# Driver Heterogeneity in Rubbernecking Behavior at an Incident Site

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## ABSTRACT

Without any presence of physical bottlenecks, incidents on freeways can affect the traffic conditions on the opposite side of the roadway, results from change in driving behavior due to rubbernecking. To this date, only homogeneous rubbernecking behavior has been analyzed, however the change of driver behavior due to rubbernecking may vary between the types of vehicles, the incident types and also between lanes (median or shoulder lanes). This paper provides insights into inter-driver heterogeneity in driving behavior while passing an incident site. We use empirical trajectory data obtained from a helicopter-mounted video camera. The length of study section is approximately 200 meters, starting at 125 meters upstream of the incident site. The analysis on speeds profiles over distance of individual vehicle passing in the opposite direction of the freeway incident was used to describe behavioral changes by assessing the points where acceleration changes.

The finding shows that the variations in speed in the upstream of incident location are substantially higher within passenger car drivers then within the truck drivers. The passenger cars in the median lane reduce the speed at 50 – 100 m before incident scene, mostly with sharp deceleration while passenger cars in the shoulder lane reduce the speed closer to the incident scene. Some drivers did not exhibit rubbernecking behavior, passing the incident with a steady speed. The variations in speed can be further described three reaction patterns: a) deceleration and acceleration, b) acceleration, and c) no speed change. Rubbernecking behavior in the opposite direction of incident is influenced by vehicle types, incident visibility, and occupying lane. The results provide a better understanding of underlying activity in rubbernecking and can be used to quantifying the rubbernecking effects, and hence are useful for incident management purposes.

Keywords: Traffic Incident, Driver Behavior, and Rubbernecking

## 1. INTRODUCTION

Incidents such as vehicle crashes, breakdown vehicles, spilled loads can cause a temporary bottlenecks due to lane blockages thus reduce the roadway capacity. Interestingly, traffic incidents also can create bottlenecks with no physical obstruction on the non-incident direction, resulting from changes in driving behavior due to rubbernecking. Rubbernecking is the term use to describe tendency of vehicles to reduce the speed to view the scene of an incident. In this study, it is assumed that if there is an acceleration changes while approaching the incident scene, then the drivers exhibit a rubbernecking behavior, due to driver attention shift to the incident.

Previous studies have addressed the presence of rubbernecking behavior at the incident location where the drivers slow down their vehicles to take a look or glance over the incidents scene. Knoop et al. (1, 2) has shown that rubbernecking may reduce the capacity by about 50 percent. According to that study, the behavioral changes of drivers during incident conditions lead to a reduction of queue discharge rates. The queue discharge rate per lane for both directions, the incident direction and the opposite direction is 60-75% of the normal queue discharge rate (3). It has been reported (4) that about 10 percent of accidents caused rubbernecking in the opposite direction. Moreover, rubbernecking can be the cause of secondary crashes as drivers slow down to view what has happened and become distracted (5).

Microscopic traffic data describing the driver behavior is essential in understanding traffic flow phenomena at incident locations and as a basis for microscopic simulation models of the driving behavior at an incident. To this date, only homogeneous or average rubbernecking behavior has been analyzed but in depth the heterogeneity in rubbernecking behavior has never been look into. The change of driver behavior due to rubbernecking may vary between the types of vehicles, the incident types and also between lanes (median or shoulder lanes). Rubbernecking behavior can be assessed by traffic parameters such as changes in speed, or reduction in flow due to a larger headway. In this study vehicle speed is chosen to be the descriptive variable in examining the heterogeneity, by assessing the variation in speed throughout the incident location. The main goal of this paper is to improve understanding on the heterogeneity in rubbernecking behavior. To achieve the goal, we seek to answer the following question: Is there a variation on driver behavior between vehicle groups and within vehicle groups when passing an incident? We do so by identifying differences in speed changes between passenger cars and trucks while passing an incident site, and classifying the speed profiles into groups based on its pattern. The findings of this paper will be useful in considering the heterogeneity in modeling microscopic driver behavior under incident conditions. It will partly answer the impacts on incidents on individual driver and can be used to evaluate the effectiveness of measures to minimize the rubbernecking behavior such as installing barriers or screens, removing the crashed vehicles away from the view of drivers in the opposite direction or by incorporating Advanced Driver Assistance System (ADAS).

The remainder of this paper is organized as follows. Section 2 provides a brief review on previous research on the heterogeneity in driving behavior under normal conditions and along incident scene, followed by Section 3, which provides the theoretical framework for the study. Then, the description and collection of data using an airborne platform is summarized in Section 4. Section 5 presents the data analysis methods in detail and Section 6 presents the graphical and descriptive results of speed profile. Next, the findings and outcome are discussed in Section 7. Finally, the conclusions and future work are presented in Section 8.

