An In-depth Analysis on Vehicle Following Gaps in Highway Work Zones: The Direct and Interdependent Impact of Leading Vehicle

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ABSTRACT

This paper analyzes the impacts of various vehicle following patterns on the vehicle following distance/gap in highway work zones. It studies the direct impact of leading vehicle on the vehicle following gap in 2-vehicle platoons and interdependent impact of the leading vehicle on the vehicle following gap between the 2nd and 3rd vehicles in a 3-vehicle platoon. The collected dataset is comprised of more than 15000 observations. Four 2-vehicle patterns and eight 3-vehicle patterns are grouped and average gaps from different patterns are compared to study the direct and interdependent impact of leading vehicle on the following distance. The 'unpaired two-sample t-test' was conducted to determine the significant differences at a 5% significant level. Sixteen hypotheses tests were performed to find the direct impact, and 32 hypotheses tests were used to identify the interdependent impact of leading vehicle on vehicle following gap between the 2nd and 3rd vehicles in 3-vehicle platoons. It is found that truck drivers maintain a significantly longer gap than car drivers when led by the same type of vehicle in both short-term and long-term work zones. In either long-term or short-term work zones if middle vehicle is truck in 3-vehicle platoons, then there is no significant impact of the leading vehicle type on the vehicle following gap between the 2nd and 3rd vehicles. The work zone type appears to have no influence over the vehicle following gap between the 2nd and 3rd vehicles, when the 3rd vehicle is truck.

Keywords

Vehicle following, gap, leading vehicle, work zone

1. INTRODUCTION

Highway work zones tend to cause risky conditions for the vehicle drivers and the construction workers. The reduced speed limits, lane closure, workers, construction machinery and barriers used over roadside tend to have negative impacts on drivers' behavior and traffic conditions. With increasing traffic demand and number of work zones, work zone safety continues to be a major priority for traffic engineers and highway agencies. The data from Ohio showed that approximately 30% of work zone crashes were due to driver following so close to the leading vehicle and thus resulting in rear-end collision. One study found a 20 percent decrease in fatal and injury crash proportions and nearly 50% proportional increase in rear-end crashes throughout long-term construction projects *(1)*. Wang, Ieda and Mannering suggested rear-end collisions account for the majority of work zone crashes and the percentage of rear-end collision in work zone crashes is much higher than that in non-work zone crashes *(2)*. It showed that rear-end collisions occurred more frequently in work zones. Rear-end collisions are generally attributed to aggressive and inattentive driving and the lack of response time of the following driver. Wang, Ieda and Mannering *(2)* and Sun and Benekohal *(3)* studied the probability of rear-end collisions in signalized intersection and highway work zone respectively, by analyzing the probability of leading vehicle decelerating, following distance and reaction time available to the following vehicle..

Some research has been conducted on the distribution of time-gap to identify the number of vehicles in car-following state and to determine the percentage of vehicles with unsafe (too close) gaps *(3,4,5,6)*. A study by Park et al. analyzed drivers' characteristics in the perception of a leading vehicle's decelerating level and found that the drivers generally underestimated the leading vehicle's decelerating level in a car-following situation *(7)*. This underestimation of leading vehicle's decelerating might easily lead to rear-end collisions for those vehicles following too close in work zone areas with adverse pavement and roadside conditions. One study investigated the vehicle following gap by developing models but that dealt with the lane changing behavior in two-lane whereas only one lane would be available in work zone area due to lane closure *(8)*. A further step was taken by Piao and McDonald through studying the vehicle following behavior under low speed traffic conditions. They concluded that time gaps varied substantially at low speeds (40 mph) but were relatively stable at high speeds (50 mph) *(9)*. This helped understand the vehicle following behavior at a reduced speed as in work zones, but the behavior might vary due to work activities, lane closure and the presence of barriers in work zone areas. In addition, we also could not differentiate driver behavior in different types of work zones such as short-term and long-term work zones.

It is well known that the car-following patterns have an impact on the vehicle following distance (gap) to some extent. Inadequate information and very limited research, however, have been reported on the impact of different vehicle following patterns on vehicle following distances. Among the limited contributing literatures, Zhang, Peeta and Zhou studied the behavior of freeway car-truck interactions in normal flow. They introduced the notion for car-truck interactions in the consideration of only the safer gap of the non-truck drivers when following a truck *(10)*.

The primary goal of the paper is to study the impact of vehicle following patterns on the following distance (gap) in both long-term and short-term work zones. The first part of this paper is dedicated to the direct impact of the leading vehicle on the following vehicle. This is followed by the study on the interdependent impact of the leading vehicle on the vehicle next to adjacent vehicle. This paper is also intended to reveal how the types of work zones influence the vehicle following gap.

2. DATA COLLECTION & ANALYSIS METHODOLOGY

This section introduces the methods used in collecting and analyzing the data from the different sites. These sites were located on interstate highways in Illinois with only one lane open due to construction. These investigation sites consist of both short-term and long-term work zones. A short-term work zone is defined as a construction or maintenance work site that remains only for less than a few days and the closed lane is enclosed using cones, barrels and barricades during the work zone activities. A long-term work zone is defined as a construction or maintenance work site that stays for more than a few days and the closed lane is enclosed using concrete barriers. A video camera was installed to capture the time point when vehicle passed specific markers placed at fixed distance apart. The general arrangement of the data collection sites is illustrated in Figure1. The measured average speed for platooning vehicles was 39.80 mph in short-term work zones. In long-term work zones, the measured average speed was 50.78 mph for platooning vehicles. The hourly volume varied from 450 vph to 850 vph for the most data collection sites.

