ITS Heartland

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Freeway Congestion Study of Different Segment Types Based on Statistic Modeling

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Abstract

This paper aims to study about the freeway congestion, its causal factors; the critical freeway segments/Bottle necks based on the analysis of available detector and incident data of Capital Beltway (I-495). With the use of statistical models, the effect of incidents, location, time periods were related with the density for different freeway segments. Separate models for Basic Freeway and Merge/Diverge segments were produced. The result showed that the time period, incidents and the locations were significantly influential over congestion. Critical segments were identified from the models and assessed with the percentage of time they exceeded the density threshold of 45 vpmpl and the Bottlenecks were identified based on same assertion. The study also recommended some countermeasures to control congestion.

Keywords: Freeway congestion; Detector data; Incident data; Segment type; Statistic model

1. Introduction

The problem of traffic congestion especially in urban areas has been a key issue in transportation sector. Furthermore, in Metropolitan city like Washington DC which ranks among top US cities in several key congestion metrics for large cities according to the 2011 Urban Mobility Report, maintaining smooth traffic mobility is a challenging task. In the same context, this study was carried out to analyze two directional traffic on portion of the DC Beltway (I-495) in the North – West quadrant starting at the intersection of I-95 from Baltimore and extending CCW to the intersection of I-66 in Virginia. Considering density as a measure of congestion, the study developed the models to relate factors affecting congestion to the surrogate of congestion based on supplied detector and incident data.

2. Literature Review

There are lots of literatures that deal with the issue of traffic congestion. Many of them deal with the effect of recurrent or non-recurrent events on freeway congestion. Several algorithms and methodologies have been proposed in the studies to identify and asses the bottlenecks in freeways.

Regarding the factors correlated to freeway congestion, Hallenbeck, Ishimaru and Nee (2003) found correlation between traffic incident and freeway performance. Similarly, Daniel (2006) demonstrated the quantitative relationship between weather patterns and surface traffic congestion. Kwon et al. (2006) found four components as delay attributed to incidents, special events, lane closures, and weather symbolizing freeway congestion. In the same context, Churchill (2012) explained about the effect of sun glare on congestion. From these studies, it is evident that there are large numbers of factors that are influential over freeway congestion. The identification of these local and global crucial factors and measuring the extent to which they impact on freeway congestion is very critical before to conceive the potential countermeasures.

Usually, traffic congestion applicable for freeways is divided into two scenarios, recurrent and noncurrent congestion. The freeway work zones related to long duration of time and mainline work led to more non-recurrent congestion (Chung, 2010). The morning and evening traffics, lane drops and the change in geometry lead to the recurring congestion. There are several ways to measure congestion. In this context, Dowling (2004) developed Performance Measurement System (PeMS) method and Non-PeMS method to estimate congestion. Zhang (2012) studied about large scale incidents with an aim to analyze and explore the correlations between incidents and traffic operations. Among those methods, the neural network has proved to be more efficient on detecting incidents (Ritchie (1993), Abdullah and Richie (1999)). Recent studies have tried to combine multiparadigm intelligent system, and try to develop a new methodology which integrates fuzzy, wavelet, and neural computing techniques to improve reliability and robustness of the algorithm (Hojjat, 1998).

New technologies have provided more options to detect freeway congestion. The application of road detectors allows analysis to be carried under dynamic mechanisms and under several patterns of freeway congestion. By using single loop detector data, Graves et al. (1998) found both recurring and non-recurring congestion propagating from downstream to upstream in triangular fashion and as a parallelogram. The non-recurring congestion propagated more rapidly than recurring congestion. Chen et al., (2003) used five minutes loop detector data to determine speed difference, and use it as an indicator of bottleneck activation. Kwon et al. (2007) found that the sample size and detector spacing have an effect on accuracy of congestion monitoring.

Recommendations to relieve freeway congestion problem have been proposed by many traffic engineers. Halati et al. (2007 suggested diversion of traffic during non-recurring congestion from the initial travel routes and subsequent re-routing of the vehicles to their destination. More suggestions were proposed by Daganzo et al. (2002) to tackle freeway congestion problem such as the use of direct control to improve the usage of downstream off-ramps, use of VMS's to improve utilization of upstream off-ramps, dynamic merge control, and dynamic speed limits, rationing free access, diversion actions, and dynamic use of shoulder lanes.

3. Data Reduction

In this study, the data collected by traffic detection were used. Probed vehicle data were not used. At first, all the detectors of I-495 were plotted on Google earth. The detectors were separately listed for each direction and all the ramp detectors were excluded. There were some detectors without any readings and they were also excluded from the list. The plot is shown in Figure 1. Using the same method, all the incidents were plotted on the map, separated by directions as shown in Figure 2.

