factors.

Table 2: Collated Estimates for Sources of Congestion

Resource/ Area of Study	Area Type	Source of Congestion				
		Recurring	Non-recurring			
		(Capacity/Bottleneck, Road Geometry, Signal Timing)	Incidents	Work Zones	Weather	Special Events/Other/ Unknown
FHWA National Estimates *(1,2)*	Urban	45%	25%	10%	15%	5%
	Rural	5%	50%	35%	10%	-
PennDOT Statewide Estimates *(3)*	Urban	25%-30%	30%-35%	20%-25%	10%-15%	5%
	Rural	10%-15%	35%	25%	20%	5%
I-95 Corridor Coalition *(4)*	Entire NHS	45%	25%	10%	15%	5%
Arterial Roadways (FL) *(5)*	Urban	50%-65%*	10%-15%*	5%-10%*	5%-10%*	5%-10%*
Freeway Segments (CA) *(6,7)*	Urban	20%-25%	25%-30%	45%-50%**		
Freeway and Arterial Segments (VA, CA, FL) *(8)*	Urban Freeway	60%-90%***	5%	1%-5%	5%-35%***	-
	Urban Arterial	45%-70%*	0%-5%	0%-5%	1%-5%	30%-50%^

**varies by time of day*
***all these factors (work zones, weather, special events, etc.) categorized as "other"*
****varies by location*
^access points, unknown factors categorized as "other"

It is seen that recurring sources of congestion contribute higher in urban areas compared to rural areas, while traffic incidents and work zones contribute a slightly higher proportion to total congestion in rural areas. Moreover, arterial segments typically exhibit a higher contribution of recurring congestion compared to freeway segments. This can be because of presence of signals, suboptimal signal timing, access points, etc., on arterial segments.

Discussion

A better understanding of the sources of congestion can help transportation professionals identify areas of improvement and design solutions better suited toward local issues in a context-sensitive manner. Nationwide estimates provided by the Federal Highway Administration often serve as a good starting point for decision-making bodies, but local factors can have considerable impacts on these estimates. Therefore, there is a push for more granular understanding of the estimates of contributions from different sources of congestion to the overall "congestion pie."

This synthesis identifies extant literature and research on causes of congestion, compiles information from local, regional and national level estimates, and summarizes these estimates to be used to update sketch-planning tools such as the Future Improvement Examination Implementation (FIXiT) tool. Available estimates from a variety of empirical studies performed at the local, state and national levels, as well as research based on simulation study are reviewed and collated to cover a reasonable range of scenarios and use-cases on both uninterrupted facilities (freeways) and interrupted facilities (arterial streets).

On average, and as a whole across the United States, non-recurring congestion (such as traffic incidents, weather, road construction and maintenance, and/or special events) accounts for more delay than recurring congestion (capacity bottleneck, sub-optimal signal timing, etc.). This is particularly true for rural areas and areas with smaller population sizes, which do not experience a lot of recurring congestion. However, larger urban areas have a significant contribution from the recurring component of delay as well.

A few state departments of transportation, local agencies and independent research efforts have examined these estimates for their own regions and corridors, and more efforts are underway to be able to extend such analyses to a more granular (segment, corridor) level and wider use.

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