Title

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ABSTRACT

Freeway collisions are thought to be affected by traffic states. To reduce the number of collisions, the study to reveal how the traffic states influence collisions are required. Therefore, the purpose of the paper is to suggest a method to relate traffic states to collision frequency in freeway. We first defined section-based traffic phases showing traffic state of a section using upstream and downstream traffic states: free flow (FF), back of queue (BQ), bottleneck front (BN) and congestion (CT). Secondly, by integrating freeway collision data and traffic data from the California PeMS database, over a three-year period, we obtained the collision frequency for each traffic phase, and compared for a 32mile section of the I-880 freeway. The results show that collision rate in BN, BQ, and CT phase are approximately 5 times higher than the collision rate in FF. Also, the proposed method shows potential for predicting collision frequencies on freeway sections when combined by traffic simulation.

Keywords: Traffic safety, Collision frequency, traffic phase

1. INTRODUCTION

Accident frequency and characteristics on freeways is related to traffic operating conditions; for example, higher accident frequencies are observed in congested conditions, but a higher number of fatal accidents have been observed in light traffic conditions during late night hours. However, the impact of traffic conditions, especially the growth and dissipation of congestion, on freeway collisions has not been investigated systematically. Understanding the relationship between traffic states on freeways and collision frequency, we can build traffic models to predict the number of accidents, and the impacts of safety related countermeasures.

Several studies have been undertaken to identify relationships between crash occurrences on freeways and traffic flow (e.g., Ceder and Livneh, 1982; Martin, 2002; Ivan, 2004). These studies analyzed crash frequencies and macroscopic characteristics of traffic flow for specific time periods (in various time intervals: from hours to years) and spaces (in various lengths: segments to corridors), and showed that there exists a relationship between crash rate and traffic flow.

Ceder and Livneh (1982) and Hall and Padelton (1988) observed how crash rates vary with traffic flows and reported that the relationship of traffic flow vs. crash rate displayed U-shape. However, macroscopic (aggregate) measures of traffic flow in these studies were too static to represent time-varying traffic conditions on freeways and, thus, the variability in crash rates (associated with many other aspects of traffic conditions) might not be fully explained.

Oh et al. (2001), Lee et al. (2002, 2003) and Golob et al. (2004) used various (microscopic and disaggregate) measures of traffic conditions from (20-sec to 5-min) loop detector data to identify traffic characteristics leading to crash occurrences and showed the statistical relationship between time-varying traffic characteristics and crash outcomes. Oh et al. (2001) identified standard deviation of 5-min average speed as an indicator separating normal and disruptive traffic conditions, and estimated crash rate with respect to the standard deviation of 5-min average speed. This study showed that the rate of crash occurrences was higher under congested traffic conditions and increased as standard deviation of speed increased. Lee et al. (2002, 2003) modeled crash frequency as a function of categorized crash precursors (variation of speeds across lanes and along the freeway, and traffic densities), control factors and exposure. The categorization of crash precursors is determined in maximizing log-likelihood of crash prediction model (Lee et al., 2003). Golob et al. (2004) applied a cluster analysis to classify traffic characteristics and investigated the levels of safety and crash types for each class. These studies demonstrated that the variability in speed is significantly associated with crash occurrences.

The objective of the research described in this paper is to propose and apply a new approach to relate traffic conditions and accidents on freeways. First, we developed a method to classify traffic states for a freeway sections. Then, for each freeway collision, we found a freeway section and traffic conditions at the time of collision occurrence. Finally, we put together the obtained information, and construct collision ratemaps relating traffic conditions and the number of collisions.

In Section 2 of the paper, we describe the study site. The proposed methodology is presented in Section 3, and Section 4 presents the results from the application of the method on the test site. Finally, Section 5 summarizes the study findings.

2. THE STUDY SITE

The study site is a northbound section of the I-880 freeway section located at San Francisco Bay Area. It starts from near San Jose area, and extends to junction location to the Bay Bridge (Figure 1). The total length of the study section about 32 miles. I-880N is a major commute route to San Francisco and is congested during both morning and afternoon peak hours. It is also a major truck route because it provides access to the Port of Oakland.