The distance between the two markers was generally about 250ft, but varied for different sites. Data were collected from 2 hours to 4 hours depending on traffic conditions during day time and fair weather condition. The time coding of videotapes made the travel time to be determined very accurately (1/30secs). The collected data were reduced to data elements. These elements were categorized into such variables as vehicle type (1-cars, 2-large pickup trucks, 3-semi trucks), time at markers 1 and 2, platoon or not, travel time, headway and gap. Headway is the distance measured between the front bumper of a leading vehicle and the front bumper of its following vehicle. Gap denotes the distance measured between the rear bumper of a leading vehicle and the front bumper of its following vehicle. In this study, gap is analyzed rather than headway because gap characteristics provide a better measure of car-following behaviors.

Firstly, the direct impact of vehicle following pattern on gap was examined. Four possible vehicle following patterns are car-car, car-truck, truck-car, truck-truck, which are described in the form of (leading vehicle)-(following vehicle). Secondly, the interdependent impact of the first vehicle on the gap between different car-following patterns was analyzed for platoons with more than 2 vehicles. Gap differences between 2-vehicle platoons and 3-vehicle platoons were also studied. Vehicle's position in a 3-vehicle platoon was described as: leading vehicle-1st vehicle, middle vehicle-2nd vehicle and last vehicle-3rd vehicle. The average gap of 2-vehicle platoons was compared with the gap between the 2nd and 3rd vehicle with different types of the leading vehicle. This is intended to check a potential interdependent impact of the leading vehicle type on following vehicles. The vehicles studied in this research were only platooning vehicles. The leading vehicles were selected randomly from all observed platoons.

In this study, gap between the 2nd vehicle and 3rd vehicle is denoted as $g_{x\text{-}x\text{-}x}$ where x is a car or a truck. By assigning different permutations to x-value, we obtained eight combinations for $g_{x\text{-}x\text{-}x}$ including $g_{c\text{-}c\text{-}c}$, $g_{t\text{-}c\text{-}c}$, $g_{c\text{-}c\text{-}t}$, $g_{t\text{-}c\text{-}t}$, $g_{c\text{-}t\text{-}c}$, $g_{t\text{-}t\text{-}c}$, $g_{c\text{-}t\text{-}t}$ and $g_{t\text{-}t\text{-}t}$ for a 3-vehicle platoon. $g_{x\text{-}x}$ is the gap between two vehicles where x is a car or truck. In a two-vehicle platoon, the combinations are $g_{c\text{-}c}$, $g_{c\text{-}t}$, $g_{t\text{-}c}$ and $g_{t\text{-}t}$ with the same subscript denotation as above. We compared the $g_{x\text{-}x\text{-}x}$ and $g_{x\text{-}x}$ such that the 2nd and 3rd vehicles of the 3-vehicle platoon are the same pattern as the 2-vehicle platoon. For example, $g_{c\text{-}c\text{-}c}$ and $g_{t\text{-}c\text{-}c}$ were compared with $g_{c\text{-}c}$. This comparison assisted in identifying the interdependent impact of the type of the leading vehicle on the following vehicles.

Two-sample t-test is conducted to evaluate the average time gap of different vehicle following patterns. The average gap from the 3-vehicle and 2-vehicle platoon were compared, the average gap for 3-vehicle platoon with different leading vehicle type and the gaps in the short-term and long-term work zone were compared to each other for the same vehicle following patterns. A 95% confidence level is used to test the hypothesis, and a totally 32 different hypotheses were tested.

3. GAP ANALYSIS

Gap characteristics of platooning vehicles were analyzed in order to (1) find the impact of various vehicle following patterns and work zone types on vehicle following gap in a 2-vehilce platoon (2) find the interdependent impact of the leading vehicle on the 3rd vehicle in a 3-vehicle platoon. One previous research by Sun and Benekohal (2005) showed that the collected work zone gap data fitted Weibull distribution (3)

3.1 The Direct Impact of the Leading vehicle on Vehicle following Gap for 2-vehicle platoon

From the accident analysis, we came to know that rear-end collisions might occur due to such factors as platoon size, vehicle following gap, and brake features of the following vehicles. This made it necessary to understand the impact of vehicle following patterns on vehicle following gap. For instance, a truck following a truck tended to keep a shorter gap than following a car. However, it remained unknown if the gap difference under different vehicle following patterns is statistically significant. This led us to analyze average gaps under different vehicle following patterns. Four vehicle following patterns were car-car, car-truck, truck-car, truck-truck, named in the form of (leading vehicle)-(following vehicle).

Table 1 and 2 show the average gaps under four vehicle-following patterns in short-term and long-term work zones, respectively. In long-term work zones, it is observed that the shortest gap occurs when a car follows a truck, the second shortest is for a truck following another truck. In short-term work zones, it is observed that the average gaps of truck-car and car-car patterns are very close, both of which are apparently shorter than the gaps of car-truck and truck-truck patterns.