## 2. LITERATURE REVIEW

### 2.1 Definition and Importance of Heterogeneity

There have been various studies on heterogeneity in traffic, which can be interpreted in different ways. Daganzo (6) proposed a behavioral theory on two types of drivers, fast (aggressive driver) and slow (timid driver) and two sets of lane: passing lanes and shoulder lanes. Kerner and Klenov (7) developed a microscopic model for heterogeneous traffic flow with different driver behavioral characteristics and vehicle parameters. The model considers three types of vehicles in modeling microscopic traffic for heterogeneous flow. The types of vehicles are based on the length and also the speed, where fast vehicles have the same length with slow vehicles and long vehicles have longer length than fast and slow vehicles. The maximum speed of fast vehicles is higher than slow and long vehicles. In free flow conditions, both studies assumed that fast vehicles choose to drive in the passing lane (median lane) and slow vehicles stay in the shoulder lanes. Thus, the mean speed in the median lane is higher than in the shoulder lane whereas in congested conditions speed of both lanes is equal. However, Banks and Amin (8) found that in congested flow, there are speed differences among the lanes. The result shows major speed oscillations in the passing lanes but very little oscillation in the shoulder lanes.

Ossen and Hoogendoorn (9) examined the extent of heterogeneity in car-following behavior within passenger car drivers and between passenger car drivers and truck drivers. Heterogeneity in the study defined as differences between the car-following behaviors under same road, traffic and weather conditions. The data of trajectory was collected by helicopter during the afternoon peak hour where almost all drivers are in the car-following behavior. The study shows large differences between the car-following behaviors of passenger car drivers, and truck drivers in general drive with a more constant speed, with less variation in time. Kim and Mahmassani (10) extend this idea and study the correlation between parameters in the car-following model and its implication on microscopic traffic simulation results, in effort to generate heterogeneity in car-following behavior in microsimulation models.

In our study, heterogeneity is defined as difference in individual driver behavior over distance when passing an incident. Following (7), we define the three groups of vehicles: a fast vehicle is a passenger car in the median lane, slow vehicles are passenger cars in the right lane and long vehicles are trucks. If in free flow conditions, the mean speed is different between lanes, is this situation also happening under incident conditions? The change in behavior with regards to speed is than attributed to rubbernecking, since there is no bottleneck on the non-incident direction.

### 2.2 Rubbernecking Effect in Incident

Not much study has been done on rubbernecking, let alone the heterogeneity in this behavior has been look into. An approach has been made to assess rubbernecking effects in incidents using CORSIM, a microscopic simulation model (11). This simulation models the rubbernecking phenomenon in adjacent lanes; as a result of passing vehicles reduce the speed as they pass an incident. In CORSIM, the parameter use to capture the rubbernecking effects is rubbernecking factor. This rubbernecking factor reproduce the capacity reduction by increases the time headway between two vehicles (11).

Hadi et al. (11) utilized a microscopic simulation model to examine the capacity reduction due to incidents. In CORSIM, rubbernecking factors were used to produce the capacity reduction as recommended by HCM. In AIMSUM, there is no rubbernecking factor hence the speed is used to calibrate the capacity reduction. The same capacity reduction as reported by HCM was obtained by assigning a lower speed in unblocked lanes.

Chen et al. (12) developed a model that describes car-following behavior across traffic oscillations (stop-and-go). Traffic oscillations observed in trajectories data formed spontaneously is not triggered by lane changing but due to rubbernecking, and confirmed by simulation results. Rubbernecking effects in this study is caused by slowing down of vehicles when approaching cleaning work in the median. The higher percentage of rubberneckers contributes to a frequent but smaller period of oscillation. However, the parameter used in the model, both the percentage of rubbernecks and speed reductions are not calibrated.

Hoogendoorn (13) utilized a driving simulator to investigate the effects of freeway incidents on longitudinal driving behavior. The experimental conditions consist of two different versions of incident and one control condition (no incident). The measurement of longitudinal driver behavior was carried out three times: before, during and after the observation of the incident. The results show that on both incident conditions, the average speed during the observation of the incident is lower than before and after the observation of the incident. Furthermore, standard deviation in speed increased significantly during and after the observation of the incidents compared to before the moment of first observation of the incidents.

Knoop et al. (3) investigated the impacts of incidents on the microscopic traffic behavior. The empirical trajectory data was collected using a digital camera mounted under a helicopter. Data from two incidents were recorded: a van rolled over, and an incident involved several trucks and passenger cars. The analysis showed substantially differences in microscopic behavior between normal conditions and conditions at an incident site. There is an evidence of rubbernecking effects in the non-incident direction. While approaching the first incident site, the average speed in the median and shoulder lane of the opposite direction dropped to a minimum of 22 km/hr and 28 km/hr, respectively. On the other hand, after the drivers had a good sight on the incident scene, they started to accelerate and increased to 53 km/hr in the shoulder lane and 68 km/hr in the median lane. The first incident shows a significant reduction in speed upstream of the incident site. The second incident, on the other hand, shows a slightly reduction in speed, but, the minimum average speed is in the downstream of incident site. Furthermore, average speed in the shoulder lane shows no significant reduction. The second incident location is on the lane near the shoulder. In term of incident visibility, the former incident is most visible (in the median). This implies that the incident visibility also plays an important role in behavioral changes.

## 3. CONCEPTUAL FRAMEWORK

Figure 1 illustrates the framework to indicate the factors that contribute to rubbernecking behavior. Note that the behavioral change in this study cannot be observed directly, but only by the change in the vehicle speed. In this study, we will therefore consider the vehicle's speed and from that derive the effects of the incident on the driving behavior. As described in Section 2, several studies have already been performed to assess rubbernecking. However, they did not differentiate between drivers, whereas we know all drivers behave differently.