Figure 1. I-880 study site

The test section is instrumented with loop detectors. The average detector spacing is approximately 0.4 mile, and there are a total of 72 detector stations. Five minutes[1] of flow, speed and occupancy loop detector data were obtained from the California PeMS database (Choe et al, 2002) for a three-year period (Jan 1, 2005 to Dec 31, 2007). The historical database maintained by the California Department of Transportation (Caltrans) is used for the work described in this paper. Traffic Accident Surveillance and Analysis System (TASAS) is a computerized database that contains the historical records of collisions on roadways under the state highway system. Collision data includes time of collision in minutes and location in post-mile based on detailed police reports. Additional information such as the collision type and the number of injuries and fatalities is also included in the collision database. The total number of vehicles involved in collisions for the three-year period is 8,765

3. METHODOLOGY

There exists limitation in matching collision data and traffic data. Both of them are point-based measurements recorded in post-mile. However the latter has fixed locations, while the former does not have fixed locations and can occur anywhere along the freeway. Therefore, matching collisions and the exact state of traffic cannot be obtained with detector data. Additionally, collisions are sporadic events spreading over the freeway sections, and cannot be easily captured by fixed surveillance systems. Therefore, we developed a new way to match collision and traffic data based on a freeway section that is defined by two detectors and contains collisions.

3.1 Section Based Traffic Phase

The identification of the traffic state in a freeway section is typically based on a single measurement located at the middle of the section; for example, we assume detector occupancy values from a detector located in the middle of a section is used to classify the section's state as free-flowing or congested. However, this approach cannot accurately describe the section's traffic state; it assumes that traffic conditions inside the section are homogeneous, which is not the case in transition or congestion. Therefore, we use measurements from both input and output boundaries to describe the traffic state of a section, as shown in Figure 2(a).

Assume that traffic phases are measured on both ends of a freeway section. Figure 2(a) shows a road section with input and output boundary variables. The traffic variables speed (v), flow (q), and density (k) (or occupancy (o)), vary along the section. In homogeneous traffic situations such as free flow and severe congestion, these variables on both ends do not have significant difference. But, in transition periods from free flow to congestion or from congestion to free flow, these variables show significant difference.

In the traditional fundamental diagram approach, two traffic phases are defined on flow-density plane: free flow and congestion (Figure 2(b)). Using these two traffic phases, we can combine them, and define traffic phases for a road section. Traffic phases for a road section can be classified into 4 phases, as shown in Figure 3: Free flow (FF), Congested Traffic (CT), Bottleneck Front (BN) and Back of Queue (BQ).

In FF, both upstream and downstream traffic phases are in free flow, and congestion (CT) does not exist inside the section. But, still we have to neglect a congestion that is totally inside the section, and does not affect boundary traffic phases. In BN phase, the section includes an active bottleneck; traffic is free flowing downstream and congested upstream. Because the location of active bottleneck usually stays in a same location, once it is formed, the BN phase will sustain for long times until the traffic demand diminishes. In the BQ phase, a road section contains a back-of-queue, i.e. upstream location is free flow phase while downstream location is congested. The location of BQ can move upstream as the wave

[1] Five minutes is approximate duration which one wave traverses the maximum detector spacing in the study route.

propagates, and we can expect that BQ phase may live shortly passing a section until it can find equilibrium demand to sustain the BQ location. Finally, CT phase means that both upstream and downstream locations are congested. Because of the existence of stop-and-go traffic in congestion, oscillations inside CT may be observed (Yeo & Skabardonis, 2009)