In **Table 1 and 2**, different vehicle following gaps are demonstrated for various vehicle following patterns. It is necessary to check for the statistical significance of the gap difference. So, ‘unpaired two-sample t-test’ was conducted to evaluate the difference among the average time gaps under different vehicle following patterns. Also the average

gaps in short-term and long-term work zones were compared to each other under the same vehicle following patterns. A 95% confidence level is used to test the hypotheses, and totally 16 different hypotheses are tested. The test results are shown in **Table 3**, where g_{c-t}^{st} denotes the average gap when a truck follows a car in the short-term work zone, and g_{t-c}^{lt} denotes the average gap for a car following truck in the long-term work zone. The t-test results indicate that there is no significant difference among the gaps under the patterns of car-car and truck-car in the short-term work zone.

From the t-test results, the following conclusion could be derived:

i) For the patterns of car-car and car-truck, the relative difference of their average gaps is (2.02-1.75)/1.75=15.43%. To verify if this difference is statistically significant, we performed two sample t-test and found the p-value of 7.31E-21 which is less than significant level (0.05). We therefore reject the null hypothesis and conclude with statistical significance between two gaps. For the patterns of truck-car and truck-truck, the relative difference is (1.62-1.46)/1.46 = 11%. The t-test gives a very small p-value of 0.00047. Therefore by rejecting null hypothesis we state that there is significant difference between their average gaps. This holds for both long-term and short-term work zones. This also shows that with the same type of leading vehicle, the truck driver tends to maintain longer gap than the car driver regardless of the work zone type. Decelerating features of trucks are worse than those of cars and thus truck drivers maintain longer gap for attaining more time to react than car.

ii) For the patterns of car-car and truck-car, the relative difference is found to be 19.7% in long-term work zone and 0.6% in short-term work zone. The t-test shows the p-value of 2.27E-21 in long-term work zones and 0.41854 in short-term ones. . The above analysis makes us believe that the leading vehicle type has a significant influence on the following distance of a car driver in long-term work zones and not in short-term ones. For the patterns of car-truck and truck-truck, the relative difference is observed as 24.7% in long-term and 21.8% in short-term work zones. The t-test gives the p-value of 9.46E-13 for long-term and 0.00114 for short-term work zones. We thus reject the null hypothesis in both cases and justify a significant difference between the two gaps. So, the leading vehicle type has a significant impact on the vehicle following gap of truck drivers in both short-term and long-term work zones i.e. they tend to maintain a longer gap when following a car than a truck. This is due to the intention of truck drivers to follow another truck as a pair when traveling long distances and therefore maintains shorter gap with another truck.

iii) In order to find out the impact of work zone type on vehicle following gap, a comparison of the average gap was performed for the same vehicle following pattern in different work zone. It is found that except the car-car pattern, all other patterns experience shorter gaps in long-term work zones than in short-term work zones.

All the findings above address the direct impact of leading vehicle type on vehicle following gap. But the leading vehicle (the 1st vehicle) may have some indirect or

interdependent impact on the vehicle next to the adjacent one in a platoon with more than two vehicles. For example, car-car pattern has an average time gap of 1.75s, it may vary when led by a truck i.e. truck-car-car pattern. Any change in average gap might be caused by the interdependent impact of the leading truck on the 3rd-position car. The next section introduces the interdependent impact of leading vehicle type and how the interdependent impacts vary in different types of work zones.

3.2 The Interdependent Impact of the Leading vehicle type on the 3rd vehicle in a 3-vehicle platoon

Vehicle following gaps between the 2nd and 3rd vehicles with different types of leading vehicle (the 1st vehicle) were compared so as to identify the interdependent impact of leading vehicle on the 3rd vehicle. **Table 4** exhibits the t-test results for 32 hypotheses at 95% confidence level where, g^{st}_{c-c-t} denotes the gap between the 2nd vehicle (car) and 3rd vehicle (truck) in short-term work zones and g^{lt}_{c-c-t} denotes the one for long-term work zones. Other denotations are defined as in previous sections.

3.2.1 Long-Term Work Zone

The average gaps between the 2nd and 3rd vehicles with different types of leading (the 1st) vehicles in long-term work zones are illustrated in Figure 2.

From the t-test results shown in Table 4, the following findings were identified for long-term work zones:

i) For the patterns of car-car-car and truck-car-car, the relative gap difference is 14.9%. The difference is proved statistically significant by rejecting the null hypothesis, as p-value (1.06E-09) is less than significant level. For the patterns of car-car-truck and truck-car-truck, the observed relative difference is 8.9%. With the p-value of 0.04, a statistical significance is found between these two gaps. Therefore, the leading vehicle type does have significant interdependent impact on both car and truck on the 3rd position if the middle vehicle is a car. This may because the 3rd vehicle can easily adjust their following distances per the required reaction time through seeing through the 2nd vehicle (a car). In addition, the relative differences of (car-car-car vs. truck-car-car) and (car-car-truck vs. truck-car-truck) indicate that leading vehicle type has more interdependent impact on the following distance of car drivers than that of truck drivers.

ii) If the middle vehicle is truck, the interdependent impact of leading vehicle type on car and truck drivers' is evaluated by comparing the following patterns:,
   - car-truck-car vs. truck-truck-car (1.50-1.44)/1.44=4.17% for car drivers,
   - truck-truck-truck vs. car-truck-truck (1.65-1.57)/1.57=5.01% for truck drivers.