In this study, we differentiate between three driver groups: (1) truck drivers (which all drive in the shoulder lane), (2) passenger cars in the shoulder lane, and (3) passenger cars in the median lane. We hypothesize that drivers of these three groups have a distinct behavior. Trucks have a high mass, which makes acceleration more difficult. Moreover, truck drivers are professionals, so they are aware of the limitations of their vehicle and can anticipate on other drivers' reactions. The combination of the two leads to the expectation that the speed changes for trucks are less: drivers are less willing to reduce speed and they are able to prevent the induced braking by keeping sufficient distance to their predecessor.

The difference between passenger cars in the shoulder lane and the median lane is more difficult to quantify. European driving rules state that overtaking is only allowed in the median lane. Hence, drivers in the median lane have a higher speed than drivers in the shoulder lane. It is difficult to point what is the cause of this difference: will drivers adapt their behavior on the lane, or do they choose their lane based on their behavior. Whatever the reason, we expect differences between the driving behavior of passenger car drivers in the median and shoulder lane. In particular, we expect the drivers in the median lane to show more variation in speed, because of their more dynamic or aggressive behavior. The drivers in the shoulder lane are possibly also influenced by the limiting speed reduction of trucks in the same lane. For this study, we cannot distinguish what part of the speed variation is due to behavioral changes and which part is due to forced changes (e.g., a leading truck slowing down). In general, the longitudinal driving pattern will be a mixture of both. Moreover, in practice it is only relevant what the actual speed pattern is, rather than to find the different causes, since the combination causes traffic delays. Therefore, we look at changes in speed.

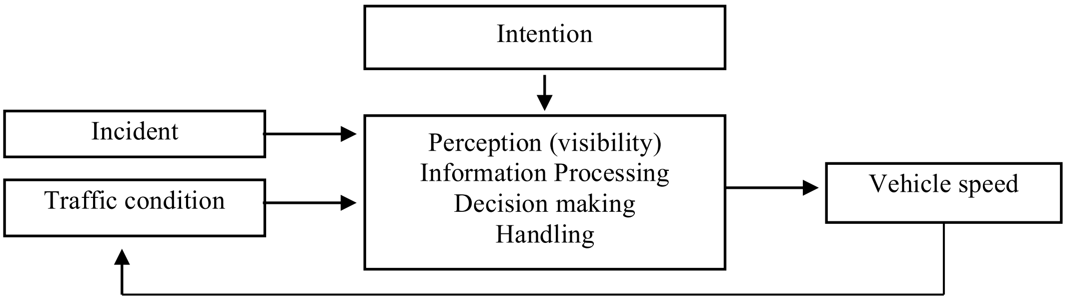


**FIGURE 1 Framework to indicate factors that influence rubbernecking behavior (adaptation from Van der Horst (14)).**

## 4. DATA DESCRIPTION AND COLLECTION

To study the behavior of individual drivers, empirical trajectory data have been collected using an airborne platform developed by Hoogendoorn et al. (15). This method uses a high-resolution digital photo camera mounted under a helicopter. Section 4.1 describes in detail the properties and characteristics of the incidents where the data are collected, while Section 4.2 gives an overview into data collection techniques. The representation of trajectories is in Section 4.3.

### 4.1 Incident Description

The incident site is located on Motorway A1, near the city of Apeldoorn, The Netherlands. The incident type is a rolled over van, ended in the median (unpaved area which separates opposing lanes of the motorway). The incident happened around 9:15 A.M on 6 June 2007, at the eastbound direction. There are two main lanes and one shoulder lane in each direction of the motorway, and no gradient. The speed limit on the motorway is 120 km/h. The weather condition during the incident was clear. Emergency vehicles were presence during the collection of data and blocked one lane in the incident direction.

### 4.2 Data Collection and Description

As mentioned beforehand, the empirical trajectory data on the incident location have been collected using a digital camera mounted under a helicopter, which flew above the incident. The height of the helicopter from the ground is around 400 m, high enough not to cause disturbance to traffic operations. Only vehicle trajectories on the opposite direction of the incident were used for further analysis in this study. Microscopic data was obtained over a length of approximately 230 meters, starting approximately 125 meters upstream of the incident site. A total of 199 vehicle trajectories were observed and collected on both lanes in the opposite direction of the incident, consisting of 123 passenger cars in the median lane, 35 trucks and 41 passenger cars in the shoulder lane. The median lane refers to the main lane beside median and the shoulder lane refers to the main lane at the shoulder side. The images or trajectories have undergone several processes, starting with stabilization and ending with a smoothing process before proceeding with the analysis. For further explanation, we refer to (16).