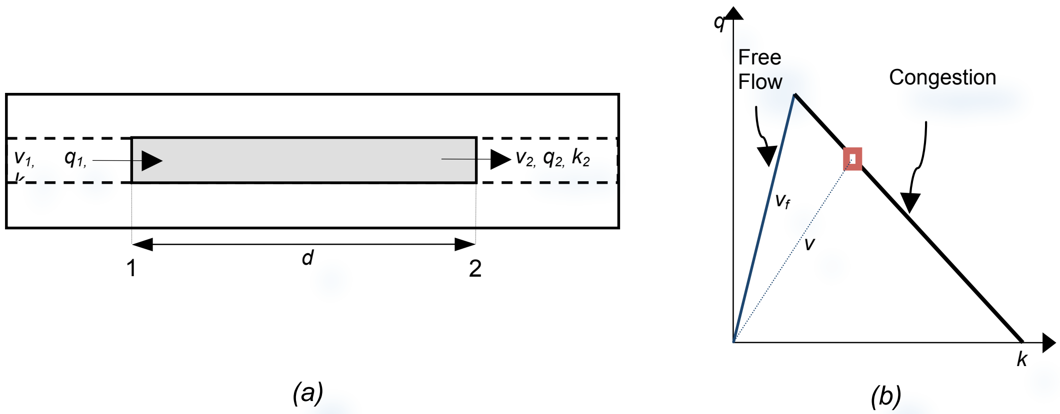


Figure 2. Definition of a road section: (a) a road section (b) traffic phases on flow-density plane

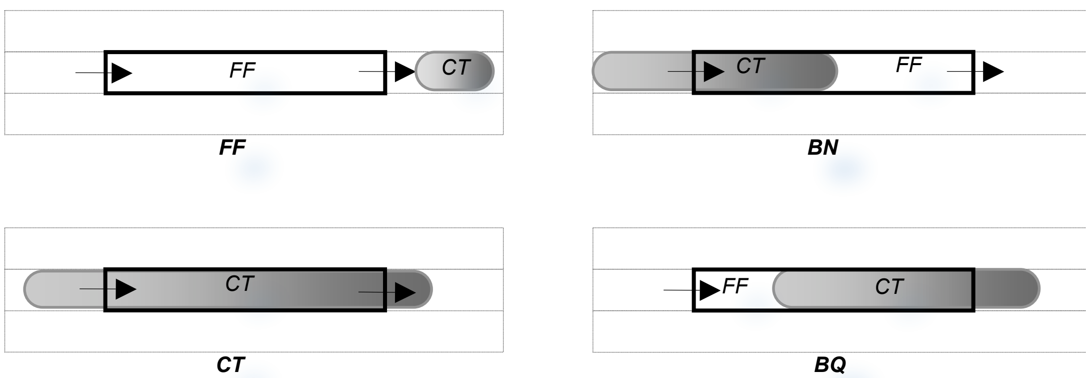
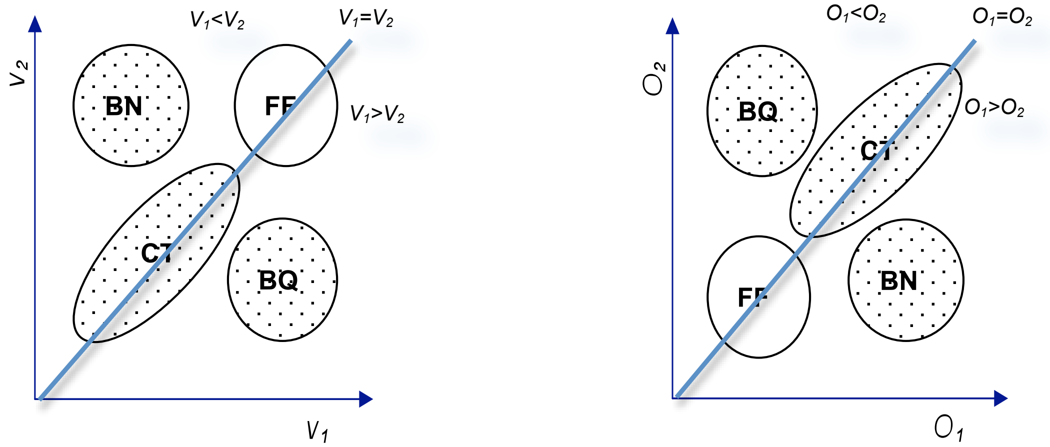