   The relative differences show that the following distances between the 2nd vehicle (truck) and 3rd vehicle (car or truck) is slightly increased if the 1st vehicle is a truck rather than a car. We, however, fail to justify statistical

significance between the gaps for both comparisons. As the truck in the middle position blocks the vicinity of the following vehicle, no significant interdependent impact of the leading vehicle can be found on the 3rd vehicle.

iii) The interdependent impact of the leading vehicle on the 3rd vehicle can also be demonstrated by comparing the average gap of 2-vehicle platoon with the average gap of a 3-vehicle platoon. For example, for truck-car-car and car-car patterns, the relative difference is (1.75-1.54)/1.54=13.64%. This difference is proved to be statistically significant as p-value from t-test is 6.47E-08. There is a decline in average gap of a pair of cars when a truck leads them. When a car leads another pair of cars, there is a significant increase in the average gap.

iv) For car-car-truck and car-truck patterns, the observed relative difference is 3% and proved statically insignificant.

3.2.2 Short-Term Work Zone

The average gaps for different vehicle following patterns in short-term work zone are shown in Figure 3. From the t-tests summarized in Table 4, the following results were observed:

i) The relative difference of the gap between the 2nd and 3rd vehicles in the patterns of car-car-car and truck-car-car is negligible, which is (1.67-1.66)/1.66=0.6%, and t-test p-value is 0.466. For car-car-truck and truck-car-truck patterns, the relative difference is significant, which is (2.23-1.63)/1.63=36.8% and this difference is proved to be statistically significant with a p-value of 0.014. From the relative difference of (car-car-car vs. truck-car-car) and (car-car-truck vs. truck-car-truck), we found that the leading vehicle type has significant interdependent impact on truck drivers and not on car drivers in short-term work zones.

ii) For the patterns of car-truck-truck and truck-truck-truck, the relative difference is 3.1% and their average gaps are proved to be not significantly different from the t-test. Therefore, it can be concluded that any vehicle (the 1st vehicle) ahead of a truck has no significant interdependent impact on the following distance for vehicle at the 3rd position.

iii) In short-term work zones, 2-vehicle car-truck pattern maintains significantly longer gap when led by a car rather than a truck. The statistical significance of the gap difference has been verified as p-value 0.014 lies within significant level. It is also statistically proved that the leading vehicle has no significant interdependent impact on the following distance between the 2nd and 3rd vehicles (car-car pattern) in short-term work zones

iv) No statistically significant difference is found in the average gaps for the following situations: the 2-vehicle car-car pattern is led by different types of vehicles, the 2-vehcile truck-car pattern led by different type of vehicles.

3*.2.3 Work Zone Type Impact on the Car-following Gap***.**

The impact of the work zone type on the car-following gap between the 2nd and 3rd vehicles in 3-vehicle platoon is investigated through the comparison of the average gaps

for the same vehicle following pattern in two different types of work zones. A few observations are summarized as follows.

i) For car-car-car pattern, the relative gap difference between short-term and long-term work zones is 6% and the t-test results show that the difference is statistically significant. When a car followed by two other cars, the car-following gap between the 2nd and 3rd cars is longer in long-term work zones than in short-term ones. When a truck leads a car-car pattern no statistical significance difference in gap can be verified between short-term and long-term work zones.

ii) For truck-truck-car pattern, the relative gap difference in gap between short-terms and long-term work zones is 15.3%. The t-test gives a p-value of 0.044, which lies within significant level. So, we conclude that there exists statistically significant difference between the gaps in two types of work zones.

iii) For the truck-car-truck pattern, the relative gap difference between short-term and long-term work zones is 17.1%, seemingly significant. However, this significance cannot be supported by the t-test. This is primarily due to the lack of adequate samples since there are only less than 20 observations of truck-car-truck patterns. Thus, for truck-car-truck pattern, no influence of work zone type can be concluded on the car-following gap between the 2nd and 3rd vehicles.

iv) For 3-vehicle platoons with the 2nd and 3rd vehicles as trucks, no significant difference is found between different types of work zones. For car-truck-car pattern, the observed relative difference of 7.6% is proved to be statistically insignificant by conducting t-test.

4. CONCLUSIONS AND RECOMMENDATIONS

The direct impact of the leading vehicle type on the car-following gap was found. Also, the indirect or interdependent impact of the leading vehicle type on car-following gap between the 2nd and 3rd vehicle in a 3-vehicle platoon is found by analyzing the average gaps. It is observed that, for the same types of leading vehicle, truck drivers tend to maintain longer gap than car drivers in long-term work zone. Truck drivers maintain shorter gap when led by a truck in both short-term and long-term work zones. In long-term work zones, car driver tend to keep shorter gap when following a truck. So, in the long-term work zone car drivers must be attentive when following a truck in order to attain more reaction time to avoid a collision. The car-following gap for the car-car pattern appears to be longer in long-term work zone than in short-term work zone. But when car follows a truck it appears to have a shorter gap in long-term work zone than in short-term work zone.