Figure 1 The detectors by direction

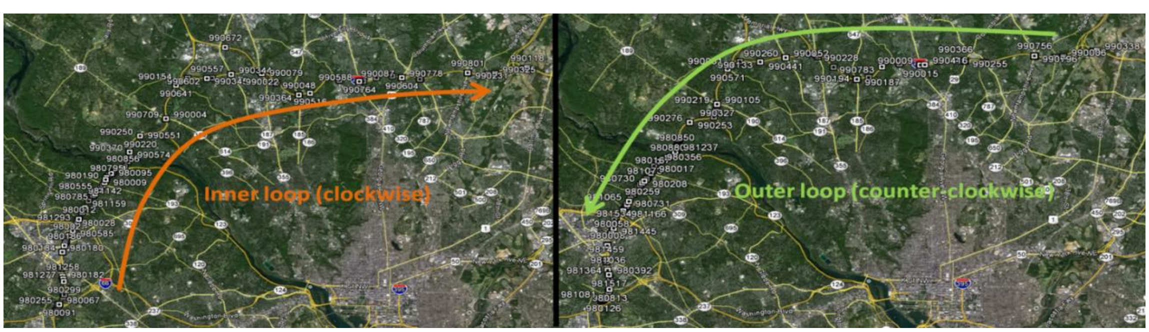

Figure 2 Incident locations identificationon each directions

Freeway segments were divided according to the detector location. Each segment: Basic Freeway, Merge, Diverge or Weave, were classified according to HCM 2010 criteria. All the incidents were related to different detectors based on the proximity of location with the assumption that an incident has influence on all the detectors on respective segment and has no influence on other segments. The concept is shown in Figure 3.

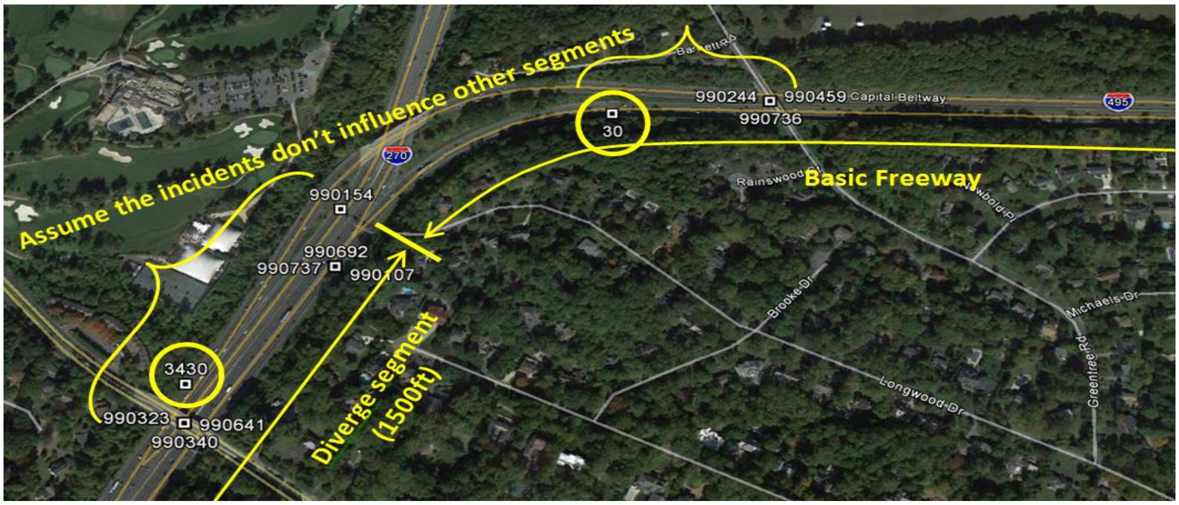

Figure 3 Link the incidents to the detectors

4. Data Analysis

4.1 Pre-Modeling Analysis

The data set was divided into separate data sets for Basic Freeway, Diverge and Merge segments. There were no data for weave. Similarly lane configurations for the segments with detector location were also recorded. From the base capacity and Free Flow speed criteria, capacity and volume to capacity ratio (V/C) for each segment were also calculated. Since some calculated V/C ratio values were not reasonable, it was decided to consider density (volume/speed/lane) as a surrogate measure of congestion. The independent variables that possibly could affect the density were identified as provided in the Table 1and their code names used in statistical analysis are shown in Table 2. The events, segment locations according to the detector positions and the time period of 2 hrs. of 24 hrs. were the independent variables. Prior to the modeling some of the outliers from the data were removed manually.