Figure 3. Illustration of traffic phases for a freeway section

3.2 Section Based Traffic Phase Diagram

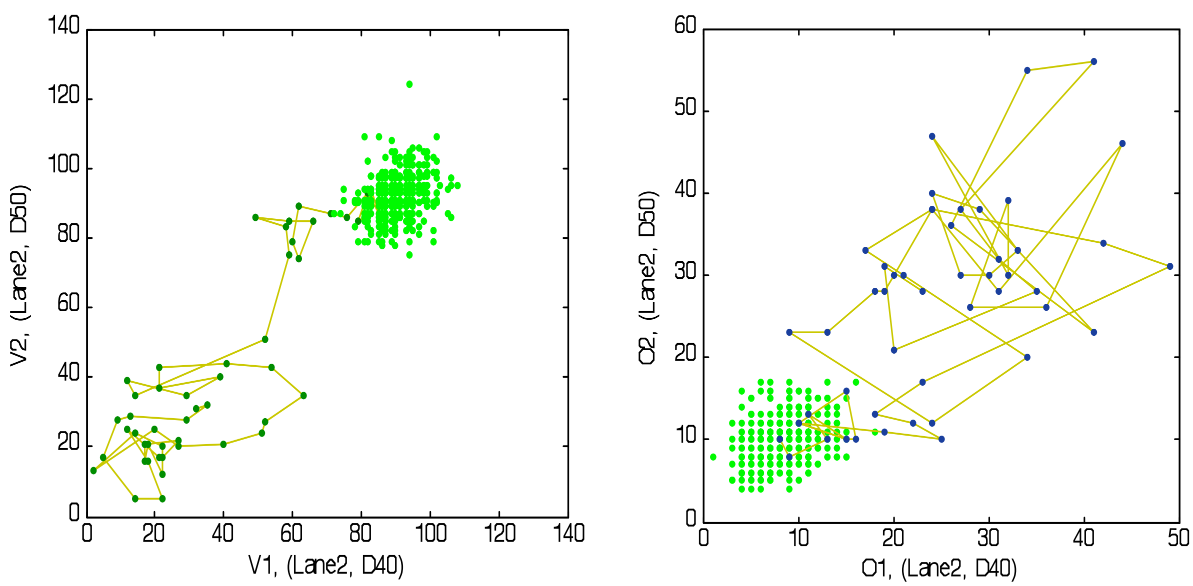
To determine the traffic phase for a freeway section we need two traffic variables upstream and downstream. Here, we have chosen speed and occupancy for constructing section traffic phase diagrams, as shown in Figure 4. In Speed diagram (VV) in Figure 4(a), FF occupies top right corner which speed is greater than free flow speed, CT phase spreads in the bottom left along the equal speed line (V_1=V_2). BN occupies a region where, $V_1 < V_2$, and BQ exists right bottom where $V_1 > V_2$.



(a) VV diagram (b) OO diagram

Figure 4. Section traffic phase diagrams

Figure 5 shows example section phase speed and occupancy diagrams for a freeway section obtained from detector data. The traffic phase starts from FF on the top right corner, and then moves to CT via BN regions. The short time span of BN can be explained by additional lane changes causing breakdown at downstream locations and propagating upstream to the current section. Note that the occupancy diagram's pattern cannot clearly show the difference of BN and CT, instead it shows more detailed evolution inside CT. Therefore, in this research, we used speed diagrams for classifying traffic phases.



(a) Speed diagram (b) Occupancy Diagram

Figure 5. Sample freeway section traffic phase diagrams

3.3 Collision Rates

Let 1 year speed data from detector station m to be $v(j,m)$, $j \in \{1..365\}$, and upstream and downstream matching speeds for collision number i to be $s_u(i)$ and $s_d(i)$ respectively. $s_u(i)$ and $s_d(i)$ are the speeds at the time of collision i. For a given traffic phase, which is defined by speed vectors (v_1, v_2) and grid size dv, the collision rate P_c per million vehicle miles traveled (MVMT) can be obtained as follows:

$$\mathrm{P_C}(v_1,v_2) = \frac{\sum_{i=1}^{\#\text{ collisions}} \mathrm{I}_{\mathrm{i}}^{C}(v_1,v_2)}{\sum_{j=1}^{365\times 288} \sum_{m=1}^{\mathrm{D-1}} \mathrm{I}_{\mathrm{j,m}}^{T}(v_1,v_2)\left(\frac{q_j^m + q_j^{m+1}}{2}\right) d_{m,m+1}} \times 1{,}000{,}000 \quad (\#\text{Collisions/MVMT}) \tag{1}$$

