applied sciences

MDPI

Article

Assessing the Impact of Increasing Tractor-Trailer Speed Limit on the Safety and Mobility of Three-Lane Highways in Egypt

Usama Elrawy Shahdah [1], Sangbin Na [2] and Jong Wan Hu [2,*]

1 Public Works Engineering Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt
2 Department of Civil and Environmental Engineering, Incheon National University, Incheon 22012, Republic of Korea
* Correspondence: jongp24@inu.ac.kr

Abstract: Currently, the speed limit for tractor-trailers (TTs) on Egyptian highways is 30 km/h lower than the speed limit for passenger cars (PCs). The main purpose of this article is therefore to evaluate the effects of an increase in TT speed limit on both the traffic safety and mobility of Egyptian three-lane highways, with speed limits of 90 and 100 km/h for PCs. A SUMO simulation model was used in this analysis. Average vehicle delay was used as a measure of mobility, while the simulated conflict ratio based on time to collision (TTC) and deceleration rate required to avoid crash (DRAC) surrogate safety measures were used as performance indicators of safety. All simulated vehicles were equipped with surrogate safety measurement (SSM) devices to extract traffic conflicts, with TTC $\leq$ 2.50 representing less sever conflicts; TTC $\leq$ 1.50 s and DRAC $\geq$ 3.35 m/s^2 representing potential conflicts; and TTC $\leq$ 0.50 s and DRAC $\geq$ 6.0 m/s^2 representing severe conflicts. The results show that increasing the speed limit for TTs would significantly reduce the average delay by approximately 27–76% for traffic volumes 500–2000 vehicle/hr/lane, with TTs comprising 2.5–15% of total traffic volume. Furthermore, in most cases, when comparing the situation after the speed limit increase for TTs with the base case (i.e., TTs with a speed limit of 60 km/h and 70 km/h for highways, and a speed limit of 90 km/h and 100 km/h for PCs), the results show no statistically significant change in the conflict ratio more than 1.0, suggesting that there is no safety change. Furthermore, due to the increase in speed limit for TTs, in some cases and for different thresholds, there is a statistically significant reduction in the conflict ratio, indicating improvements in terms of safety.

Keywords: differential speed limits; uniform speed limits; highway safety; trucks; SUMO; micro-simulation; Egypt

check for updates

Citation: Shahdah, U.E.; Na, S.; Hu, J.W. Assessing the Impact of Increasing Tractor-Trailer Speed Limit on the Safety and Mobility of Three-Lane Highways in Egypt. *Appl. Sci.* **2022**, *12*, 12702. https://doi.org/10.3390/app122412702

Academic Editor: Luís Picado Santos

Received: 7 November 2022
Accepted: 6 December 2022
Published: 11 December 2022

1. Introduction

Tractor-trailers (TTs) are types of trucks (i.e., large trucks) that are mainly used for transporting different kind of goods and materials from one place to another. TTs can be classified into single-trailer trucks and multi-trailer trucks, with total length ranges between 21 m (69 ft) and 29 m (95 ft) [1]. Large trucks are essential to Egypt's economy, as the majority of goods are transported by them.

For highways, there are two distinguished speed limit rules: the first is the uniform speed limit (USL), in which all vehicles operate with the same speed limit; and the second is the differential speed limit (DSL), where large vehicles and other types of vehicles operate with different speed limits. All Egyptian highways use the DSL rule, where large truck speed is restricted to be 30 km/h less than the highway speed limit for passenger cars (PCs). For highways with a speed limit of 90 km/h for PCs, the speed limit of large trucks is 60 km/h, while for highways with a speed limit of 100 km/h for PCs, the speed limit for large trucks is 70 km/h.

Internationally, in Canada, the provinces of Ontario and Quebec are the only provinces to apply DSL to restrict the large truck speed limit [2] using mandated speed devices to limit large trucks' speed to 105 km/h for highways with a speed limit of 100 km/h [2,3]. As of June 2016, seven of the fifty-two states in the United States of America (USA) operate a DSL for PCs and heavy vehicles on selected highways [4], while in June 2014 there were eight states [5]. The main idea of using the DSL strategy is to reduce the severity of collisions involving heavy vehicles [6,7].

Large trucks require a much greater stopping distance than light vehicles. When a large truck is involved in a collision, the outcome tends to be notable for its severity when compared to average motor vehicle collisions [3]. On average, approximately one in five Ontario traffic fatalities result from a collision involving a large truck [3]. Although, large truck drivers are far less likely to be guilty of a fatal accident than other drivers involved in the same accident [3]. Heavy vehicle collisions on high-speed highways are largely due to human errors such as speeding, drunk driving and fatigued driving. Speed is considered an important contributing factor to heavy vehicle collisions on high-speed highways [8].

The DSL has two effects: the positive effect which results from the improvement in vehicle dynamics (brakes and maneuvers) for trucks at lower speeds; and the negative effect of the increase in speed fluctuations and the number of interactions between vehicles. These two effects act in opposite directions, and ultimately lead to an observable effect on safety data on motorways [9]. Based on the opinions of speed deviations from truck drivers, DSL increases interactions between vehicles and increases the probability of accidents [9].

Garber et al. (2003 and 2006) [10,11] compared USL safety effects for all vehicles and DSLs for cars and heavy trucks for rural highways for the period 1991 to 2000 from nine states in the United States, and came to the conclusion that the speed limit directive does not have a uniform influence on safety [10,11]. In addition, the results of [4] support the transition from DSL to USL on two-lane rural highways in Montana.

1.1. Surrogate Safety Measures

Surrogate safety measures derived from microscopic traffic simulations have recently been used to evaluate the safety of transportation systems (e.g., [6,12–18], etc.). One of the major advantages of using simulation modeling is that it allows potential treatments to be tested before application [19]. Commonly used micro-simulation software include VISSIM [20], PARAMICS [21], AIMSUN [22], SUMO [23,24], INTEGRATION [25], CORSIM [26], MITSIMLab [27], etc. The SUMO model supports all the modeling functions needed to implement adequate surrogate safety measures. Therefore, in this study, both safety and mobility were used to adapt different speed limit strategies on Egyptian highways, and were evaluated using the SUMO microscopic traffic simulation model. SUMO has the ability to use different types of car-following (CF) models, such as the Krauss model (the default SUMO CF model) [28], the Intelligent Driver Model (IDM) [29], the Wiedemann74 model (2-parameter model), the Wiedemann99 model (10-parameter model), the Adaptive Cruise Control (ACC) model [30], etc. It is worth noting that the Wiedemann models are the default models used by the VISSIM software.

The use of micro-simulations in road safety studies requires the use of surrogate safety indicators that are a function of the speed and distance of "vehicle pairs", such as time to collision (TTC) [31,32], deceleration rate to avoid the collision (DRAC) [33], time to accident (TTA) [32], encroachment time (ET) [34], crash potential index (CPI) [18,19], etc. SUMO allows extracting simulated conflicts as a direct result of the simulations. The raw trajectories of vehicle pairs can also be processed using the well-known surrogate safety assessment model (SSAM) [35].

In this study, TTC is used to reflect the potential of the accident and is calculated simply [36,37]. TTC can be expressed as the time difference between two vehicles before they crash if they follow their respective trajectories at their current speeds [31]. Two-vehicle collision severity can be considered based on the lowest TTC value. Van der Horst (1990) [38] reported that potential collisions are a concern when the TTC value is less than 1.50 s for specific vehicles' interactions. Archer (2005) [37] also suggested TTC $\leq$ 1.50 s as a critical value for road safety in urban areas. In addition, AASHTO (2011 and 2018) [39,40] recommended the TTC value of 2.5 s for brake reaction time, which is used in the development of highways' stopping sight distances.

In addition to TTC, deceleration rate to avoid collision (DRAC) is used as another measure of safety performance. DRAC is defined as the rate at which a vehicle must decelerate to avoid collision with another vehicle [36,37]. DRAC for rear-end (RE) conflicts can be expressed as [19]:

$$DRAC(t) = \frac{(V_n(t) - V_{n-1}(t))^2}{2(X_n(t) - X_{n-1}(t) - L_{n-1})} \tag{1}$$

where:

t = time interval;
V = vehicle speed;
n = following vehicle;
$n - 1$ = leading vehicle;
X = position of the vehicle;
L = vehicle length.

For potential angle crashes, estimates of DRAC are obtained as [19]:

$$DRAC(t) = \frac{{V_n}^2(t)}{2D_n(t)} \tag{2}$$

where $D_n(t)$ is the distance between the projected collision point and vehicle "n" in the main traffic stream.

AASHTO (2011, 2018) [39,40] stated that most motorists decelerate at a rate greater than 4.5 m/s^2 when having to stop in front of unexpected object on the roadway. About 90% of all drivers decelerate at rates greater than 3.4 m/s^2, as this deceleration is within the driver's ability to stay within their lane and maintain control of the steering wheel while driving and braking on wet roads. Therefore, 3.4 m/s^2, which can be considered as a comfortable deceleration for most drivers, is recommended as the deceleration threshold to determine the stopping sight distance. Archer [37] proposes a threshold value of 3.35 m/s^2 for critical situation. Guido et al. [41] also chose a threshold value of 3.35 m/s^2 in their work on road safety. Hyden (1996) ([42] as cited in [19]) suggested that a DRAC greater than 6.0 m/s^2 is an indication that emergency response is required.