Due to the interdependent impact of the leading truck, there is a decrease when the following vehicle patterns are either car-car or car-truck pattern. A shorter vehicle following gap is observed between two cars when led by a truck than by a car. All the 2-vehicle platoons except the car-car pattern have no significant interdependent impact of the leading vehicle on their average gaps in long-term work zone. But the same car-car pattern has no interdependent impact of leading vehicle on average gap in short-term

work zone. The type of work zone is proved to have significant impact for car-car-car and truck-truck-car patterns. Due to the size of car in car-truck pattern, the average gap is increased when led by a car than a truck. When truck is in the middle position, the leading vehicle has no significant interdependent impact on the average time gap between 2nd and 3rd vehicles because the large size of truck blocks the vicinity of vehicle following. For truck-truck-car pattern, car-following gap between the 2nd and 3rd vehicles is found shorter in long-term than in short-term work zones. As we know that vehicles following so closer to each other may be the cause for more rear-end collisions as they need to attain more reaction in order to avoid collision. So, the patterns with shorter car-following gaps may be studied further for safety measures in maintaining longer gaps.

This paper studies the direct impact of leading vehicle on vehicle following gap and interdependent impact of the leading vehicle on vehicle following gap between the 2nd and 3rd vehicles in 3-vehicle platoons. Further study may include the impact of leading vehicle on car-following gap between the 3rd and 4th for a longer platoon.

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Table 1: Long-term Work Zone 2-vehicle Platoon Average Gap

Pattern	c-c	t-c	c-t	t-t
Avg. gap	1.75	1.46	2.02	1.62
# of observations	8079	534	579	202
Standard deviation	0.6763	0.5922	0.7312	0.5318
Standard error	0.0075	0.0256	0.0304	0.0374
Co-efficient of variation	38.65%	40.56%	36.2%	32.83%

Table 2: Short-term Work Zone 2-vehicle Average Gaps

Pattern	c-c	t-c	c-t	t-t
Avg. gap	1.65	1.64	2.18	1.79
# of observations	659	100	103	52
Standard deviation	0.650	0.5875	0.7691	0.6671
Standard error	0.0253	0.0588	0.076	0.093
Co-efficient of variation	39.39%	35.82%	35.28%	37.27%

Table 3. Results of t-test for Time Gap (direct impact)

	Hypothesis	Level of significance (α)	P value (one tail)	Reject the Null hypothesis?
Short-term work zone	$H_0: g^{st}_{c-c} = g^{st}_{t-c}; H_A: g^{st}_{c-c} > g^{st}_{t-c}$	5%	0.41854	Fail to Reject
	$H_0: g^{st}_{c-c} = g^{st}_{c-t}; H_A: g^{st}_{c-c} < g^{st}_{c-t}$	5%	1.24E-13	Reject
	$H_0: g^{st}_{c-t} = g^{st}_{t-t}; H_A: g^{st}_{c-t} < g^{st}_{t-t}$	5%	0.001137	Reject
	$H_0: g^{st}_{t-c} = g^{st}_{t-t}; H_A: g^{st}_{t-c} < g^{st}_{t-t}$	5%	0.0803	Fail to Reject
	$H_0: g^{st}_{c-c} = g^{st}_{t-t}; H_A: g^{st}_{c-c} < g^{st}_{t-t}$	5%	0.0769	Fail to Reject
	$H_0: g^{st}_{c-t} = g^{st}_{t-c}; H_A: g^{st}_{c-t} > g^{st}_{t-c}$	5%	3.14E-08	Reject
Long-term	$H_0: g^{ltt}_{c-c} = g^{lt}_{t-c}; H_A: g^{lt}_{c-c} > g^{lt}_{t-c}$	5%	2.27E-21	Reject
	$H_0: g^{lt}_{c-c} = g^{lt}_{c-t}; H_A: g^{lt}_{c-c} < g^{lt}_{t-t}$	5%	7.31E-21	Reject
	$H_0: g^{lt}_{c-t} = g^{lt}_{t-t}; H_A: g^{lt}_{c-t} > g^{lt}_{t-t}$	5%	9.46E-13	Reject
	$H_0: g^{lt}_{t-c} = g^{lt}_{t-t}; H_A: g^{lt}_{t-c} < g^{lt}_{t-t}$	5%	0.00047	Reject
	$H_0: g^{lt}_{c-c} = g^{lt}_{t-t}; H_A: g^{lt}_{c-c} > g^{lt}_{t-t}$	5%	0.0042	Reject
	$H_0: g^{lt}_{c-t} = g^{lt}_{t-c}; H_A: g^{lt}_{c-t} > g^{lt}_{t-c}$	5%	8.68E-41	Reject
short-term Vs long-worke	$H_0: g^{st}_{c-c} = g^{lt}_{c-c}; H_A: g^{st}_{c-c} < g^{lt}_{c-c}$	5%	0.00044	Reject
	$H_0: g^{st}_{c-t} = g^{lt}_{c-t}; H_A: g^{st}_{c-t} > g^{lt}_{c-t}$	5%	0.19303	Fail to Reject
	$H_0: g^{st}_{t-c} = g^{lt}_{t-c}; H_A: g^{st}_{t-c} > g^{lt}_{t-c}$	5%	0.003	Reject
	$H_0: g^{st}_{t-t} = g^{lt}_{t-t}; H_A: g^{st}_{t-t} > g^{lt}_{t-t}$	5%	0.0271	Reject

Table 4. Results of T-test for Time Gap (interdependent impact)