where,

$$\mathrm{I}_{\mathrm{i}}^{\mathrm{C}}(v_1,v_2) = \begin{cases} 1 & if\,(v_1 \le s_u(i) < v_1 + dv, v_2 \le s_d(i) < v_2 + dv) \\ 0 & otherwise \end{cases},$$

$$\mathrm{I}_{\mathrm{i,m}}^{\mathrm{T}}(v_1,v_2) = \begin{cases} 1 & if\,(v_1 \le v(i,m) < v_1 + dv, v_2 \le v(i,m+1) < v_2 + dv) \\ 0 & otherwise \end{cases},$$

$d_{m,m+1}$: the distance between detector m and $m+1$,
D: the number of detectors,
q^m_j: flow at detector m, for the record j.

The numerator in Equation (1) is the total number of collisions inside a grid cell as shown in Fig. 6, and the denominator gives the total vehicle miles traveled calculated from the detector data. Using Equation (1), we can obtain collision rate for each cell. Collision rates for 4 traffic phases, i.e. FF, BN BQ, and CT, can be derived by aggregating each cell's rate for each traffic phase, respectively.

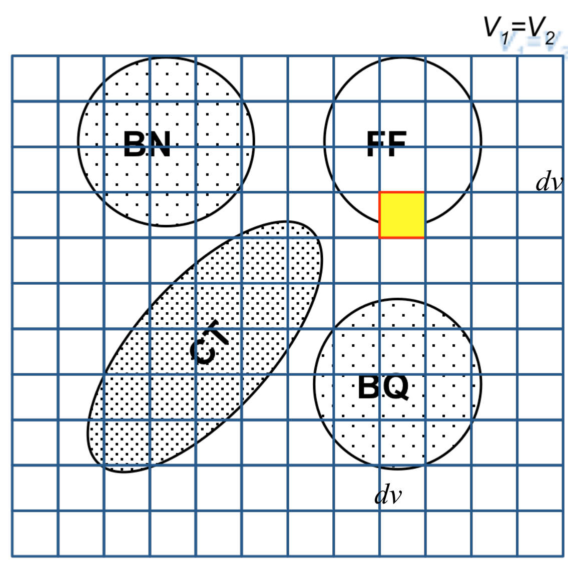


Figure 6. Grid cell for collision rate

4. RESULTS

Table 1 shows the calculated vehicle miles of travel (VMT) for each traffic phase. From 2005 to 2007, the VMT for FF and CT phases increases while decreases for BN and BQ. Figure 7 shows the collision rate for each traffic phase. In FF phase, the number of collisions per MVMT is less than 1, but the other traffic phases have higher collision rates ranging 4 to 5 collisions per MVMT. The average number of collisions per MVMT is in the range of 1.06 to 1.24. The average collision rate is decreasing, but collisions in the BN, BQ and CT states all increased in 2007. However, because the FF VMT is about 90% of the total VMT, the decrease in collision rate in FF outweighs the increase in collisions in the other traffic states.

Table 1. Vehicle Miles Traveled

Year	FF	BN	BQ	CT	Total
2005	908,099,733	30,639,251	31347858	55,411,656	1,025,498,497
2006	949,416,674	26,601,555	32970456	70,004,861	1,078,993,547
2007	1,059,437,887	23,136,559	29134062	76,923,361	1,188,631,869