1.2. Research Objectives

To the authors' knowledge, no studies have been found in the literature that have examined the effect of increasing the speed limit of trailers on the safety or mobility performance of Egyptian motorways. The primary objective of this study is therefore to evaluate the effects of speed limit increase for trailers on the safety and mobility of three-lane highways with speed limits of 90 and 100 km/h.

The average delay (second/vehicle) was used as the measurement of mobility efficiency, and simulated conflicts were used as the safety measure to evaluate the traffic safety of increasing TT speed limit. The SUMO model was used to generate conflicts with TTC $\leq$ 2.50 s for minor conflicts (low severity), TTC $\leq$ 1.50 s for moderate conflicts, and TTC $\leq$ 0.50 s for severe conflicts. In addition to TTC, the surrogate safety indicator DRAC is also used to assess whether the two measures produce the same results or not. A traffic conflict with DRAC $\leq$ 3.35 m/s^2 is used to indicate a low-severity conflict, and a DRAC $\geq$ 6.0 m/s^2 is used to indicate a serious conflict.

2. Study Framework

SUMO [23] was used to model and obtain the vehicle trajectories. The Wiedemann-99 car-following model, which is the most widely used model in the literature within the VISSIM simulation model (e.g., [6,18,43–47], etc.), was used in this analysis. This research work adapted the calibrated parameters of Wiedemann-99 from [6,48], as shown in Table 1, but since drivers in Egypt usually have small gaps, the CC0 was set to 1.50 m for PCs, and was set to 2.50 m (default sumo parameter) for TT vehicles. It should be noted that the number of simulated conflicts that occurred is not the focus of this study, as this study focuses on the relative number of simulated conflicts before and after the TT speed limit increase (i.e., the conflict rate).

Table 1. Wiedemann-99 parameters.

Parameter	Unit	Description	SUMO Default Values	VISSIM Default Values	Calibrated Values [6]
CC0	m	Standstill gap	2.50	1.50	2.44
CC1	s	Headway time: time gap that the following driver keeps for a safety-in-moving state	1.30	0.90	1.09
CC2	m	'Following' variation: range of gap between the two vehicles in the "following" regime	8.00	4.00	4.00
CC3	s	Threshold for entering "following" regime	−12.00	−8.00	−6.09
CC4	m/s	Negative 'following' threshold	−0.25	−0.35	−0.35
CC5	m/s	Positive 'following' threshold	0.35	0.35	1.88
CC6	10^{-4} rad/s	Speed dependency of oscillation	6.00	11.44	11.44
CC7	m/s^2	Oscillation acceleration: actual acceleration during oscillation in the unconscious following regime	0.25	0.25	0.25
CC8	m/s^2	Standstill acceleration: desired acceleration when the vehicle starts from the standing condition	2.00	3.50	3.50
CC9	m/s^2	Desired acceleration at 80 km/h	1.50	1.50	1.50

After running the simulation for a certain period, the delay can be obtained from the road network with traffic and geometric characteristics, and the trajectories of all vehicles can be obtained in each simulation step. Then, the individual vehicle trajectories are transformed into pairs of vehicles for a given interaction type (i.e., leading and trailing vehicles for rear-end interaction) to obtain the number of simulated conflicts.

SUMO can directly output simulated traffic conflicts by equipping all vehicles with a surrogate safety measure (SSM) device. SUMO can also generate floating car data (FCD) containing the name, location, angle and type of each vehicle, which can be processed with the Python tool "*traceExporter*" (provided by SUMO) to track vehicle trajectories in the "trj" file format for direct use with SSAM software [35] to extract vehicle conflicts.

In this analysis, vehicle positions with velocity, acceleration and deceleration profiles were obtained every $\frac{1}{4}$ second and a step length of 0.50 s was used. Standard vehicle lengths were used for both PC and TT vehicles. Additionally, the "*lcSpeedGainLookahead*" (i.e., look-ahead time in seconds for anticipating slow down) was set to 5.0 s, and the "*lcStrategic*" (i.e., the eagerness for performing strategic lane changing) was set to 10 for both PC and TT vehicles.

A general framework for estimating highway delays and conflicts is shown in Figure 1. The procedure begins by using SUMO to simulate the movements of all vehicles (PCs and TTs) on the highway network for a specified period. Input data are highway geometry, number of lanes, lane configuration, number of on/off ramps, etc. The traffic volumes simulated are 500, 750, 1000, 1500, and 2000 vehicle/h/lane. Four different levels are considered for the TT volume (i.e., 2.50%, 5.0%, 7.50%, 10.0% and 15%). The traffic volume is distributed as follows:

- Seventy percent of total traffic volume from mainline to mainline;
- Twenty percent of total traffic volume from mainline to off-ramp;
- Ten percent of total traffic volume from on-ramp to mainline.

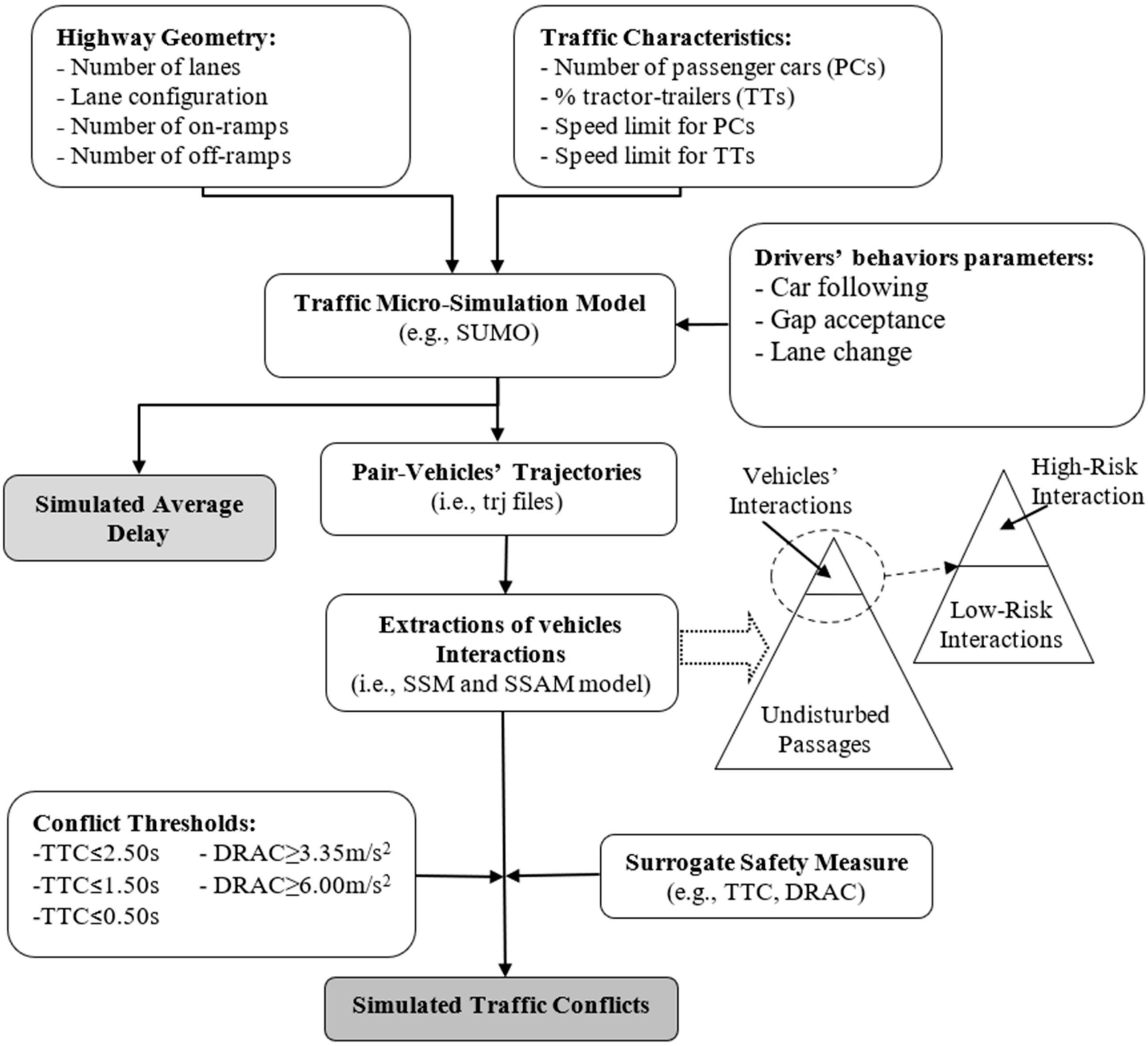

Figure 1. Study framework.

The combinations of traffic volumes for both PCs and TTs are presented in Table 2.

Table 2. Different combinations of traffic volumes, %TTs and speed limit.