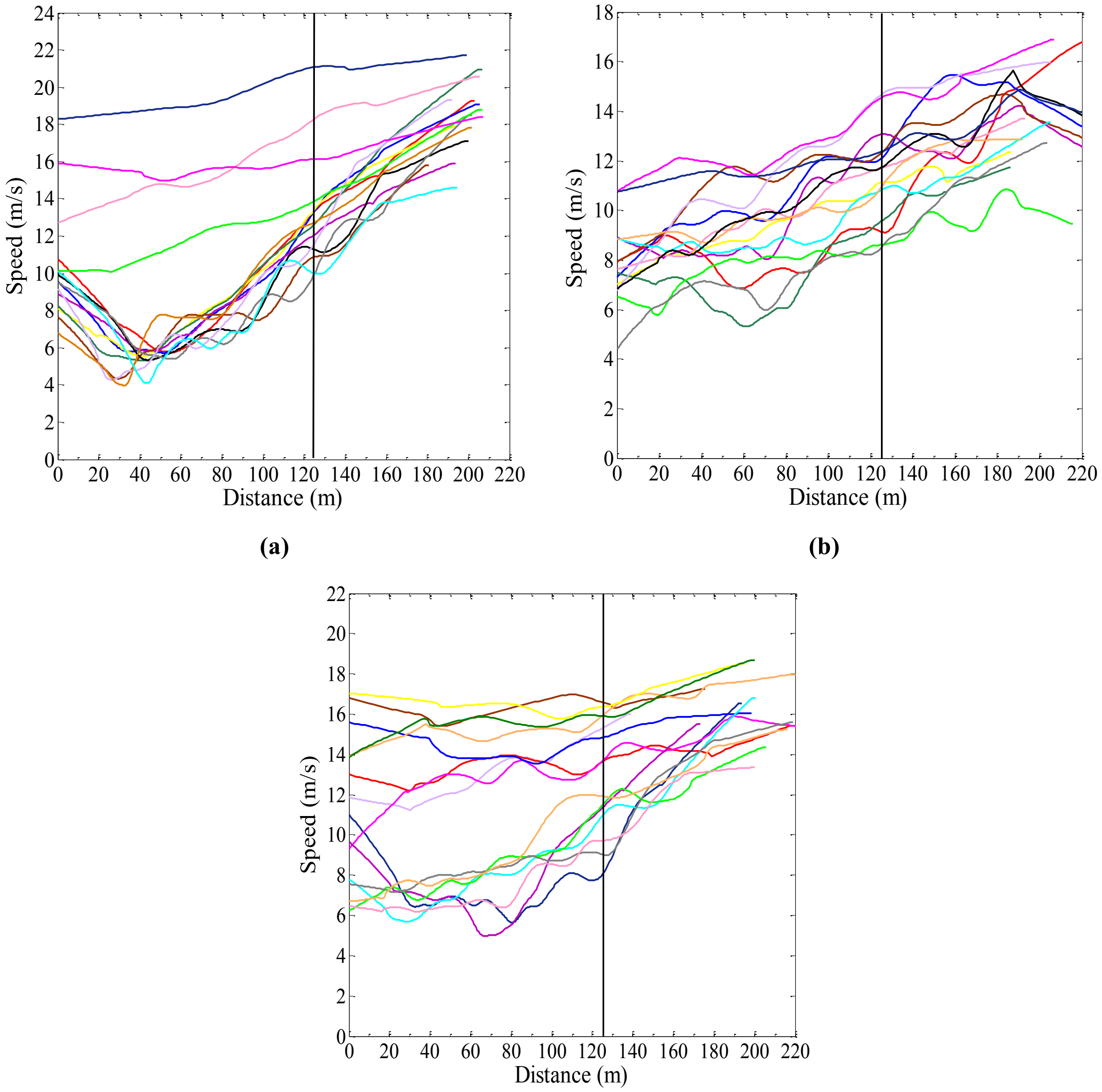
### 4.3 Overview of the collected data

The speed data were separated into three vehicle groups: passenger cars in the median lane, trucks, and passenger cars in the shoulder lane. In order to determine the changes in speed due to rubbernecking behavior, we plot the speed over incremental distances for each individual vehicle. The speed data is calculated with 0.1s intervals. We then analyze the speed versus distance plots of the incident area to determine the intersecting point where the deceleration and acceleration meets, indicating the rubbernecking activity. As mentioned, we group all vehicles speed into three groups: (1) truck drivers (which all drive in the shoulder lane), (2) passenger cars in the shoulder lane and (3) passenger cars in the median lane, as presented in Figure 2. The black vertical line on the graph represents the location of the incident. Note that Figures 2 (a-c) only serve as a sample, showing the speeds of 15 out of the total number of vehicles in each group as an overview of individual trajectories.

Figure 2(a) shows the speed profiles of passenger cars in the median lane. Upstream of incident location, most of the passenger car drivers in the fast driving lane decelerate sharply when approaching the incident, followed by acceleration. The point where acceleration changes is 50 - 100 meters upstream of the incident site. However, some drivers show a different speed pattern, as can be seen from a constant speed and inclining speed patterns. The diagram clearly shows that the rubbernecking behavior is different for different drivers. This behavior might be restricted to car following (where the driver has to reduce the speed when his/her predecessor decelerates and not solely due to rubbernecking; the actual reason is not examined in this study).