Table1: Selection of Independent Variables

Independent Variables	Sub-Categories
Events	Incident, Disabled Vehicle, Planned Lane Closure as defined by Agency
Locations	According to the considered detector positions
Time periods	Two hours period in 24 hr

Table 2: Event Codes

	Event Type	Code	Event Type	Code	
Events	Incident	Incident	Location	At Zone_id 3345	Location_3345
	Diabled Vehicle	Disabled_Vehicle		At Zone_id 3362	Location_3362
	Planned Lane closure	Planned Roadway Closure		At Zone_id 3363	Location_3363
Time	12 AM- 2AM	Time (0-1)		At Zone_id 3379	Location_3379
	2 AM-4 AM	Time(2-3)		At Zone_id 3428	Location_3428
	4 AM-6 AM	Time(4-5)		At Zone_id 3430	Location_3430
	6 AM-8 AM	Time (6-7)		At Zone_id 3435	Location_3435
	8 AM -10 AM	Time (8-9)		At Zone_id 3436	Location_3436
	10 AM-12AM	Time (10-11)		At Zone_id 3466	Location_3466
	12 PM-2 PM	Time (12-13)		At Zone_id 3467	Location_3467
	2 PM-4 PM	Time (14-15)		At Zone_id 3468	Location_3468
	4 PM-6 PM	Time (16-17)		At Zone_id 3520	Location_3520
	6 PM-8 PM	Time (18-19)		At Zone_id 3522	Location_3522
	8 PM-10 PM	Time (20-21)		At Zone_id 3532	Location_3532
	10 PM-12 PM	Time (22-23)		At Zone_id 3534	Location_3534

4.2 Models and Discussion on Models

To relate the identified independent variables to the density, a surrogate measure of congestion, Linear Regression Modeling was performed using IBM SPSS Statistics 21®. Four models each for Basic Freeway and Merge/Diverge segment for inner and outer loops were developed.

4.2.1 Case A: Inner Loop, Basic Freeway Segments

The following model for case A was developed performing Linear Regression.

Density = 23.32 – 22.112* Time (0-1) - 23.438 * Time (2-3) - 19.882* Time (4-5) - 10.513* Time (6-7) -7.403* Time (8-9) -7.911* Time (10-11) -7.7078* Time (12-13) + 1.614* Time (16-17) -5.578* Time (18-19) -13.049* Time (20-21) -17.621* Time (22-23) + 5.116* Disabled Vehicle +4.149* Planned Roadway Closure + 8.317 * Location_28 + 1.12 * Location_30 + 4.618* Location_31 + 6.069* Location_3346 + 4.544* Location_3422 -12.328 * Location_3531

(Adjusted R-Square = 0.486)

From the model, it is clear that the significant variables as time periods, 0-1, 2-3, 4-5, 6-7, 8-9, 10-11, 12-13, 18-19, 20-21, 22-23 and the segment at the location 3531 detector zone ID are contributing towards the decrement of density. However, time 16-17 (4 PM-6 PM) which falls in evening peak hour, the events like disabled vehicle and planned roadway closure, and the segments at the location of 28,30, 31,3346 and 3422 are found contributing towards the density increment. It implies that the road (Basic Freeway Segments) experiences the congestion on evening peak hour time and the locations as 28, 30, 31, 3346 and 3422 are the congested segments. The events as disabled vehicle and planned roadway closure contributed towards the non-recurring congestion.

4.2.2 Case B: Inner Loop, Merge/Diverge Segments

The following model for case B was developed performing Linear Regression.

Density = 31.613 – 24.289* Time (0-1) – 26.00 * Time (2-3) – 21.797* Time (4-5) - 10..648* Time (6-7) -8.345* Time (8-9) -8.352* Time (10-11) -6.39* Time (12-13) – 0.661* Time (14-15) -6.033* Time (18-19) -13.643* Time (20-21) -18.76* Time (22-23) + 3.022* Incident + 2.22 * Location_3363 – 4.637* Location_3430 – 2.72* Location_3466 – 4.389* Location_3468 - 19.589 * Location_3522

(Adjusted R-Square = 0.578)

From the model it clear that the significant variables as time periods, 0-1, 2-3, 4-5, 6-7, 8-9, 10-11, 12-13, 14-15,18-19, 20-21, 22-23 and the segments at the locations 3430, 3466, 3468, 3522 zone IDs are contributing towards the decrement of density. However, the events like incident and the segments at the location of 3363 were found contributing towards the density increment. It implies that these events are responsible for the non-recurring congestion and the segment 3363 is a significantly congested segment.