Strategy	Total Volume (Vehicle/h/Lane)	Tractor-Trailer (TT) Volume (% from Total Volume)	Speed Limit
USL	500 750 1000 1500 2000	2.50, 5.0, 7.50, 10.0 and 15.0	**PCs:** 90 km/h - **TTs:** 90 km/h **PCs:** 100 km/h - **TTs:** 100 km/h
DSL	500 750 1000 1500 2000	2.50, 5.0, 7.50, 10.0 and 15.0	**PCs:** 90 km/h - **TTs:** 60 km/h - **TTs:** 70 km/h - **TTs:** 80 km/h **PCs:** 100 km/h - **TTs:** 70 km/h - **TTs:** 80 km/h - **TTs:** 90 km/h

Figure 2 shows the geometry of the tested highway network, which is similar to the network used by [6,48], with the following assumptions:

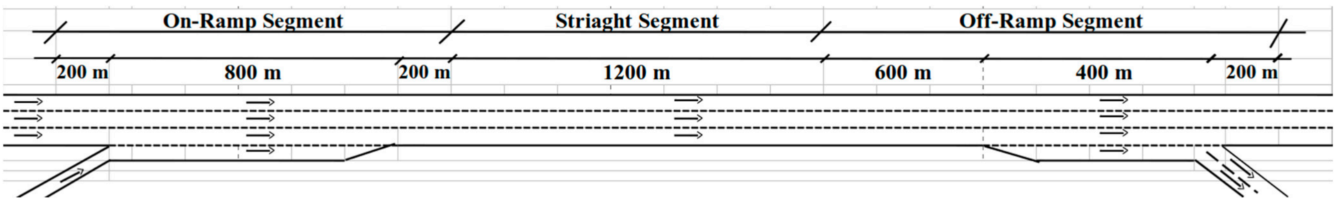

Figure 2. Hypothetical highway section.

One on-ramp entrance with one lane;
One auxiliary merge lane after the on-ramp, 800 m in length;
One off-ramp exit with two lanes;
One auxiliary diverge lane before the off-ramp, 400 m in length;
A lane width of 3.65 m;

Three distinguished segments, namely, on-ramp, straight, and off-ramp, each 1200 m in length.

In this study, one hour and forty minutes (i.e., 100 min or 6000 s) of traffic were simulated. For each scenario, 10 simulation runs, with each run using different random seeds, were applied with a warm-up period of 20 min. The last 20 min were also excluded, and only the middle 60 min were used. The simulation was performed for different speed limits for TT vehicles. Then, the output of the SSM file generated by SUMO was used to obtain the average number of total conflicts using three TTC thresholds: TTC $\leq$ 2.50 s, TTC $\leq$ 1.50 s and TTC $\leq$ 0.50 s; and two DRAC thresholds: DRAC $\geq$ 3.35 m/s^2, and DRAC $\geq$ 6.0 m/s^2, using the 10 simulation runs.

Traffic Conflict Ratio

To evaluate the effectiveness of increasing the TT speed limit with different traffic demand, the simulated conflicts before and after increasing the TT speed limit are estimated, and the conflict ratio (ρ) is obtained as follows [15,16]:

$$\rho = \frac{C_a}{C_b} \tag{3}$$

with a variance of:

$$Var(\rho) = (C_a/C_b)^2 \times \left[\left(Var(C_a)/{C_a}^2\right) + \left(Var(C_b)/{C_b}^2\right)\right] \quad (4)$$

where:

ρ = conflict ratio;
C_a = average number of conflicts after increasing the speed limit (i.e., after);
C_b = average number of conflicts before increasing the speed limit (i.e., before);
$Var(C_a)$ = variance of the conflicts in the after;
$Var(C_b)$ = variance of the conflicts in the before.

The "ρ" value can be viewed as a modification factor based on conflicts [12]. A value of "ρ" greater than "1.0" means that increasing the TT speed limit would increase the number of simulated conflicts and thus the number of accidents, while a value of "ρ" less than "1.0" means that increasing the TT speed limit will reduce the number of simulated conflicts and therefore reduce the number of accidents. A value of "ρ" equal to "1.0" would suggest that there is no safety change due to the increase in TT speed limit. The "ρ" statistical significance can be obtained in the same way as collision modification factors (CMFs). For CMFs, the speed limit increase would be statistically significant if the given confidence interval does not contain "1.0" [49]. In this study, the increase in the TT speed limit can be concluded to be statistically significant if the given confidence interval of "ρ" does not contain "1.0", because a value of "1.0" would imply the absence of a treatment effect [49,50]. The 5% significance level can be estimated as follows:

$$CI_{95\%} = \rho \pm 1.96 \times SE \quad (5)$$

where:

$CI_{95\%}$ = the confidence interval at the 5% significance level;
SE = the standard error from the 10 simulations.

3. Study Results

3.1. Delay Results

3.1.1. Delay Results for Highway Speed Limit of 90 km/h

Table 3 shows the simulated average network delay (in seconds per vehicle) along with standard deviations (between parentheses) for all vehicles from the 10 simulations. For the base scenario (i.e., TT speed limit of 60 km/h), the simulation results show that by increasing the traffic volume, the average network delay increases. The highest network delay happens at 2000 vehicle/h/lane with 15% TTs. These results are intuitive and are expected, which means that the simulation results are fine.

As shown from Table 3, increasing the TT speed limit to 70, 80, and 90 km/h would result in a reduction in the average network delay for all traffic volumes (500 to 2000 vehicle/h/lane) and for all percentages of TTs, compared with the base condition (i.e., TT speed limit of 60 km/h). All the reduction cases were found to be statistically significant at the 5% significance level. The relative reduction, from 60 to 70 km/h, was between 27.25% and 62.04%, with respect to the base case (60 km/h). Increasing the TT speed limit from 60 to 80 km/h, the relative delay reduction was between 38.07% and around 71.75%, and from 60 to 80 km/h, the relative delay reduction was between 38.35% and 76.32%. The delay reduction increases with increasing traffic volume and the increase in TT percentage, and the highest reductions occur at 2000 vehicle/h/lane with 15% TTs. It is worth noting that increasing the speed limit for TTs from 70 to 80 km/h would result in delay reduction between 14.88% and 31.67%, while increasing the speed limit for TTs from 80 to 90 km/h would result in the lowest delay reductions, which would be between 0.44% and 16.18%.

Table 3. Delay (in sec/vehicle) results for speed limit of 90 km/h.

Volume (vphpl)	%TTs	Tractor-Trailer Speed			
		60 km/h	**70 km/h**	**80 km/h**	**90 km/h**
500	2.5	2.61 (0.21) [a,b,c]	1.90 (0.08) [a,d,e]	1.62 (0.06) [b,d]	1.61 (0.09) [c,e]
1000		6.78 (0.52) [a,b,c]	4.91 (0.15) [a,d,e]	4.36 (0.11) [b,d]	4.31 (0.22) [c,e]
1500		13.44 (0.80) [a,b,c]	9.76 (0.39) [a,d,e]	8.84 (0.22) [b,d,f]	8.58 (0.20) [c,e,f]
2000		29.56 (2.52) [a,b,c]	20.56 (0.54) [a,d,e]	19.10 (0.70) [b,d]	18.83 (0.57) [c,e]
500	5	3.48 (0.26) [a,b,c]	2.10 (0.13) [a,d,e]	1.66 (0.08) [b,d]	1.59 (0.09) [c,e]
1000		8.43 (0.44) [a,b,c]	5.44 (0.12) [a,d,e]	4.60 (0.10) [b,d,f]	4.42 (0.16) [c,e,f]
1500		16.32 (0.70) [a,b,c]	10.52 (0.29) [a,d,e]	9.21 (0.20) [b,d,f]	8.83 (0.23) [c,e,f]
2000		36.41 (1.59) [a,b,c]	23.33 (0.59) [a,d,e]	20.62 (0.42) [b,d,f]	19.69 (0.52) [c,e,f]
500	7.5	4.06 (0.25) [a,b,c]	2.37 (0.07) [a,d,e]	1.69 (0.09) [b,d]	1.63 (0.08) [c,e]
1000		9.48 (0.31) [a,b,c]	5.78 (0.18) [a,d,e]	4.62 (0.07) [b,d,f]	4.36 (0.10) [c,e,f]
1500		20.01 (1.63) [a,b,c]	11.88 (0.29) [a,d,e]	9.52 (0.24) [b,d,f]	8.91 (0.19) [c,e,f]
2000		43.42 (2.57) [a,b,c]	26.54 (0.83) [a,d,e]	22.32 (0.74) [b,d,f]	20.97 (0.51) [c,e,f]
500	10	4.56 (0.28) [a,b,c]	2.52 (0.08) [a,d,e]	1.72 (0.13) [b,d]	1.68 (0.07) [c,e]
1000		10.78 (0.74) [a,b,c]	6.25 (0.18) [a,d,e]	4.72 (0.09) [b,d,f]	4.43 (0.13) [c,e,f]
1500		21.82 (1.83) [a,b,c]	12.58 (0.45) [a,d,e]	9.69 (0.22) [b,d,f]	8.92 (0.28) [c,e,f]
2000		54.61 (3.08) [a,b,c]	30.16 (1.17) [a,d,e]	24.19 (0.53) [b,d,f]	22.29 (0.90) [c,e,f]
500	15	5.41 (0.29) [a,b,c]	2.83 (0.13) [a,d,e]	1.74 (0.07) [b,d,f]	1.58 (0.06) [c,e,f]
1000		12.97 (0.88) [a,b,c]	6.91 (0.30) [a,d,e]	4.96 (0.20) [b,d,f]	4.48 (0.19) [c,e,f]
1500		27.30 (1.86) [a,b,c]	14.41 (0.46) [a,d,e]	10.28 (0.38) [b,d,f]	9.15 (0.16) [c,e,f]
2000		113.17 (10.45) [a,b,c]	42.97 (2.08) [a,d,e]	31.97 (2.42) [b,d,f]	26.79 (0.92) [c,e,f]

[a] The difference between the TT speed in the 60 and 70 km/h scenarios is significant at the 5% significance level.
[b] The difference between the TT speed in the 60 and 80 km/h scenarios is significant at the 5% significance level.
[c] The difference between the TT speed in the 60 and 90 km/h scenarios is significant at the 5% significance level.
[d] The difference between the TT speed in the 70 and 80 km/h scenarios is significant at the 5% significance level.
[e] The difference between the TT speed in the 70 and 90 km/h scenarios is significant at the 5% significance level.
[f] The difference between the TT speed in the 80 and 90 km/h scenarios is significant at the 5% significance level.
The standard deviations are in parentheses.