The speed profiles over distance of truck drivers and passenger cars in the shoulder lane of motorway can be seen in Figure 2(b) and (c), respectively. From Figure 2(b), we learn that the majority of truck drivers show acceleration within the study area. Since the approaching speed of truck drivers at the beginning of study section is low, it can be assumed that the deceleration of truck drivers occurs farther upstream, more than 125 m from the incident site. However, a few truck drivers show a constant speed and some even decelerate at certain distance, followed by acceleration towards the end of study area.

The majority of speed profiles of the passenger cars in the shoulder lane are constant, as is shown in Figure 2(c). There are also drivers that decelerate slightly up to a certain distance, and then accelerate while passing the incident site. Moreover, it can be seen from the graph that there are vehicles or drivers in unstable condition where their speeds are fluctuating throughout the study area.



**(a)** **(b)**

**(c)**

**FIGURE 2 The speed profiles: (a) passenger car drivers in the median lane, (b) truck drivers, and (c) passenger car drivers in the shoulder lane.**

## 5. DATA ANALYSIS

To examine the heterogeneity or variation in driving behavior passing an incident location, we use the vehicle speeds data as the significant effect variable in this study. Significant decrease in speeds may result from rubbernecking behavior, whereas no or a minimal change in speed may indicate no rubbernecking behavior. Two types of analyses were set up. First, it is studied for all distances along the road whether there was a difference in speed between the vehicle categories (more detailed description in section 5.1). Second, the speed profiles as function of distance were classified, and it was analyzed whether there was a difference in the distribution of vehicles over the categories for the different vehicle classes (a more detailed description follows in section 5.2).

### 5.1 Analysis on Difference in Speed at a Location

We analyzed the speed data for different parts along the road. The main reasons are a) to measure the variation in vehicle speeds and, b) to determine the statistical difference in speed between each vehicle class and within vehicle class. We split the roadway in segments of 10 meters. In each segment, there are speeds for vehicles in all classes. Using a t-test, we test whether differences in mean speed between the vehicle classes are significant. In the remainder of the paper, the distance along the roadway, the independent variable in this study, is denote by x.

### 5.2 Speed Pattern Classification

The dominant patterns of speed profiles for passenger cars and trucks were defined, and set as three distinct patterns. To reduce the noise in speed data without compromising it, we use a piecewise linear function to get the best fit in the speed profiles plot. A piecewise linear function consist of a linear lines or segments fitted on set of data points ($x_i$,$y_i$). The purpose of this approach is to enable driver behavior pattern recognition and classification. The lines are found by fitting a piecewise continuous function to find the best linear approximation of the speed data with minimum sum of squares of error. The speed is the dependent variable and distance is an independent variable. Obviously, increasing the number of line segments in the piecewise fit will decrease the error. The final error is the sum of the error for the fit plus a penalty for each intermittent point. We choose to have 0 or 1 intermittent point where the slope of the line changes. We tested various values for the penalty (in the order of 1 m/s) and the results did not change.

Using this fit, we classify the trajectories in categories. We first look at the absolute difference between the highest fitted speed and the lowest fitted speed. If this difference does not exceed 5 m/s, we consider the vehicles to be driving at a more or less constant speed, which is category c. Separation between the other two categories is based on the fact whether there is a decelerating and accelerating part (and hence an intermittent point – category a) or not (single piece function, category b). Summarizing, we have the following categories:

*Category a* represents vehicles that decelerate when approaching the study area, and accelerate after certain distance.

*Category b* represents vehicles that only accelerate in the study area.

*Category c* consists of vehicles that have no significant changes in speed. They traveled through the incident site at almost a constant speed. The speed variation was very small, around 5 m/s or less.

## 6. RESULTS

### 6.1 Statistical Analysis on Speed Data

This section presents the statistical analysis on driver behavior passing the incident site with regard to the speed. Figure 3 shows the spread in speed for each vehicle group. We can observe that there are wide variations of speed of passenger car drivers at the beginning of study section, especially the one in the left lane. Measurement of central tendency suggest that most of the passenger cars in the left lane reduce the speed between x = 20 and 30 m, while in the right lane between x = 50 and 70 m. Since this is the point where the average speed drops, it can be assumed that the points are the rubbernecking zone, where most of the drivers reduce their speed. However, there is no speed drop for truck drivers, suggesting that most of the truck drivers continue to accelerate throughout the incident location.