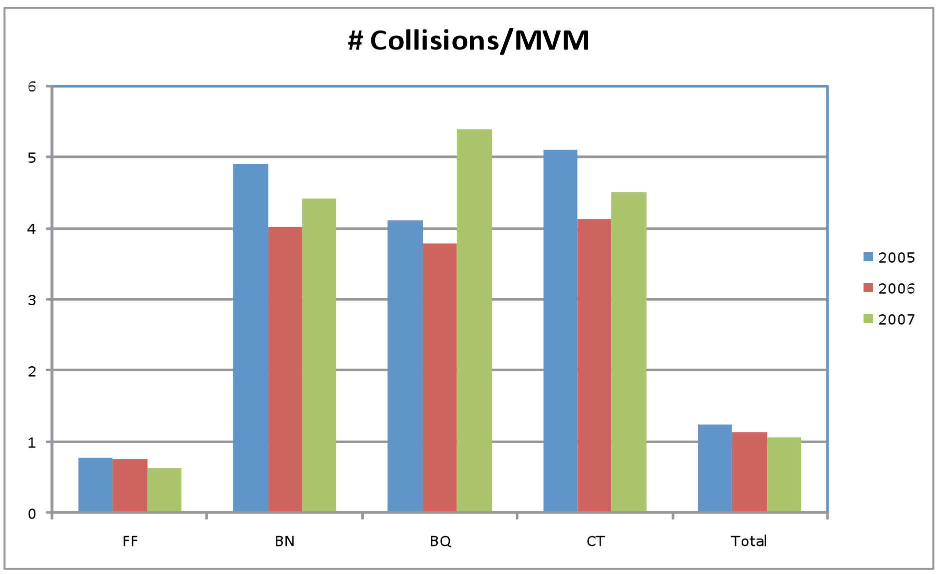
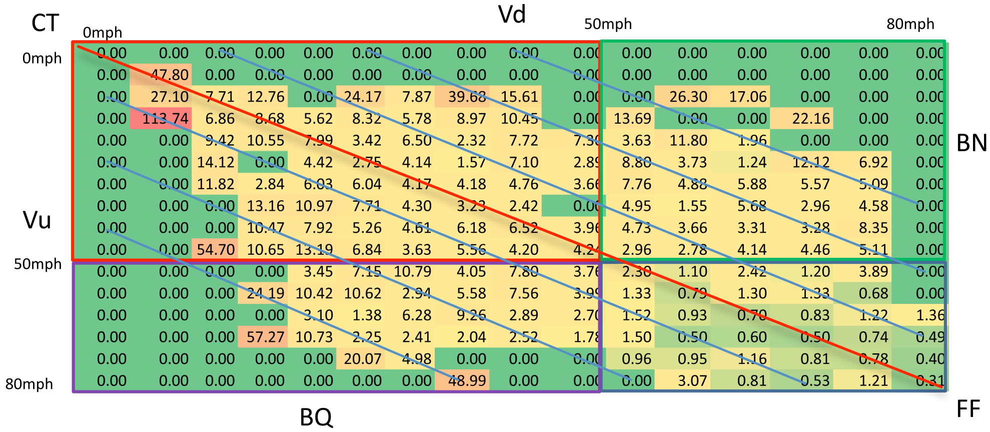
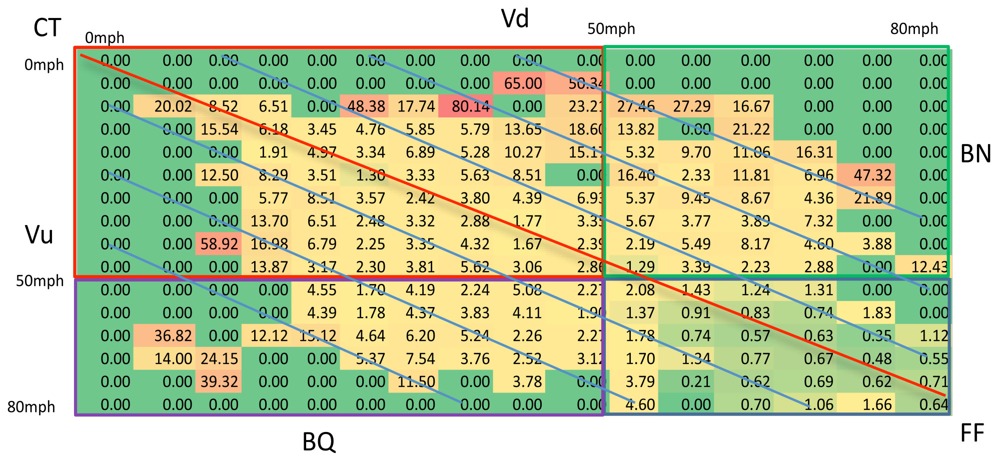