3.1.2. Simulated Average Delay Results for Highway Speed Limit of 100 km/h

For the speed limit of 90 km/h, Table 4 shows the simulated average network delay for all vehicles from the 10 runs. For the base scenario (i.e., TT speed limit of 70 km/h), the simulation results show that by increasing the traffic volume, the average network delay increases. The maximum network delay happens at 2000 vehicle/h/lane at TTs of 15%. These results are intuitive and are expected, which means that the simulation results are fine.

As shown from Table 4, increasing the TT speed limit to 80, 90, and 100 km/h would result in a reduction in the average network delay for all traffic volumes (500 to 2000 vehicle/h/lane) and for all percentages of TTs, compared with the base condition (i.e., TT speed limit of 70 km/h). For the 90 km/h speed limit, all the reduction cases were found to be statistically significant at the 5% significance level. The relative reduction, from 70 to 80 km/h, was between 23.10% and 41.94%, with respect to the base case (70 km/h). When increasing the TT speed limit from 70 to 90 km/h, the relative delay reduction was between 27.15% and around 60.33%, and from 70 to 100 km/h, the relative delay reduction was between 29.28% and 58.83%. The delay reduction increases with increasing traffic volume and with increasing TT percentage, and the highest reductions occur at 500 vehicle/h/lane with 15% TTs. It is worth noting that increasing the speed limit for TTs from 80 to 90 km/h would result in delay reduction between 5.27% and 31.68%, while increasing the speed limit for TTs from 80 to 90 km/h would result in the lowest delay reductions, which would be between 0.23% and 7.82%.

Table 4. Delay results for speed limit of 100 km/h.

Volume (vphpl)	%TTs	Tractor-Trailer Speed km/h			
		70 km/h	80 km/h	90 km/h	100 km/h
500	2.5	1.99 (0.07) [a,b,c]	1.53 (0.09) [a,e]	1.45 (0.11) [b]	1.41 (0.07) [c,e]
1000		5.12 (0.13) [a,b,c]	4.32 (0.12) [a,d,e]	4.03 (0.14) [b,d]	4.01 (0.10) [c,e]
1500		9.82 (0.15) [a,b,c]	8.48 (0.27) [a,d,e]	7.87 (0.20) [b,d]	7.82 (0.19) [c,e]
2000		19.98 (0.49) [a,b,c]	17.51 (0.52) [a,d,e]	16.33 (0.51) [b,d]	16.06 (0.29) [c,e]
500	5	2.51 (0.15) [a,b,c]	1.77 (0.07) [a,d,e]	1.41 (0.09) [b,d]	1.41 (0.09) [c,e]
1000		6.07 (0.14) [a,b,c]	4.76 (0.17) [a,d,e]	4.24 (0.15) [b,d,f]	4.08 (0.15) [c,e,f]
1500		11.36 (0.30) [a,b,c]	9.28 (0.26) [a,d,e]	8.11 (0.22) [b,d,f]	7.73 (0.27) [c,e,f]
2000		23.22 (0.43) [a,b,c]	19.55 (0.75) [a,d,e]	17.05 (0.39) [b,d]	17.01 (0.69) [c,e]
500	7.5	2.95 (0.16) [a,b,c]	1.82 (0.08) [a,d,e]	1.36 (0.11) [b,d]	1.41 (0.07) [c,e]
1000		6.67 (0.28) [a,b,c]	5.02 (0.12) [a,d,e]	4.19 (0.18) [b,d]	4.04 (0.18) [c,e]
1500		12.93 (0.50) [a,b,c]	9.93 (0.25) [a,d,e]	8.06 (0.26) [b,d]	7.91 (0.17) [c,e]
2000		27.86 (1.03) [a,b,c]	22.13 (0.97) [a,d,e]	18.54 (0.57) [b,d,f]	17.54 (0.44) [c,e,f]
500	10	3.18 (0.18) [a,b,c]	1.95 (0.08) [a,d,e]	1.40 (0.08) [b,d]	1.44 (0.07) [c,e]
1000		7.31 (0.20) [a,b,c]	5.27 (0.17) [a,d,e]	4.21 (0.12) [b,d]	4.12 (0.16) [c,e]
1500		14.29 (0.66) [a,b,c]	10.68 (0.39) [a,d,e]	8.27 (0.19) [b,d,f]	7.88 (0.21) [c,e,f]
2000		32.39 (0.80) [a,b,c]	24.97 (0.63) [a,d,e]	19.78 (0.61) [b,d,f]	18.93 (0.50) [c,e,f]
500	15	3.60 (0.15) [a,b,c]	2.09 (0.10) [a,d,e]	1.43 (0.11) [b,d]	1.48 (0.06) [c,e]
1000		8.52 (0.28) [a,b,c]	5.81 (0.19) [a,d,e]	4.35 (0.15) [b,d,f]	4.19 (0.16) [c,e,f]
1500		16.45 (0.55) [a,b,c]	11.75 (0.30) [a,d,e]	8.67 (0.18) [b,d,f]	8.08 (0.17) [c,e,f]
2000		45.58 (2.50) [a,b,c]	31.33 (1.41) [a,d,e]	23.28 (0.56) [b,d,f]	21.46 (0.66) [c,e,f]

[a] The difference between the TT speed in the 70 and 80 km/h scenarios is significant at the 5% significance level.
[b] The difference between the TT speed in the 70 and 90 km/h scenarios is significant at the 5% significance level.
[c] The difference between the TT speed in the 70 and 100 km/h scenarios is significant at the 5% significance level.
[d] The difference between the TT speed in the 80 and 90 km/h scenarios is significant at the 5% significance level.
[e] The difference between the TT speed in the 80 and 100 km/h scenarios is significant at the 5% significance level.
[f] The difference between the TT speed in the 90 and 100 km/h scenarios is significant at the 5% significance level.
The standard deviations are in parentheses.

3.2. Simulated Traffic Conflict Results

3.2.1. Speed Limit of 90 km/h for PCs

For the base case of TTs with a 60 km/h speed limit, the results show that for all TTC and DRAC thresholds, the total number of traffic conflicts increases with increasing traffic volume for different TT percentages. The maximum number of conflicts occurred at 2000 vehicle/h/lane and 15% TTs.

The mean and standard errors of the conflict ratios ("ρ") for total conflicts at TTC $\leq$ 2.50 s, TTC $\leq$ 1.50 s, TTC $\leq$ 0.50 s, DRAC $\geq$ 3.35 m/s^2, and DRAC $\geq$ 6.0 m/s^2 for different TT speed limit scenarios versus the base scenario (60 km/h) are shown in Tables 5–7.

Table 5. Conflict ratio between TT speed of 60 km/h before and TT speed of 70 km/h after for PC speed limit of 90 km/h.