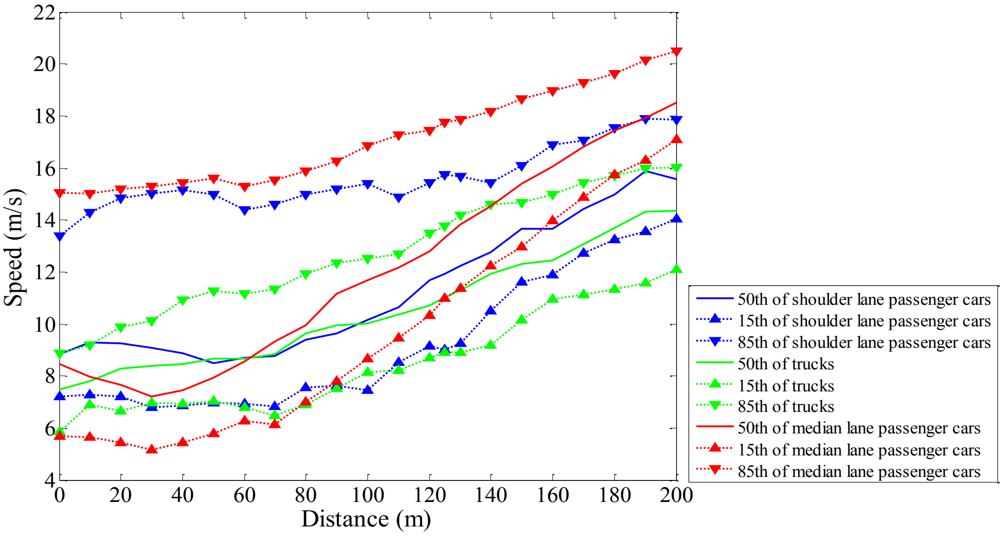


**FIGURE 3 Speed distributions (15th Percentile, Median and 85th Percentile).**

Figure 4 shows the difference of mean speed between each vehicle group and the results of independent T-test. There are three sets of pairs in this test: 1) Trucks in the shoulder lane and passenger cars in the shoulder lane, 2) Trucks in the shoulder lane and passenger cars in the median lane and 3) Passenger cars in the median and passenger cars in the shoulder lane. The plots show large differences in speed between truck drivers and passenger car drivers in the shoulder lane, even though both vehicle groups are in the same lane. The passenger car drivers start with a higher speed than truck drivers, but the wide difference in speed between them is closer towards the incident site, hence there is no statistical difference in speed between the two groups between x = 90 and 120 m. After passing the incident, the difference continues to increase with a slow rate. Let's now consider the difference between trucks and passenger car drivers in the median lane. The approaching mean speed of passenger cars is higher than trucks drivers but the difference decreased until there is no significant difference between x = 30 and 40 m. This is believed to be where the rubbernecking zone lies, i.e. where the drivers drive at the lowest speed to look on the incident. After the rubbernecking zone, the passenger cars continue to speed up and resulting a large difference in mean speed. Between the passenger cars, right lane drivers approaching the incident location with a slightly higher speed than left lane drivers, but there is no significantly difference in speed. At x = 60 to 80 m, the difference in mean speed between this vehicle groups is nil. After this point, the left lane passenger cars accelerate and increase the difference between these two vehicles.

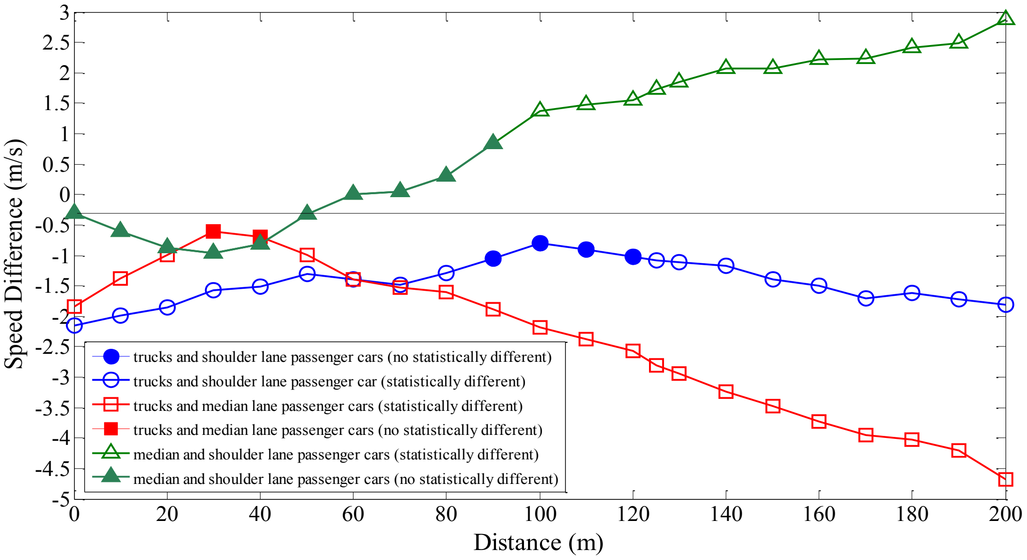


**FIGURE 4 Mean speed difference and independent t-test.**

## 6.2 Speed Profile Patterns Classification

The speed profiles of individual vehicle were classified based on its pattern as explained in section 5.2. Figure 5 shows the distribution of vehicles in each category. Figure 6 shows examples of speed profile patterns. A blue line represent the individual speed profile and a piecewise linear fit to it is represented by the red line.

As shown in Figure 6(a), a driver in *category a* reduces the speed when approaching the incident site. After passing a certain point or rubbernecking zone, approximately between 20 and 100 m, the driver increases the speed and starts accelerating towards the end of the study area. Pattern *a* most likely represent the rubbernecking behavior at the incident location. We can see from the percentage in the Figure 5 that nearly half of the passenger cars in the median lane exhibit this behavior, whereas in the shoulder lane, not more than 1/3 of the vehicles reduce their speed to view the incident. Even though most of the vehicles show this pattern, regardless of the group, the deceleration of passenger cars in the median lane is steeper than the rest of the groups. The percentage of median lane passenger cars that reduce their speed above 3 m/s from starting point to minimum point is 20.3% (half of the total percentage in *category a*). Meanwhile only one truck (2.9%) and four (9.8%) right lane passenger cars fits the profile.