Figure 7. Collision rates of traffic states on I-880 freeway

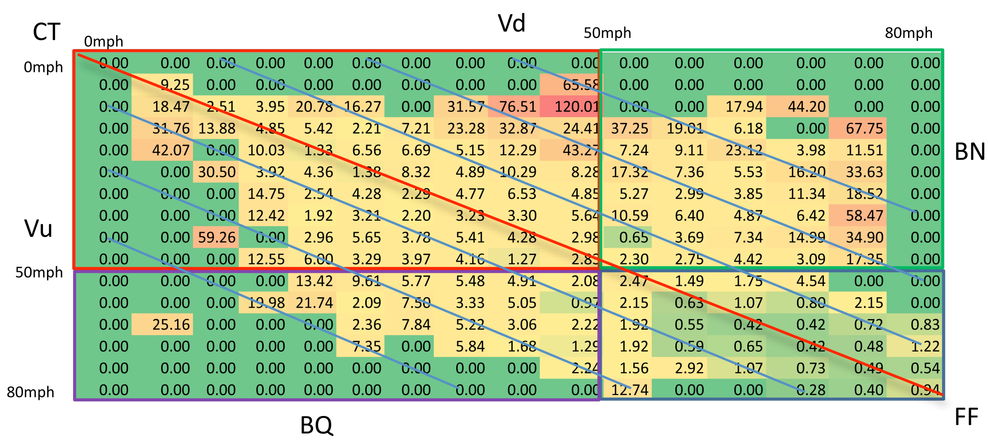
Figure 8 shows the obtained collision rate maps. The horizontal axis shows downstream speed from 0 mph to 80 mph, and the vertical axis shows the upstream speed. The size of the grid cell is 5 mph. The entire space is divided into 4 traffic phases. A cell is classified as FF if both upstream and downstream speeds are greater than 50 mph, and as CT if both speeds are less than 50 mph. If the downstream speed is greater than 50 mph while upstream speed is less than 50 mph, the cell is assigned to BN, and BQ in the opposite case. Speed threshold value of 50 mph is chosen arbitrarily as an example to show the method, and can be re-defined according to situation. Figures show oval-shape distribution of collisions. The diagonal line from top left to bottom right represents that both speeds are same and the section is homogeneous in terms of traffic. Because the time periods of BN and BQ are relatively short and, traffic states are concentrated along this line.



(a) Year 2005



(b) Year 2006



(c) Year 2007

Figure 8. Collision rate maps

From the collision rate maps we can find some collision patterns: In FF, the number of collisions per MVMT is lowest among all traffic phases and it increases as the level of congestion increases, in other words, as the speed drops. One thing noticeable is that as the speed difference between upstream speed and downstream speed increases, the rate also increases. The diagonal lines in the figures show speed differences levels, i.e. the top upper diagonal line shows speed difference level (v_d-v_u) of 40 mph, and the next lines represent 25 mph, 10 mph, 0 mph, -10mph, -25mph, and -40 mph speed differences. When the absolute value of the speed difference level increases the collision probabilities increases. In BQ traffic, the increase of collisions with speed difference is very natural. The collision increases in BN can be caused by the lane changing vehicles because the locations of active bottleneck usually coincide with merging or weaving locations with a high frequency of lane changes. Also, lane changes in merging location generate stop-and-go traffic waves that cannot be observed on the collision rate maps and can cause back-end collisions influenced by speed difference.

Figure 9, drawn from Figure 8, shows the relationship between the collision rates and speed difference. The horizontal axis shows absolute value of the speed difference and the vertical one for number of collisions per MVMT. As expected intuitively, the number of collisions has strong positive relationship with speed difference. Although a linear fitting line is drawn, the relationship it is not necessarily linear, and it seems that a second order function may fit better Because the collision rate is affected by the difference of two vehicles' stopping distances having second order function of speed, second order function may fit better than the linear function. . In this research finding detailed relationship with speed difference is left for further study.