Volume (vphpl)	%TTs	DRAC $\geq$ 3.35	DRAC $\geq$ 6.0	TTC $\leq$ 0.50	TTC $\leq$ 1.50	TTC $\leq$ 2.50
500	2.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	0.050 (0.050)	0.429 (0.389)
1000		0.012 (0.005)	1.000 (0.000)	1.000 (0.000)	0.143 (0.178)	0.700 (0.264)
1500		0.235 (0.146)	0.050 (0.050)	2.000 (2.517)	0.913 (0.485)	0.318 (0.060)
2000		1.067 (0.374)	2.500 (2.934)	0.625 (0.422)	0.830 (0.155)	0.406 (0.051)
500	5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	10.00 (10.49)	0.625 (0.341)
1000		0.375 (0.323)	0.050 (0.050)	1.000 (0.000)	0.286 (0.334)	0.109 (0.048)
1500		0.176 (0.101)	0.500 (0.601)	1.000 (1.414)	1.000 (0.325)	0.358 (0.073)
2000		1.000 (0.322)	3.000 (2.404)	2.800 (1.830)	0.834 (0.079)	0.282 (0.017)

Table 5. *Cont.*

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	7.5	1.000 (1.414)	1.000 (0.000)	1.000 (0.000)	1.000 (1.414)	0.417 (0.224)
1000		0.500 (0.391)	1.000 (0.000)	1.000 (0.000)	0.750 (0.676)	0.213 (0.083)
1500		0.200 (0.152)	0.050 (0.050)	2.000 (2.828)	0.759 (0.264)	0.229 (0.023)
2000		0.857 (0.453)	1.500 (1.462)	2.000 (1.750)	0.588 (0.125)	0.291 (0.032)
500	10	0.025 (0.018)	1.000 (0.000)	1.000 (0.000)	0.100 (0.100)	0.429 (0.457)
1000		0.125 (0.131)	1.000 (0.000)	1.000 (0.000)	0.012 (0.006)	0.252 (0.075)
1500		0.500 (0.289)	0.050 (0.050)	0.667 (0.818)	0.641 (0.201)	0.341 (0.058)
2000		0.833 (0.414)	1.000 (0.875)	0.800 (0.764)	0.233 (0.041)	0.192 (0.015)
500	15	1.000 (1.414)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)	1.000 (0.720)
1000		1.000 (1.414)	1.000 (0.000)	1.000 (0.000)	0.238 (0.178)	0.235 (0.057)
1500		1.667 (1.129)	3.000 (3.367)	4.000 (4.807)	0.276 (0.115)	0.234 (0.035)
2000		0.089 (0.029)	0.333 (0.267)	0.278 (0.187)	0.032 (0.007)	0.128 (0.016)

The standard deviations are in parentheses.

Table 6. Conflict ratio between TT speed of 60 km/h before and TT speed of 80 km/h after for PC speed limit of 90 km/h.

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	2.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	0.500 (0.707)	0.286 (0.250)
1000		0.012 (0.005)	1.000 (0.000)	1.000 (0.000)	0.714 (0.687)	0.400 (0.149)
1500		0.118 (0.085)	0.050 (0.050)	0.500 (0.707)	0.739 (0.417)	0.207 (0.054)
2000		0.200 (0.112)	0.500 (0.707)	1.500 (0.905)	1.038 (0.214)	0.293 (0.038)
500	5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)	0.375 (0.291)
1000		0.006 (0.003)	0.050 (0.050)	1.000 (0.000)	0.286 (0.257)	0.163 (0.057)
1500		0.003 (0.001)	0.025 (0.017)	0.050 (0.050)	0.810 (0.327)	0.194 (0.044)
2000		1.067 (0.310)	2.500 (1.863)	3.200 (1.988)	0.738 (0.137)	0.217 (0.020)
500	7.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	0.100 (0.100)	0.008 (0.004)
1000		0.012 (0.005)	1.000 (0.000)	1.000 (0.000)	0.750 (0.676)	0.170 (0.059)
1500		0.005 (0.002)	0.050 (0.050)	2.000 (2.828)	0.690 (0.273)	0.156 (0.023)
2000		0.714 (0.314)	3.000 (2.285)	1.667 (1.309)	0.516 (0.125)	0.211 (0.021)
500	10	0.025 (0.017)	1.000 (0.000)	1.000 (0.000)	1.000 (1.414)	0.429 (0.270)
1000		0.006 (0.002)	1.000 (0.000)	1.000 (0.000)	0.250 (0.274)	0.055 (0.032)
1500		0.333 (0.240)	1.000 (1.414)	1.000 (1.006)	0.744 (0.190)	0.220 (0.030)
2000		1.083 (0.454)	1.000 (0.720)	1.800 (1.504)	0.205 (0.055)	0.112 (0.011)
500	15	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)	0.033 (0.017)
1000		1.000 (1.414)	1.000 (0.000)	1.000 (0.000)	0.143 (0.111)	0.033 (0.018)
1500		0.667 (0.559)	2.000 (2.404)	2.000 (2.828)	0.500 (0.162)	0.139 (0.019)
2000		0.065 (0.030)	0.333 (0.365)	0.556 (0.409)	0.024 (0.008)	0.083 (0.015)

The standard deviations are in parentheses.

Table 7. Conflict ratio between TT speed of 60 km/h before and TT speed of 90 km/h after for PC speed limit of 90 km/h.

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	2.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	0.050 (0.050)	0.014 (0.008)
1000		0.012 (0.005)	1.000 (0.000)	1.000 (0.000)	0.014 (0.011)	0.003 (0.001)
1500		0.003 (0.001)	0.050 (0.050)	0.050 (0.050)	0.609 (0.315)	0.033 (0.014)
2000		0.800 (0.284)	2.500 (2.739)	1.250 (0.757)	0.972 (0.151)	0.003 (0.001)
500	5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)	1.375 (0.715)
1000		0.006 (0.003)	0.050 (0.050)	1.000 (0.000)	0.571 (0.468)	0.076 (0.025)
1500		0.118 (0.084)	0.500 (0.601)	3.000 (3.367)	1.429 (0.493)	0.040 (0.013)
2000		0.800 (0.362)	4.000 (3.127)	2.000 (1.520)	0.710 (0.091)	0.003 (0.001)

Table 7. *Cont.*

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	7.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (1.414)	5.083 (1.659)
1000		0.012 (0.005)	1.000 (0.000)	1.000 (0.000)	0.500 (0.433)	0.543 (0.121)
1500		0.200 (0.152)	1.000 (1.414)	3.000 (3.682)	0.759 (0.288)	0.170 (0.029)
2000		1.214 (0.460)	4.500 (3.468)	2.500 (1.964)	0.527 (0.123)	0.018 (0.003)
500	10	0.025 (0.017)	1.000 (0.000)	1.000 (0.000)	0.100 (0.100)	13.28 (5.444)
1000		0.006 (0.002)	1.000 (0.000)	1.000 (0.000)	0.250 (0.274)	0.598 (0.114)
1500		0.833 (0.359)	1.000 (1.414)	1.000 (1.006)	1.103 (0.275)	0.812 (0.074)
2000		0.750 (0.381)	0.667 (0.559)	2.600 (1.922)	0.302 (0.068)	0.057 (0.005)
500	15	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)	177.00 (91.03)
1000		0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	0.005 (0.001)	4.013 (0.399)
1500		1.000 (0.720)	0.050 (0.050)	3.000 (3.682)	0.362 (0.131)	1.398 (0.144)
2000		0.145 (0.045)	0.333 (0.267)	0.889 (0.562)	0.009 (0.001)	0.037 (0.004)

The standard deviations are in parentheses.

Increasing TT Speed Limit from 60 to 70 km/h (Table 5)

- ***TTs = 2.5%:***

For DRAC ≥ 3.35 m/s^2, the results in Table 5 show that increasing the TT speed limit reduced the conflict ratio (i.e., increased safety) by 0.05 to 0.24 for a traffic volume of 500 to 1500 vehicles/h/lane. This implies that the total conflicts in the after period (i.e., increasing the speed limit of TTs to 70 km/h) reduced from 0.76 to 0.95 times the total conflicts for the base case of 60 km/h TTs. For 2000 vehicles/h/lane, the results show an increase in the conflict ratio of 1.067, implying a safety problem, but this increase is not statistically significant different from "1.0" at the 5% level.

For DRAC ≥ 6.0 m/s^2, the results show that there is no difference in conflict ratio (ρ = 1) for traffic volumes of 500 and 1000 vehicles/h/lane; at a traffic volume of 1500 vehicles/h/lane, there is a statistically significant reduction in the conflict ratio of 0.05 (i.e., increase in safety thereafter); and there is an increase in the conflict ratio at 2000 vehicles/h/lane, but this increase is not statistically different from one at the 5% level.

For TTC ≤ 0.50 s, the results show that there is no difference in conflict ratio (ρ = 1) for traffic volumes of 500 and 1000 vehicles/h/lane (same as for DRAC ≥ 6.0 m/s^2); at a traffic volume of 1500 vehicles/h/lane, there is a statistically significant increase in the conflict ratio; and there is a reduction in the conflict ratio at 2000 vehicles/h/lane, but neither the increase or reduction at the 1500 and 2000 volumes are statistically different from one at the 5% level.

For TTC ≤ 1.50 s and TTC ≤ 2.50 s, the results show that there is reduction in conflict ratio for all traffic volumes (i.e., increased safety). These reductions are statistically significant only at 500 and 1000 vehicle/h/lane for TTC ≤ 1.50 s, and 1500 and 2000 vehicle/h/lane for TTC ≤ 2.50 s.

- ***TTs = 5.0–15.0%:***

For TT percentages of 5.0 to 15.0%, the results are similar to 2.5%, with no statistically significant increase in the conflict ratio, and all cases showing increases in the conflict ratio in the after period. While for some cases there are statistically significant reductions in the conflict ratio, most of the reduction cases are not statistically different from the one at the 5% level, which suggests there is no change in safety.

Increasing TT Speed Limit from 60 to 80 km/h (Table 6)

- ***TTs = 2.5%:***

For a DRAC ≥ 3.35 m/s^2, the results in Table 6 show that increasing the TT speed limit reduced the conflict ratio (i.e., increased safety) by 0.05 to 0.20 for all traffic volumes. This implies that the total simulated conflicts in the after period (i.e., increasing the speed limit of TTs to 80 km/h) reduced the total simulated conflicts by 0.80 to 0.95 times compared to the base case of 60 km/h TTs.