The highest percentage of each group is in *category b*. Almost half of the vehicles from each group passing the incident location without reducing their speed, as can be seen in Figure 6(b). The drivers in this category approaching the incident with a low speed, continue to accelerate to the downstream of incident. For the vehicles in the shoulder lane, this behavior is the most distinct pattern compared to others. The most interesting insight is that there are some vehicles that were not affected by the presence of incident. The drivers in *category c* choose not to rubberneck and keep on maintaining their speed with small variation when passing the incident location (Figure 6(c)). Based on total numbers, out of 199 vehicles in this study, 27 vehicles or 13.6 percent fits in this category.

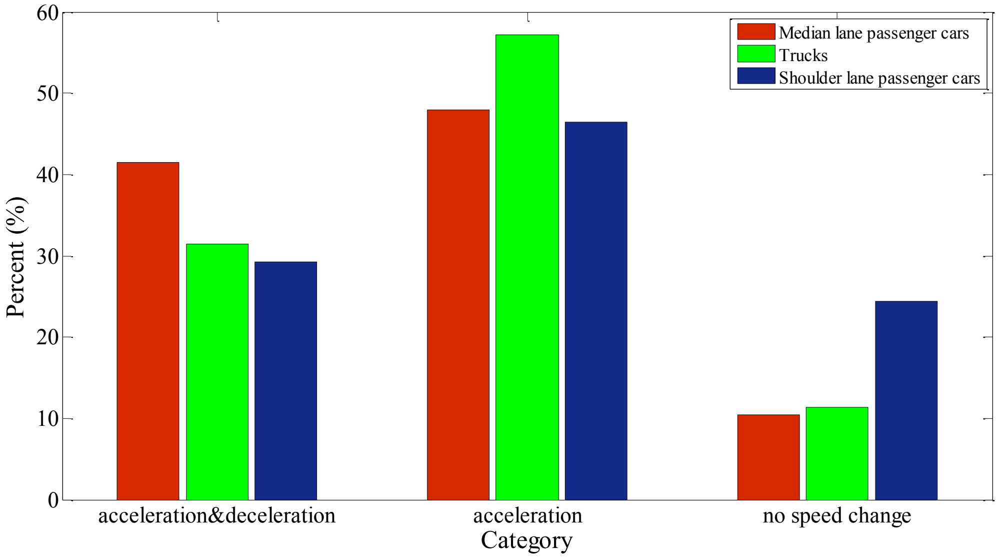
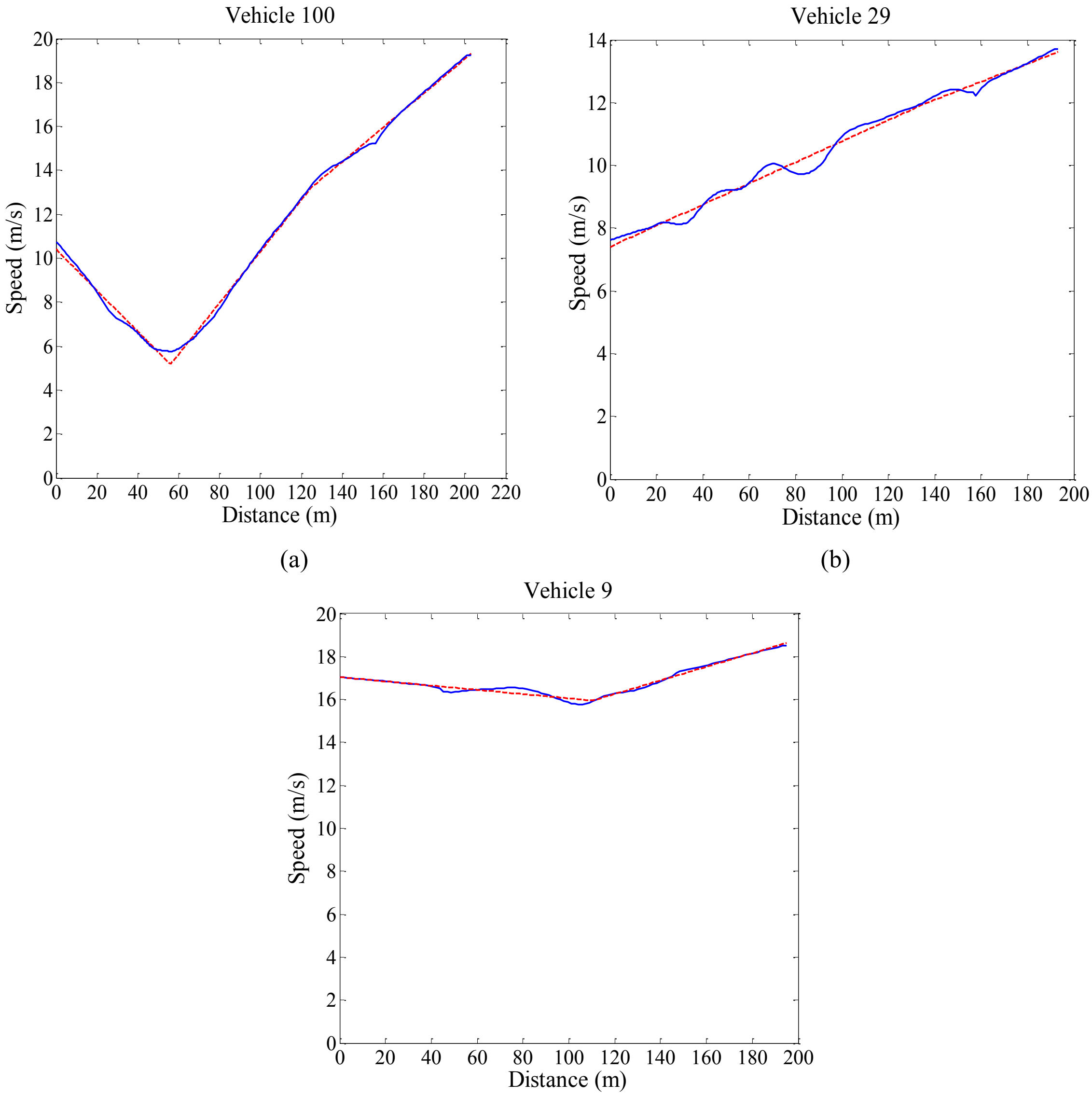