	Hypothesis	Significant Level (α)	P Value (one tail)	Reject the Null Hypothesis?
Short-term work zone	$H_0: g^{st}_{c-c-c} = g^{st}_{t-c-c}; H_A: g^{st}_{c-c-c} > g^{st}_{t-c-c}$	5 %	0.466	Fail to Reject
	$H_0: g^{st}_{c-c-t} = g^{st}_{t-c-t}; H_A: g^{st}_{c-c-t} > g^{st}_{t-c-t}$	5 %	0.014	Reject
	$H_0: g^{st}_{c-t-c} = g^{st}_{t-t-c}; H_A: g^{st}_{c-t-c} < g^{st}_{t-t-c}$	5 %	0.121	Fail to Reject
	$H_0: g^{st}_{c-t-t} = g^{st}_{t-t-t}; H_A: g^{st}_{c-t-t} > g^{st}_{t-t-t}$	5 %	0.447	Fail to Reject
	$H_0: g^{st}_{c-c-c} = g^{st}_{c-c}; H_A: g^{st}_{c-c-c} > g^{st}_{c-c}$	5 %	0.380	Fail to Reject
	$H_0: g^{st}_{t-c-c} = g^{st}_{c-c}; H_A: g^{st}_{t-c-c} > g^{st}_{c-c}$	5 %	0.480	Fail to Reject
	$H_0: g^{st}_{c-c-t} = g^{st}_{c-t}; H_A: g^{st}_{c-c-t} > g^{st}_{c-t}$	5 %	0.380	Fail to Reject
	$H_0: g^{st}_{t-c-t} = g^{st}_{c-t}; H_A: g^{st}_{t-c-t} < g^{st}_{c-t}$	5 %	0.016	Reject
	$H_0: g^{st}_{c-t-c} = g^{st}_{t-c}; H_A: g^{st}_{c-t-c} < g^{st}_{t-c}$	5 %	0.222	Fail to Reject
	$H_0: g^{st}_{t-t-c} = g^{st}_{t-c}; H_A: g^{st}_{t-t-c} > g^{st}_{t-c}$	5 %	0.280	Fail to Reject
	$H_0: g^{st}_{c-t-t} = g^{st}_{t-t}; H_A: g^{st}_{c-t-t} < g^{st}_{t-t}$	5 %	0.195	Fail to Reject
	$H_0: g^{st}_{t-t-t} = g^{st}_{t-t}; H_A: g^{st}_{t-t-t} < g^{st}_{t-t}$	5 %	0.217	Fail to Reject
Long-	$H_0: g^{lt}_{c-c-c} = g^{lt}_{t-c-c}; H_A: g^{lt}_{c-c-c} > g^{lt}_{t-c-c}$	5 %	1.06E-09	Reject
	$H_0: g^{lt}_{c-c-t} = g^{lt}_{t-c-t}; H_A: g^{lt}_{c-c-t} > g^{lt}_{t-c-t}$	5 %	0.040	Reject
	$H_0: g^{lt}_{c-t-c} = g^{lt}_{t-t-c}; H_A: g^{lt}_{c-t-c} > g^{lt}_{t-t-c}$	5 %	0.210	Fail to Reject
	$H_0: g^{lt}_{c-t-t} = g^{lt}_{t-t-t}; H_A: g^{lt}_{c-t-t} > g^{lt}_{t-t-t}$	5 %	0.171	Fail to Reject
	$H_0: g^{lt}_{c-c-c} = g^{lt}_{c-c}; H_A: g^{lt}_{c-c-c} > g^{lt}_{c-c}$	5 %	0.0084	Reject
	$H_0: g^{lt}_{t-c-c} = g^{lt}_{c-c}; H_A: g^{lt}_{t-c-c} > g^{lt}_{c-c}$	5 %	6.47E-08	Reject

	$H_0: g^{lt}_{c-c-t} = g^{lt}_{c-t}; H_A: g^{lt}_{c-c-t} < g^{lt}_{c-t}$	5 %	0.1170	Fail to Reject
	$H_0: g^{lt}_{t-c-t} = g^{lt}_{c-t}; H_A: g^{lt}_{t-c-t} < g^{lt}_{c-t}$	5 %	0.1144	Fail to Reject
	$H_0: g^{lt}_{c-t-c} = g^{lt}_{t-c}; H_A: g^{lt}_{c-t-c} < g^{lt}_{t-c}$	5 %	0.2898	Fail to Reject
	$H_0: g^{lt}_{t-t-c} = g^{lt}_{t-c}; H_A: g^{lt}_{t-t-c} > g^{lt}_{t-c}$	5 %	0.3121	Fail to Reject
	$H_0: g^{lt}_{c-t-t} = g^{lt}_{t-t}; H_A: g^{lt}_{c-t-t} < g^{lt}_{t-t}$	5 %	0.2118	Fail to Reject
	$H_0: g^{lt}_{t-t-t} = g^{lt}_{t-t}; H_A: g^{lt}_{t-t-t} < g^{lt}_{t-t}$	5 %	0.3471	Fail to Reject
Short-term Vs Long-term	$H_0: g^{st}_{c-c-c} = g^{lt}_{c-c-c}; H_A: g^{st}_{c-c-c} < g^{lt}_{c-c-c}$	5 %	0.0045	Reject
	$H_0: g^{st}_{c-c-t} = g^{lt}_{c-c-t}; H_A: g^{st}_{c-c-t} > g^{lt}_{c-c-t}$	5%	0.1170	Fail to Reject
	$H_0: g^{st}_{c-t-c} = g^{lt}_{c-t-c}; H_A: g^{st}_{c-t-c} > g^{lt}_{c-t-c}$	5 %	0.1341	Fail to Reject
	$H_0: g^{st}_{c-t-t} = g^{lt}_{c-t-t}; H_A: g^{st}_{c-t-t} > g^{lt}_{c-t-t}$	5 %	0.3592	Fail to Reject
	$H_0: g^{st}_{t-c-c} = g^{lt}_{t-c-c}; H_A: g^{st}_{t-c-c} > g^{lt}_{t-c-c}$	5 %	0.1253	Fail to Reject
	$H_0: g^{st}_{t-t-c} = g^{lt}_{t-t-c}; H_A: g^{st}_{t-t-c} > g^{lt}_{t-t-c}$	5 %	0.0441	Reject
	$H_0: g^{st}_{t-t-t} = g^{lt}_{t-t-t}; H_A: g^{st}_{t-t-t} > g^{lt}_{t-t-t}$	5 %	0.3708	Fail to Reject
	$H_0: g^{st}_{t-c-t} = g^{lt}_{t-c-t}; H_A: g^{st}_{t-c-t} > g^{lt}_{t-c-t}$	5 %	0.1321	Fail to Reject