For DRAC $\geq$ 6.0 m/s^2, the results show that there is no difference in conflict ratio (ρ = 1) for 500 and 1000 vehicles/h/lane; at 1500 vehicles/h/lane, there is a statistically significant reduction in the conflict ratio of 0.05 (i.e., increase in safety thereafter); and there is reduction in the conflict ratio at 2000 vehicles/h/lane, but this reduction is not statistically different from the one at the 5% level.

For TTC $\leq$ 0.50 s and TTC $\leq$ 1.50 s, the results show that there is no statistically significant difference in conflict ratio for all traffic volumes, while for TTC $\leq$ 2.50 s, the results show that there is significant reduction in conflict ratio for all traffic volumes (i.e., increased safety).

- ***TTs = 5.0–15.0%:***

For TT percentages of 5.0 to 15.0%, the results are similar to 2.5%, with no statistically significant increase in the conflict ratio, and all cases showing an increase in the conflict ratio in the after period. While for some cases there were statistically significant reductions in the conflict ratio, most of the reduction cases were not statistically different from the one at the 5% level, suggesting there was no change in safety.

Increasing TT Speed Limit from 60 to 90 km/h (Table 7)

The results of increasing the TT speed limit from 60 to 90 km/h are similar to the previous case (increase to 70 and 80 km/h). For all of the cases that showed an increase in the conflict ratio (one case for DRAC $\geq$ 3.35 m/s^2; three cases for DRAC $\geq$ 6.0 m/s^2; four cases for TTC $\leq$ 0.5 s; one case for TTC $\leq$ 1.50 s; and four cases for TTC $\leq$ 2.50 s), no statistically significant differences were found compared to the 5% level. For other cases, there were significant reductions in the conflict ratio, but most cases showed either no change in the conflict ratio (ρ = 1), or no statistically significant difference compared to the 5% level for the other cases, showing a reduction in the conflict ratio.

3.2.2. Speed Limit of 100 km/h for PCs

Tables 8–10 show the simulated conflict ratio results for increasing the TT speed limit from 70 km/h to 80 km/h, 90 km/h, and 100 km/h, respectively.

Table 8. Conflict ratio between TT speed of 70 km/h before and TT speed of 80 km/h after for PC speed limit of 100 km/h.

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	2.5	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)
1000		0.017 (0.008)	1.000 (0.000)	0.100 (0.100)	0.250 (0.286)	0.357 (0.141)
1500		0.429 (0.254)	40.00 (26.67)	20.00 (20.00)	1.240 (0.415)	0.545 (0.094)
2000		1.556 (0.758)	2.000 (1.732)	1.750 (0.892)	1.283 (0.223)	0.831 (0.088)
500	5	0.017 (0.012)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.333 (0.409)
1000		0.005 (0.002)	1.000 (0.000)	1.000 (0.000)	3.500 (2.774)	0.485 (0.154)
1500		0.538 (0.329)	1.000 (1.414)	1.500 (1.841)	0.813 (0.261)	0.575 (0.112)
2000		0.765 (0.254)	0.500 (0.401)	1.200 (1.070)	0.769 (0.150)	0.674 (0.066)
500	7.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.100 (0.100)
1000		0.143 (0.152)	1.000 (0.000)	1.000 (0.000)	0.033 (0.024)	0.229 (0.104)
1500		0.176 (0.096)	1.000 (1.414)	2.000 (2.404)	1.000 (0.401)	0.557 (0.083)
2000		0.448 (0.134)	0.400 (0.321)	0.105 (0.109)	0.983 (0.155)	0.680 (0.083)
500	10	0.025 (0.017)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)	0.429 (0.400)
1000		0.167 (0.200)	1.000 (0.000)	1.000 (0.000)	1.500 (1.462)	0.444 (0.162)
1500		0.214 (0.116)	1.000 (1.414)	0.025 (0.017)	0.342 (0.124)	0.521 (0.094)
2000		1.067 (0.364)	1.000 (0.943)	2.000 (2.404)	1.000 (0.192)	0.581 (0.057)

Table 8. *Cont.*

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	15	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.333 (0.374)
1000		0.167 (0.178)	20.00 (20.00)	10.00 (10.00)	1.333 (0.690)	0.583 (0.190)
1500		1.000 (1.414)	1.000 (0.000)	10.00 (10.00)	0.692 (0.295)	0.615 (0.117)
2000		3.250 (1.386)	1.000 (0.943)	1.250 (0.889)	0.442 (0.087)	0.385 (0.045)

The standard deviations are in parentheses.

Table 9. Conflict ratio between TT speed of 70 km/h before and TT speed of 90 km/h after for PC speed limit of 100 km/h.

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	2.5	1.000 (0.000)	1.000 (0.316)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
1000		0.017 (0.008)	1.000 (0.316)	0.100 (0.100)	0.250 (0.286)	0.179 (0.088)
1500		0.143 (0.149)	1.000 (0.000)	30.00 (21.34)	0.800 (0.278)	0.412 (0.074)
2000		0.333 (0.206)	0.500 (0.601)	0.500 (0.391)	1.141 (0.220)	0.653 (0.063)
500	5	0.017 (0.013)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)	0.667 (0.650)
1000		0.091 (0.097)	1.000 (0.000)	1.000 (0.000)	1.000 (0.943)	0.424 (0.161)
1500		0.231 (0.186)	3.000 (3.682)	1.000 (1.414)	0.500 (0.148)	0.438 (0.053)
2000		0.353 (0.169)	0.667 (0.443)	1.200 (0.888)	0.846 (0.184)	0.523 (0.045)
500	7.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)	2.000 (2.404)
1000		0.007 (0.003)	1.000 (0.000)	1.000 (0.000)	1.333 (1.094)	0.429 (0.138)
1500		0.059 (0.060)	0.050 (0.050)	1.000 (1.414)	1.143 (0.495)	0.379 (0.057)
2000		0.552 (0.207)	0.800 (0.569)	0.895 (0.460)	0.809 (0.144)	0.483 (0.062)
500	10	0.025 (0.017)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.143 (0.167)
1000		0.008 (0.006)	1.000 (0.000)	1.000 (0.000)	0.500 (0.601)	0.178 (0.072)
1500		0.071 (0.073)	0.050 (0.050)	0.500 (0.601)	0.421 (0.160)	0.265 (0.082)
2000		1.133 (0.529)	2.000 (2.028)	6.500 (6.996)	1.200 (0.211)	0.454 (0.045)
500	15	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)	0.333 (0.374)
1000		0.008 (0.003)	1.000 (0.000)	10.00 (10.00)	1.000 (0.521)	0.444 (0.189)
1500		2.000 (2.404)	1.000 (0.000)	30.00 (21.34)	1.154 (0.368)	0.546 (0.105)
2000		3.500 (1.495)	1.500 (1.258)	1.750 (1.105)	0.584 (0.122)	0.253 (0.033)

The standard deviations are in parentheses.

Table 10. Conflict ratio between TT speed of 70 km/h before and TT speed of 100 km/h after for PC speed limit of 100 km/h.

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	2.5	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.316)
1000		0.017 (0.008)	1.000 (0.000)	0.100 (0.100)	1.250 (0.889)	0.357 (0.141)
1500		0.143 (0.149)	20.00 (20.00)	20.000(20.00)	0.880 (0.357)	0.352 (0.076)
2000		1.111 (0.510)	0.500 (0.601)	1.000 (0.759)	0.989 (0.196)	0.723 (0.087)
500	5	0.017 (0.012)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.333 (0.409)
1000		0.005 (0.002)	1.000 (0.000)	1.000 (0.000)	0.500 (0.601)	0.273 (0.100)
1500		0.154 (0.118)	0.050 (0.050)	2.000 (2.285)	0.563 (0.260)	0.346 (0.079)
2000		0.353 (0.190)	0.500 (0.314)	2.800 (2.015)	1.096 (0.197)	0.573 (0.074)
500	7.5	0.050 (0.050)	1.000 (0.000)	1.000 (0.000)	10.00 (10.00)	1.000 (1.414)
1000		0.007 (0.003)	1.000 (0.000)	1.000 (0.000)	0.033 (0.024)	0.143 (0.070)
1500		0.353 (0.261)	1.000 (1.414)	1.500 (1.841)	1.190 (0.491)	0.471 (0.105)
2000		0.724 (0.244)	1.600 (0.969)	0.421 (0.256)	1.009 (0.140)	0.470 (0.063)
500	10	0.025 (0.017)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.143 (0.167)
1000		0.008 (0.006)	1.000 (0.000)	1.000 (0.000)	1.000 (0.943)	0.222 (0.077)
1500		0.286 (0.129)	2.000 (2.404)	0.750 (0.731)	0.553 (0.208)	0.395 (0.075)
2000		0.600 (0.200)	2.000 (1.563)	2.000 (2.404)	0.768 (0.160)	0.373 (0.037)

Table 10. *Cont.*

Volume (vphpl)	%TTs	DRAC ≥ 3.35	DRAC ≥ 6.0	TTC ≤ 0.50	TTC ≤ 1.50	TTC ≤ 2.50
500	15	1.000 (1.414)	1.000 (0.000)	1.000 (0.000)	10.00(10.00)	0.667 (0.559)
1000		0.333 (0.254)	1.000 (0.000)	20.00 (20.00)	1.000 (0.676)	0.583 (0.242)
1500		2.000 (2.404)	40.00 (26.67)	20.00 (20.00)	0.846 (0.338)	0.328 (0.064)
2000		2.375 (1.019)	3.500 (2.672)	2.125 (1.261)	0.551 (0.101)	0.233 (0.025)

The standard deviations are in parentheses.