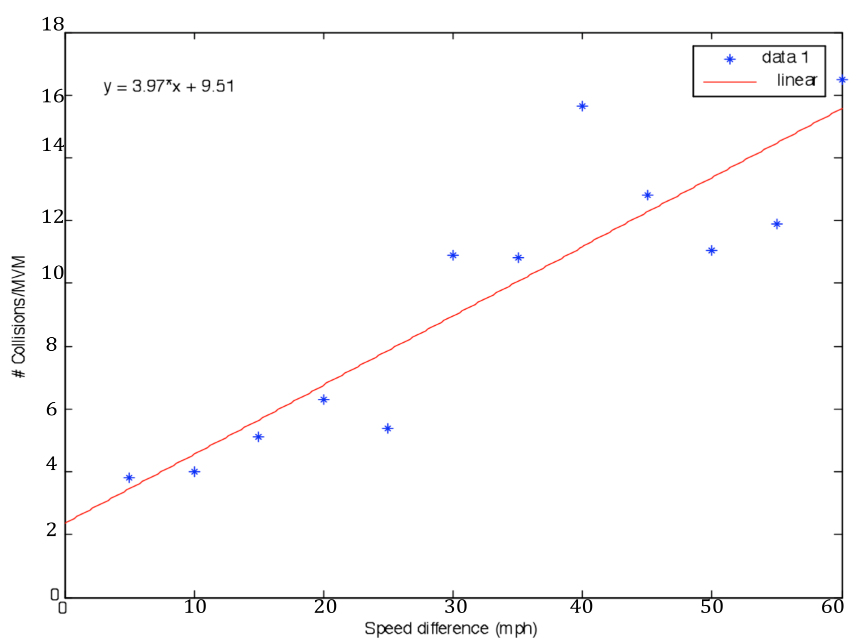


Figure 9. Collisions vs. Speed difference

We can apply this method to predict the number of collisions for given traffic conditions. This method can be applied to situations where there is no previous information on the number of collisions and we can determine the traffic phases through other means (e.g., corridor simulation models). For example, we assume that we know the collision rates of the previous year, and the traffic phases of current year are obtained by traffic simulation. We can predict the number of collisions for year 2006 and 2007 (Table 2).

The error in predicting total collisions is 8% for 2006, and 4% for 2007. This simple illustration shows the application potential of the proposed method.

Table 2. Prediction test based on historic information

2006

Traffic Phase	FF	BN	BQ	CT	Total
VMT	949,416,673.8	26,601,555.44	32,970,456.44	70,004,861.35	1,078,993,547
2005 Collision Frequency	7.83E-07	4.90E-06	4.12E-06	5.11E-06	
Expected Collisions	743	130	136	358	1367
Actual Collisions	659	102	157	347	1265
Error in %	12.80	27.68	-13.58	3.03	8.05

2007

Traffic Phase	FF	BN	BQ	CT	Total
VMT	1,059,437,887	23,136,559.24	29,134,061.76	76,923,360.82	1,188,631,869
2006 Collision Frequency	7.51E-07	4.02E-06	3.79E-06	4.13E-06	
Expected Collisions	796	93	110	318	1317
Actual Collisions	660	106	162	352	1266
Error in %	20.62	-12.54	-31.98	-9.66	4.00

5. CONCLUSIONS

In this paper we suggested a methodology to understand the relationship between collisions and traffic states on freeway traffic. We developed a new method for classification of traffic phases for freeway sections based on measurements at the section boundaries. The proposed phases defined as free flow (FF), congested traffic (CT), bottleneck front (BN) and back of queue (BQ) capture the entire range of freeway operating conditions. We applied the method on a 32 mile freeway section and found collision rates for each traffic phases. We found that the collision rates in BN, BQ, CT is 4-5 times higher than the one in FF.

As a future research, the developed method can be applied to reveal details of collisions including collision type, road geometry, and fatalities for each traffic state. The proposed method can be used to predict the collision frequency based on measured or simulated traffic operating conditions. Simulation models can provide as output the traffic phases on the section under study and the method can be applied to determine the collision frequency. Ongoing work includes methods for determining high collision concentration locations for a wide range of traffic and geometric characteristics.

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