4.2.3 Case C: Outer Loop, Basic Freeway Segments

The following model for case C was developed performing Linear Regression.

Density = 33.435 – 23.9* Time (0-1) – 25.397 * Time (2-3) – 18.467* Time (4-5) + 2.123* Time (8-9) -5.592* Time (10-11) -5.271* Time (12-13) + 0.571* Time (16-17) -5.324* Time (18-19) -12.546* Time (20-21) -18.037* Time (22-23) + 36.939* Incident - 4.911* Planned Roadway Closure – 4.468 * Location_29 – 11.205* Location_35 – 9.053* Location_36 – 5.658* Location_38 – 9.153 * Location_3420 + 3.486*Location_3530
(Adjusted R-Square = 0.578)

From the model it clear that the significant variables as time periods, 0-1, 2-3, 4-5, 6-7, 10-11, 12-13, 18-19, 20-21, 22-23, events as Planned Roadway Closure, and the segments at the locations 29, 35, 36, 38, 3420 detector zone IDs are contributing towards the decrement of density. However, time at 16-17 (4 PM-6 PM) which falls in evening peak period, the events like incident and the segment at the location of 3530 were found contributing towards the density increment. It implies that the outer loop Basic Freeway Segments is congested in evening peak hour. The events like incident and the planned roadway closure are responsible for non-recurring congestion. The segment at the location 3530 is a significantly congested segment..

4.2.4 Case B: Outer Loop, Merge/Diverge Segments

The following model for case C was developed performing Linear Regression.

Density = 42.733 – 33.051* Time (0-1) – 35.004 * Time (2-3) – 26.877* Time (4-5) – 3.543* Time (6-7) -11.731* Time (10-11) -11.974* Time (12-13) – 3.583* Time (14-15) -3.626* Time (16-17) -11.632* Time (18-19) -20.608* Time (20-21) - 26.255* Time (22-23) + 12.407* Disabled Vehicle + 9.978* Incident – 5.532* Planned Roadway Closure – 17.003 * Location_3345 – 4.598* Location_3379 – 6.674* Location_3428 + 5.577* Location_3435 – 11.781 * Location_3467 – 8.442*Location_3520 +7.302*Location_3532

(Adjusted R-Square = 0.413)

From the model it clear that the significant variables as time periods, 0-1, 2-3, 4-5, 6-7, 10-11, 12-13, 14-15,16-17,18-19, 20-21, 22-23, events as incidents and Planned Road Closure, and the segments at the locations 3345, 3379, 3428, 3467 and 3520 detector zone IDs are contributing towards the decrement of density. However, time at 16-17 (4 PM-6 PM) which falls in evening peak period, the events like incident and the segment at the location of 3435 and 3532 were found contributing towards the density increment. It implies that these segments experience congestion on evening peak hour especially and the segments 3435 and 3532 are significantly congested segments.

5. Identification of Bottlenecks

Based on the statistical analysis as explained in Section 2, it can be conferred the segments which were found significantly increasing the density of the freeway should be the critical location. These segments are listed in Table 3. Taking the marginal density of 45 vehicles per mile per lane (vpmpl), the percentage of instances that exceeds 45 vpml densities on that segments were also calculated as shown in Table 3. 45 vpmpl is also a margin above which LOS of basic freeway segments go out of capacity. As shown in Table 3, the Basic Freeway segment: Location_3422 in inner road, Basic Freeway segment: Location_3530 and Diverge segment: Location_3532 have the condition exceeding density of 45 vpmpl on above 10 % of the total time. On this basis, these segments can be treated as bottlenecks.

Table 4: Critical Segments

	Inner				Outer			
	Basic Freeway	**Percentage of time Density Exceeds 45**	**Merge or Diverge**	**Percentage of Time Density Exceeds 45**	**Basic Freeway**	**Percentage of time Density Exceeds 45**	**Merge or Diverge**	**Percentage of Time Density Exceeds 45**
Critical Locations	**Location_28**	6.72%	Location_3363 (Merge)	8.87%	Location_3530	13.56%	Location_3435 (Merge)	0.69%
	Location_30	2.15%					Location_3532 (Diverge)	10.91%
	Location_31	0.95%						
	Location_3346	6.43%						
	Location_3422	10.70%						