The results for the PC speed limit of 100 km/h are similar to the results obtained at the PC speed limit of 90 km/h. Of all the cases that show an increase in conflict ratio, there is no statistically significant difference compared to the 5% level. For other cases, there is a significant reduction in the conflict ratio, but most cases show either no change in the conflict ratio (ρ = 1) or no statistically significant difference compared to the 5% level.

4. Conclusions

This study describes a simulation study to evaluate the effects of increasing the speed limit of tractor-trailers (TTs) on the safety and mobility of Egyptian three-lane highways. In this study, only highways with speed limits of passenger cars of 90 and 100 km/h were considered. For the 90 km/h speed limit for PCs, the TT speed limits considered were 60, 70, and 80 km/h for the differential speed limit (DSL) strategy, along with the TT speed limit of 90 km/h for the uniform speed limit (USL) strategy. For the 100 km/h speed limit for PCs, the TT speed limits considered were 70, 80, and 90 km/h, for the DSL strategy, and 100 km/h for the USL strategy.

The average network delay (second/vehicle) was used as the measure of mobility performance, and the conflict ratio based on both the deceleration rate to avoid crash (DRAC) and the time to collision (TTC) surrogate safety measures were used as indicators of safety performance. The SUMO model was used to model the increase in the TT speed limits and their effects for different traffic volumes along with different percentages of TTs. The SUMO surrogate safety measure (SSM) file, as a direct output of the SUMO model, was used to obtain simulated conflicts with TTC ≤ 2.50 s, representing less severe conflicts; TTC ≤ 1.50 s, representing medium-severity conflicts; and TTC ≤ 0.50 s, representing severe conflicts. Additionally, DRAC ≥ 3.35 m/s^2, representing less severe to medium-severity conflicts, and DRAC ≥ 6.0 m/s^2, representing severe conflicts, were used as well. Based on the simulation results, we can conclude the following results:

For the speed limit of 90 km/h for PCs, increasing TT speed limit to 70, 80, and 90 km/h would result in statistically significant reduction in the average network delay for all traffic volumes (500 to 2000 vphpl) and for all percentages of TTs (2.5–15% of total traffic volume), compared with the base condition (i.e., TT speed limit of 60 km/h); the relative delay reduction, from 60 to 70 km/h, was between 27.25% and 62.04%. When increasing TT speed limit from 60 to 80 km/h, the relative delay reduction was between 38.07% and 71.75%; and from 60 to 80 km/h, the relative delay reduction was between 38.35% and 76.32%. Additionally, increasing the speed limit for TTs from 70 to 80 km/h would result in delay reduction between 14.88% and 31.67%, while increasing the speed limit for TTs from 80 to 90 km/h would result in delay reductions between 0.44% and 16.18%.

For the speed limit of 100 km/h for PCs, increasing TT speed limit to 80, 90, and 100 km/h would result in a statistically significant reduction in the average network delay for all traffic volumes (500 to 2000 vphpl) and for all percentages of TTs (2.5–15% of total traffic volume) compared with the base condition (i.e., TT speed limit of 70 km/h). The relative reduction, from 70 to 80 km/h, was between 23.10% and 41.94%. When increasing the TT speed limit from 70 to 90 km/h, the relative delay reduction was between 27.15% and 60.33%, and from 70 to 100 km/h, the relative delay reduction was between 29.28% and 58.83%. In addition, increasing the speed limit for TTs from 80 to 90 km/h would result in delay reduction between 5.27% and 31.68%, while increasing the speed limit for TTs from 80 to 90 km/h would result in delay reductions between 0.23% and 7.82%.

In terms of safety, in general increasing the TT speed limit would result in statistically significant safety enhancement in some cases (i.e., conflict ratio less than 1.0), and no statistically significant change in the safety situation (i.e., conflict ratio not different than 1.0) for all other cases (i.e., increase or reduction in the conflict ratio between after and before).

For all cases showing an increase in conflict ratio, there was no statistically significant difference between the conflict ratio and 1.0 at the 5% level for all cases, which means there was no change in the safety situation between before and after.

For all other cases, either there was no change in the conflict ratio (ρ = 1), or no statistically significant difference compared to the one at the 5% level for the other cases showing a reduction in conflict ratio.

Based on the results of this study, there is no evidence that decreasing the speed limit of TTs by 30 km/h, 20 km/h, or 10 km/h less than the speed limit of PCs would result in any enhancement in the safety situation, as there was no statistically significant change in the conflict ratio to support such results; hence, it is recommended to increase the speed limit for TTs on Egyptian highways and use the USL strategy. This would significantly reduce the delay already encountered with the current DSL policy of reducing the speed limit by 30 km/h less than PCs.

It should be noted that the study results assume that all drivers obey their speed limits 100% of the time (i.e., no speeding), which may not be the case in real life. Therefore, the actual safety situation may differ from that obtained in this simulation study if the speed limit is exceeded.

To confirm the results of this study, it is strongly recommended to use observed crashes, which were not available to the author, along with simulated surrogate safety measures.

Author Contributions: Conceptualization, U.E.S. and S.N.; software, U.E.S.; formal analysis, U.E.S., S.N. and J.W.H.; investigation, U.E.S. and S.N.; writing—original draft preparation, U.E.S.; writing—review and editing, U.E.S. and S.N.; visualization, U.E.S. and S.N.; supervision, J.W.H.; methodology, U.E.S., S.N. and J.W.H.; project administration, J.W.H.; funding acquisition, S.N. and J.W.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Incheon National University Research Grant in 2022.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. TRB. *Transportation Research Board. Highway Capacity Manual: A Guide for Multimodal Mobility Analysis*, 6th ed.; The National Academies Press: Washington, DC, USA, 2016.
2. Wang, M. Impact of Operational Speed Characteristics of Heavy Vehicles on High-Speed Highways. Master's Thesis, York University, Toronto, ON, Canada, 2019.
3. Plonka, S.C.; Byrne, P.A.; Ma, T.; Rubin, F.; Dessau, E. *Evaluation of Ontario ' s Speed Limiter Program for Large Trucks: A Study of Safety Outcomes Post 2009 Legislation: Final Report*; Ministry of Transportation: Toronto, ON, Canada, 2018.
4. Gates, T.J.; Savolainen, P.T.; Russo, B.J.; Hamzeie, R.; Kay, J.J.; Frazier, S.; Finkelman, J. *Safety and Operational Impacts of Differential Speed Limits on Two-Lane Rural Highways in Montana: Final Report*; Montana Department of Transportation: Helena, MT, USA, 2016.
5. Savolainen, P.; Gates, T.; Hacker, E.; Davis, A.; Frazier, S.; Russo, B.; Rista, E.; Parker, M.; Mannering, F.; Schneider, W. *Evaluating the Impacts of Speed Limit Policy Alternatives*; Michigan Department of Transportation. Office of Research Administration: Detroit, MI, USA, 2014.
6. Saccomanno, F.F.; Duong, D.; Cunto, F.; Hellinga, B.; Philp, C.; Thiffault, P. Safety Implications of Mandated Truck Speed Limiters on Freeways. *Transp. Res. Rec.* **2009**, *2096*, 65–75. [CrossRef]
7. Davis, H.; Gudishala, R.; Zeringue, K.; Wilmot, C.; Codjoe, J.; Roberts, M. *Literature Review of the Implications of Differential Speed Limit Implementation*; Louisiana Transportation Research Center: Baton Rouge, LA, USA, 2017.