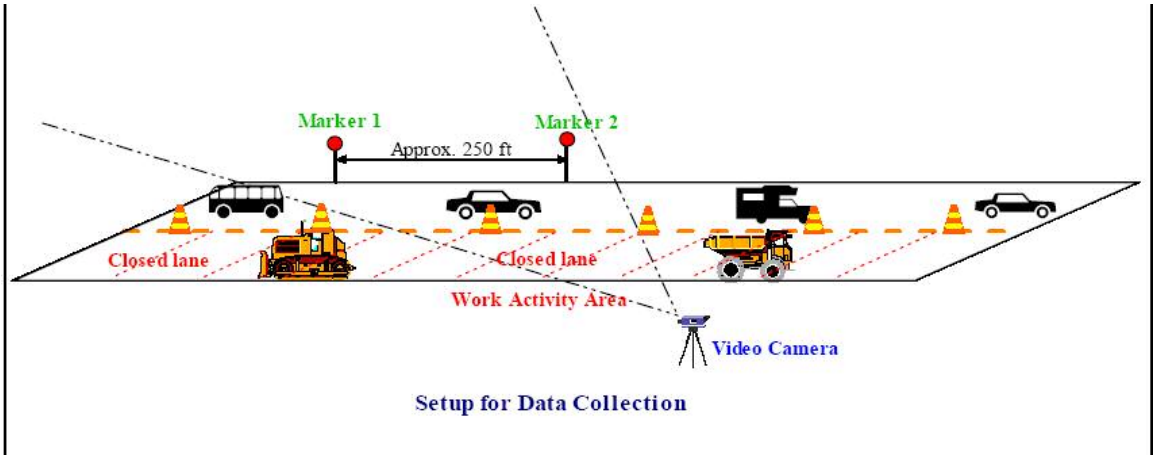

Figure 1. Setup for Data Collection

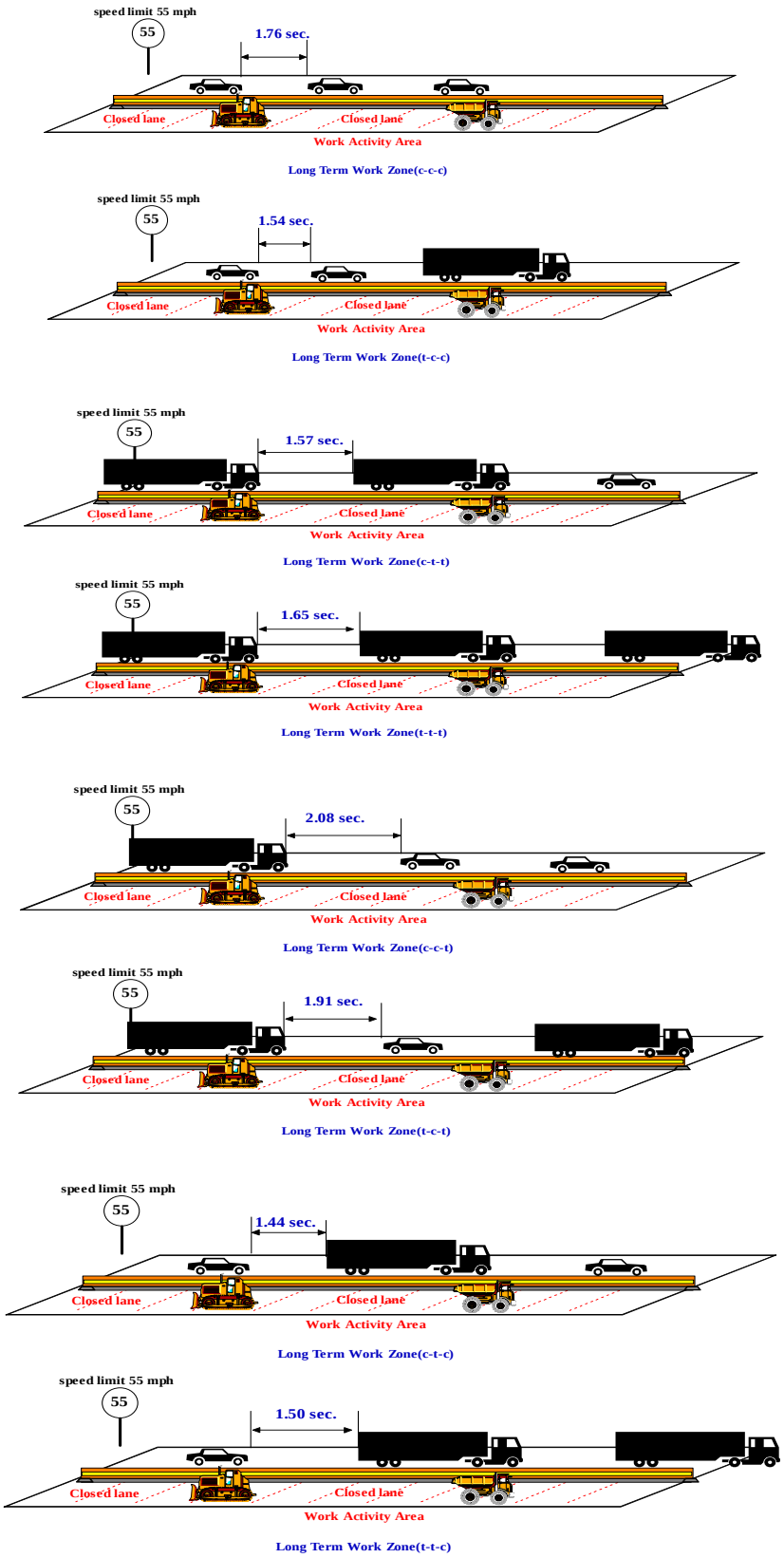