6. Conclusion and Recommendation

6.1 Conclusion

The study looked in depth into the factors that affect the congestion on the study segments. The independent variables like incident, location and time period were found significantly influencing the freeway congestion as evidenced by four models of different segments corresponding to inner and outer freeway. Among the most common observations on the all segment types of both inner and outer freeway, the density was observed increased on evening peak period at 4 PM-6 PM except on inner loops merge/diverge segments. The different categories of incidents were observed significantly impacting the density of different segments. These incidents can be taken as the factor contributing to non- recurring congestion. Two Basic Freeway and one Merge segments on inner roadway, and one Basic Freeway, one Merge and one Diverge segments on outer roadway were identified as most congested segment. On the basis of congestion level with density above 45 vpmpl more than 10 % of time, three segments (Location_3422, Location_3530 and Location_3532) were identified as bottle necks, as shown in Figure 4.

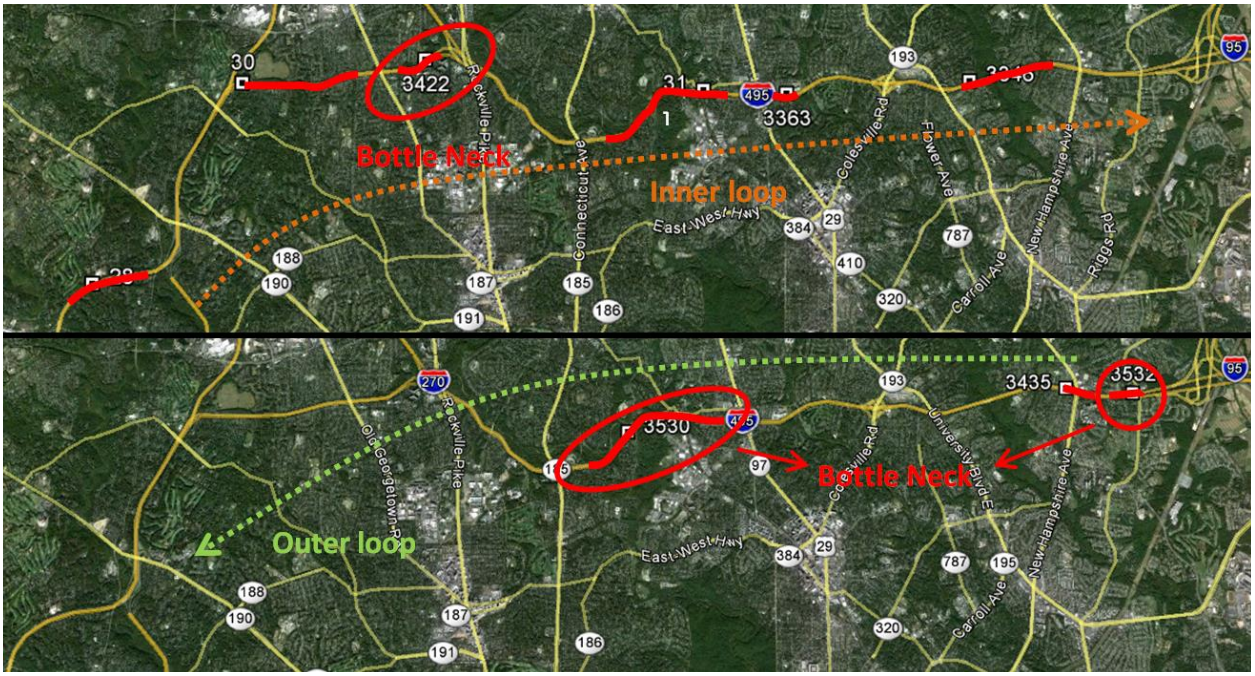

Figure 4 Critical segment and bottle necks

6.2 Recommendation

1. Bottle necks are found especially in the area near the diverge ramp and in the areas where exists the curve geometry and diverge/merge points. Specially in the diverge area, to reduce the impact of diverging vehicle to through vehicles, the lane markings of the most outer lane leading to diverge ramp should be delineated solid white at least 300-400 feet upstream from the gorge areas.

2. In order to make the drivers aware of the changing geometry, the guide signs and advisory speed sign should be placed well before such locations. It will help driver slow down smoothly while approaching these locations. The abrupt breaking would affect the following vehicles leading to the congestion.

3. Study should be done to assess the need of ramp metering on all the on ramps of the study segments.

4. To reduce the speed turbulence, it is necessary to put the speed limit same for whole segment as far as possible with other constraints.

5. It is advisable to put variable message sign which can be permanent or trailer based to warn the lane blockage or congestion ahead due to any incidents.

6. Route diversion for severe non- recurring congestion will be a good alternative for traffic management in critical conditions.

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