8. NHTSA. *National Highway Traffic Safety Administration. Speed Enforcement Program Guidelines*; National Highway Traffic Safety Administration: Washington, DC, USA, 2008.
9. Johnson, S.L.; Pawar, N. *Cost-Benefit Evaluation of Large Truck-Automobile Speed Limit Differentials on Rural Interstate Highways*; National Academy of Sciences: Washington, DC, USA, 2005.
10. Garber, N.J.; Miller, J.S.; Yuan, B.; Sun, X. Safety Effects of Differential Speed Limits on Rural Interstate Highways. *Transportation Research Record* **2003**, *1830*, 56–62. [CrossRef]
11. Garber, N.J.; Miller, J.S.; Sun, X.; Yuan, B. Safety Impacts of Differential Speed Limits for Trucks and Passenger Cars on Rural Interstate Highways: A Modified Empirical Bayes Approach. *J. Transp. Eng.* **2006**, *132*, 19–29. [CrossRef]
12. Shahdah, U.E. Empirical Bayesian Before-and-After Analysis of Treatments: Simulated Traffic Conflict Approach. *Int. J. Traffic Transp. Eng.* **2020**, *10*, 48–60. [CrossRef]
13. Xing, L.; He, J.; Abdel-Aty, M.; Cai, Q.; Li, Y.; Zheng, O. Examining Traffic Conflicts of up Stream Toll Plaza Area Using Vehicles' Trajectory Data. *Accid. Anal. Prev.* **2019**, *125*, 174–187. [CrossRef] [PubMed]
14. Charly, A.; Mathew, T.V. Estimation of Traffic Conflicts Using Precise Lateral Position and Width of Vehicles for Safety Assessment. *Accid. Anal. Prev.* **2019**, *132*, 105264. [CrossRef] [PubMed]
15. Shahdah, U.; Saccomanno, F.; Persaud, B. Integrated Traffic Conflict Model for Estimating Crash Modification Factors. *Accid. Anal. Prev.* **2014**, *71*, 228–235. [CrossRef] [PubMed]
16. Shahdah, U.; Saccomanno, F.; Persaud, B. Application of Traffic Microsimulation for Evaluating Safety Performance of Urban Signalized Intersections. *Transp. Res. Part C Emerg. Technol.* **2015**, *60*, 96–104. [CrossRef]
17. Saccomanno, F.F.; Cunto, F.; Guido, G.; Vitale, A. Comparing Safety at Signalized Intersections and Roundabouts Using Simulated Rear-End Conflicts. *Transp. Res. Rec.* **2008**, *2078*, 90–95. [CrossRef]
18. Cunto, F.; Saccomanno, F.F. Calibration and Validation of Simulated Vehicle Safety Performance at Signalized Intersections. *Accid. Anal. Prev.* **2008**, *40*, 1171–1179. [CrossRef] [PubMed]
19. Cunto, F. Assessing Safety Performance of Transportation Systems Using Microscopic Simulation. Ph.D. Thesis, University of Waterloo, Waterloo, ON, Canada, 2008.
20. PTV. Planung Transport Verkehr AG. PTV VISSIM: Computer Software. Available online: https://www.myptv.com/en/mobility-software/ptv-vissim (accessed on 1 June 2022).
21. Sykes, P. Traffic Simulation with Paramics. In *Fundamentals of Traffic Simulation*; Barceló, J., Ed.; Springer: New York, NY, USA, 2010; pp. 131–171.
22. Casas, J.; Ferrer, J.L.; Garcia, D.; Perarnau, J.; Torday, A. Traffic Simulation with Aimsun. In *Fundamentals of Traffic Simulation*; Barceló, J., Ed.; Springer: New York, NY, USA, 2010; pp. 173–232.
23. Lopez, P.A.; Behrisch, M.; Bieker-Walz, L.; Erdmann, J.; Flötteröd, Y.-P.; Hilbrich, R.; Lücken, L.; Rummel, J.; Wagner, P.; WieBner, E. Microscopic Traffic Simulation Using Sumo. In Proceedings of the 2018 21st International Conference on Intelligent Transportation Systems (ITSC), Maui, HI, USA, 4–7 November 2018; pp. 2575–2582.
24. Krajzewicz, D. Traffic Simulation with SUMO–Simulation of Urban Mobility. In *Fundamentals of Traffic Simulation*; Barceló, J., Ed.; Springer: New York, NY, USA, 2010; pp. 269–293.
25. Rakha, H.; Van Aerde, M. *INTEGRATION Release 2.40 for Windows: Users Guide, Volume I: Fundamental Model Features.*; M. Van Aerde & Assoc., Ltd.: Blacksburg, VA, USA, 2013.
26. McTrans. CORSIM: Microscopic Traffic Simulation Model. Available online: https://mctrans.ce.ufl.edu/tsis-corsim (accessed on 1 June 2022).
27. Ben-Akiva, M.; Koutsopoulos, H.N.; Toledo, T.; Yang, Q.; Choudhury, C.F.; Antoniou, C.; Balakrishna, R. Traffic Simulation with MITSIMLab. In *Fundamentals of Traffic Simulation*; Barceló, J., Ed.; International Series in Operations Research & Management Science; Springer: New York, NY, USA, 2010; Volume 145, pp. 233–268. ISBN 978-1-4419-6141-9.
28. Krauß, S. *Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics*; University of Cologne: Köln, Germany, 1998.
29. Treiber, M.; Hennecke, A.; Helbing, D. Congested Traffic States in Empirical Observations and Microscopic Simulations. *Phys. Rev. E–Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.* **2000**, *62*, 1805–1824. [CrossRef] [PubMed]
30. Milanés, V.; Shladover, S.E. Modeling Cooperative and Autonomous Adaptive Cruise Control Dynamic Responses Using Experimental Data. *Transp. Res. Part C Emerg. Technol.* **2014**, *48*, 285–300. [CrossRef]
31. Hayward, J.C. *Near Miss Determination through Use of a Scale of Danger*; Highway Research Record: National Research Council; Highway Research Board: Washington, DC, USA, 1972; pp. 24–34.
32. Hydén, C. *The Development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflicts Technique*; Trafikteknik Tekniska Hoegskdan i Lund: Lund, Sweden, 1987.
33. Cooper, D.F.; Ferguson, N. *Traffic Studies at T-Junctions. 2. A Conflict Simulation Record*; Traffic Engineering and Control; Hemming Group, Limited: London, UK, 1976; Volume 17.
34. Allen, B.L.; Shin, B.T.; Cooper, P.J. Analysis of Traffic Conflicts and Collisions. *Transp. Res. Rec.* **1978**, *667*, 67–74.
35. Pu, L.; Joshi, R. Surrogate Safety Assessment Model (SSAM)—Software User Manual. 2008. Report Number: FHWA-HRT-08-050. Available online: https://rosap.ntl.bts.gov/view/dot/1008 (accessed on 1 January 2022).
36. Gettman, D.; Head, L. Surrogate Safety Measures from Traffic Simulation Models. *Transp. Res. Rec.* **2003**, *1840*, 104–115. [CrossRef]

37. Archer, J. *Indicators for Traffic Safety Assessment and Prediction and Their Application in Micro-Simulation Modelling: A Study of Urban and Suburban Intersections*; KTH Royal Institute of Technology: Stockholm, Sweden, 2005.
38. van der Horst, A.R.A. A Time-Based Analysis of Road User Behaviour in Normal and Critical Encounters. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 1990.
39. AASHTO (American Association of State Highway and Transportation Officials). *A Policy on Geometric Design of Highways and Streets*, 7th ed.; AASHTO: Washington, DC, USA, 2018; ISBN 9781560516767.
40. AASHTO (American Association of State Highway and Transportation Officials). *A Policy on Geometric Design of Highways and Streets*, 6th ed.; AASHTO: Washington, DC, USA, 2011.
41. Guido, G.; Saccomanno, F.; Vitale, A.; Astarita, V.; Festa, D. Comparing Safety Performance Measures Obtained from Video Capture Data. *J. Transp. Eng.* **2011**, *137*, 481–491. [CrossRef]
42. Hyden, C. Traffic Conflicts Technique: State-of-the-Art. In *Traffic Safety Work with Video-Processing*; Topp, H.H., Ed.; Green Series 43; University Kaiserlauten, Transportation Department: Kaiserslauten, Germany, 1996.
43. Durrani, U.; Lee, C.; Maoh, H. Calibrating the Wiedemann's Vehicle-Following Model Using Mixed Vehicle-Pair Interactions. *Transp. Res. Part C Emerg. Technol.* **2016**, *67*, 227–242. [CrossRef]
44. Ahmed, H.U.; Huang, Y.; Lu, P. A Review of Car-Following Models and Modeling Tools for Human and Autonomous-Ready Driving Behaviors in Micro-Simulation. *Smart Cities* **2021**, *4*, 314–335. [CrossRef]
45. Kaths, H.; Keler, A.; Bogenberger, K. Calibrating the Wiedemann 99 Car-Following Model for Bicycle Traffic. *Sustainability* **2021**, *13*, 3487. [CrossRef]
46. Chaudhari, A.A.; Srinivasan, K.K.; Chilukuri, B.R.; Treiber, M.; Okhrin, O. Calibrating Wiedemann-99 Model Parameters to Trajectory Data of Mixed Vehicular Traffic. *Transp. Res. Rec.* **2022**, *2676*, 718–735. [CrossRef]
47. Higgs, B.; Abbas, M.M.; Medina, A. Analysis of the Wiedemann Car Following Model over Different Speeds Using Naturalistic Data. In Proceedings of the 3rd International Conference on Road Safety and Simulation (RSS), Indianapolis, IN, USA, 14–16 September 2011; pp. 1–22.
48. Saccomanno, F.; Philp, C.; Cunto, F.; Doung, D.; Sooklall, R.; Thiffault, P.; Spoerri, A.; Orribine, B.; Hakomaki, E.; Tremblay, P. *Safety Implications of Mandated Truck Speed Limiters on Canadian Highways*; Transport Canada: Ottawa, ON, Canada, 2008. Available online: https://tc.canada.ca/sites/default/files/migrated/tp14807e.pdf (accessed on 1 May 2022).
49. FHWA. Federal Highway Administration. Crash Modification Factors Clearinghouse. Available online: http://www.cmfclearinghouse.org (accessed on 1 June 2022).
50. AASHTO (American Association of State Highway and Transportation Officials). *Highway Safety Manual*; American Association of State Highway and Transportation Officials: Washington, DC, USA, 2010.