Figure 2. Long term work zone 3-vehicle platoon

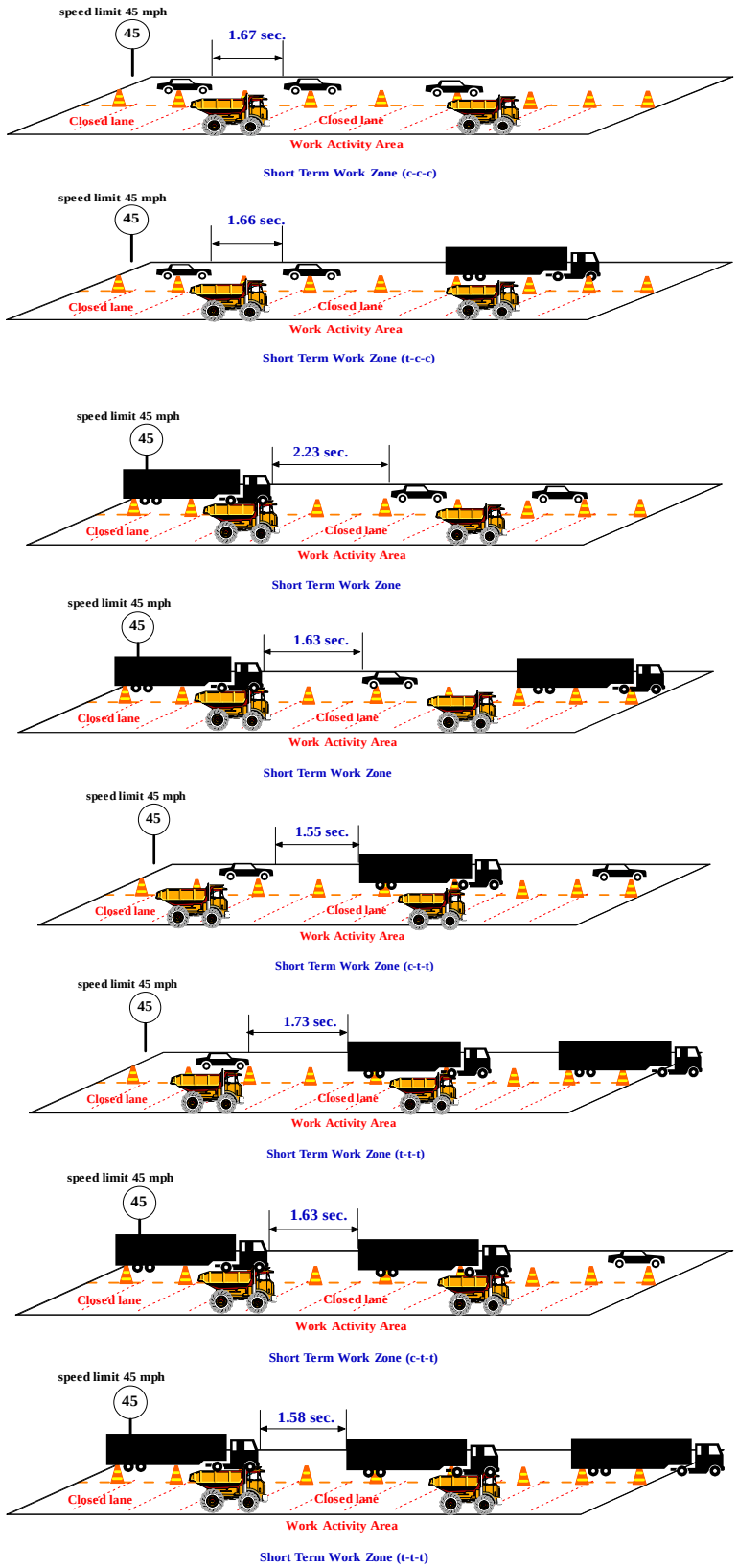

Figure 3. Short term work zone 3-vehicle platoon