FIGURE 5 The distribution of vehicles in each category.



(a)

(b)

(c)

FIGURE 6 Speed profile patterns: (a) *Category a*, (b) *Category b*, (c) *Category c.*

## 7. DISCUSSION

This study provides the insight into heterogeneity of vehicle speed in rubbernecking behavior. The analysis shows that there is a high variation in speed profiles between individual vehicles. Similar speed patterns appear in the plots, mostly within the same vehicle groups. The variation in speed is higher upstream of incident site and lower downstream of the incident site. There is no absolute point on where the acceleration of vehicles increase or decrease, but it was found that the lowest speed of median lane vehicles is further upstream than shoulder lane passenger cars, within $x = 25$ to 70 m. On the other hand, the shoulder lane passenger cars reduce the speed when closer to the incident scene. This can be described by the location of the incident itself. Since the passenger cars in the left lane is close to median (where the incident happened), the drivers are aware of the incident earlier than drivers in the right lane. That might be the reason why the drivers in the right lane reduce their speed when they are closer to the incident scene. In contrast, truck drivers have a higher point of view, thus the drivers can see the incident farther ahead. The truck drivers tend to reduce their speed earlier and accelerate while passing the incident, thus the rubbernecking zone of trucks is nowhere to be found in the study section.

There is significance difference in mean speed between vehicles in median and shoulder lanes. However, at certain points, the results show no statistical difference in mean speed between these vehicle groups, and the points varies between pairs. This implies that the point where there is no significant difference between truck drivers and passenger cars driver is where the passenger car drivers slow down the vehicles. There are three definite patterns of speed profile of vehicles while passing an incident site that can be established in order to study the behavior of drivers. By fitting a piecewise linear function on the speed profiles to reduce the noise and find the best fit, a better view and understanding of the behavior of drivers can be attained. Passenger cars in the median lane are significantly affected by the incident, and demonstrate a sharp deceleration when approaching the incident scene. On the other hand passenger cars in the shoulder lane approach the incident with a higher speed than those in the left lane. Some drivers, however, were not affected by the existence of incident and maintain a steady speed, suggesting that not all vehicles choose to rubbernecks while passing an incident site.

The findings show that the speed of individual vehicle varies between vehicle class, occupying lane and distance to the incident. Vehicles react differently while passing an incident location. Different incident characteristics such as incident severity, number of vehicles involved might produce a different result. This study gives an insight into underlying processes that leads to a speed reduction and variation in non-incident direction.

## 8. CONCLUSION AND FUTURE WORK

This study analyzed the rubbernecking behavior in the opposite direction of the freeway accident. The study suggests that there is high variation in driver behavior during incident conditions. Passenger cars in the median lane show a much higher variation in speed. In fact, they go from higher speeds to lower speeds and accelerate to higher speeds. This can be due to the driver type in the median lane or due to a view on the accident site. Truck drivers, all in the shoulder lane, showed a completely different type of behavior. They mainly accelerated through the section, indicating that they had to slow down for the congestion caused by the other drivers, but they anticipated and started accelerating earlier. Drivers of passenger cars in the shoulder lane showed a more dynamic behavior than the truck drivers, but speed variations were less than the trucks.

Based on the findings, rubbernecking behavior in the opposite direction of incident is influenced by vehicle types, incident visibility, and type of driver (based on occupying lane). Therefore, the actual location of the bottleneck can vary for the driver population. The results provide a better understanding of underlying activity in rubbernecking and can be used to establish a framework in quantifying the rubbernecking effects.

In this study, we did not differentiate between speed reductions due to car-following behavior and speed reductions due to rubbernecking. This will get more attention in future work. Moreover, it is proposed to find the correlation between driver sight distance and the point of speed reduction.

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