ÉVALUATION DES IMPACTS DE SÉCURITÉ DE DEPASSEMENT SUR LES ROUTES RURALES A DEUX VOIES DE CARS DIFFERENTIEL ET VITESSE TRUCKS LIMITES A L'AIDE DE SIMULATION MICROSCOPIQUE

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ABSTRACT

Récemment, un certain nombre de juridictions en Amérique du Nord ont adopté des lois pour limiter la vitesse des camions sur les routes à deux voies, à travers les limites de vitesse différentielle. Cette stratégie de sécurité peut affecter le comportement de dépasser sur ces routes et les implications de cette stratégie pour les accidents au cours de dépassement ne sont pas bien comprises. On peut soutenir que le comportement le dépassement est l'élément le plus complexe et important de la conduite sur les autoroutes à deux voies, et joue un rôle important dans la sécurité routière. Le facteur le plus important dans le dépassement de modélisation est l'acceptation écart pour les dépassements. La présence d'un gros camion dans le flux de trafic peut avoir un effet significatif sur la logique d'acceptation écart pour dépasser, résultant en grande partie de la différence dans les caractéristiques des camions, telles que les profils de vitesse et de maniabilité.

Cet article présente une plate-forme de micro-simulation pour la modélisation du comportement d'acceptation de dépassement écart applique le modèle de routes rurales à deux voies sous réserve de la réduction des limites de vitesse des camions. Les conséquences pour la sécurité des limites de vitesse pour camions différentiel routes à deux voies différentes pour des volumes de trafic ont été évalués. Il a été constaté que l'imposition de limites de vitesse réduites pour les camions augmenter le nombre de dépassements entre voitures et camions, la sécurité routière par conséquent, est compromise. Le cadre de la route à deux voies microscopique a été montré comme une alternative viable d'évaluation de la sécurité routière.

1. INTRODUCTION

Rural two-lane highways represent the lion’s share of route-kilometers in many developed and developing countries. In spite of growth in freeway construction, two-lane highways are still the dominant highway type in North America and Europe. In the United States, the Federal Highway Administration [1] reports that two-lane highways represent about 61% of total urban and rural route miles nation-wide. According to the Transportation Association of Canada [2], 93% of all domestic passengers’ trips in 1990 and 84 billion tonne-kilometres of freight in 1988 took place on rural two-lane highways, and this percentage has not changed significantly over the last decade.

Traffic safety poses special challenges for two-lane rural highways, and one of the major aspects of these challenges is the need to provide safe overtaking opportunities. Lamm et al [3] reported that more than 60% of fatalities from road accidents took place on rural two-lane highways. A 2006 study by Transport Canada (5) reported a similar rate of fatal collisions for rural two-lane highways. According to the FHWA [4], 13.9 percent of overtaking-related collisions on two-lane highways resulted in fatalities or serious injuries, as compared to 9.4 percent of all road accidents on this type of road.

Due to the severity of truck accidents, in terms of infrastructure damage and societal costs of injuries and fatalities, some jurisdictions in North America have introduced legislation mandating truck speed limits. We refer to these speed controls for trucks as Differential Speed Limits or DSL. For example, the state of Washington has posted speed limits of 60 mph (95.6 km/h) and 70 mph (112.7 km/h) for trucks and cars respectively. In Arkansas State the truck/car speed limits are 65 mph (104.6 km/h) and 70 mph (112.7 km/h), respectively. Table 1 shows some of the U.S. jurisdiction with DSL and the associated posted speed limits. Also shown is a sample of states with uniform speed limits (USL) for cars and trucks.

Table 1 – Differential Speed Limits and Uniform Speed Limits in the United States

States	Truck Posted Speed Limits, mph (km/h)	Car Posted Speed Limits, mph (km/h)	Posted Speed Difference mph (km/h)
Washington	60 (95.6)	70 (112.7)	10 (16.1)
Oregon	55 (88.5)	65 (95.6)	10 (16.1)
California	55 (88.5)	70 (112.7)	15 (24.1)
Louisiana	65 (95.6)	70 (112.7)	5 (8)
Michigan	55 (88.5)	65 (95.6)	10 (16.1)
Texas	70 (112.7)	70 (112.7)	0
New Mexico	75 (120.7)	75 (120.7)	0
South Carolina	65 (95.6)	65 (95.6)	0

As shown in Table 1, the posted speed limit varies greatly between states. Also, the posted speed limits for the DSL states vary. In the United States, individual states can enact their own highway speed limit legislation since 1995, and this accounts for the aforementioned observations.

Studies on the safety implication of DSL have taken a statistical before-and-after approach. However, these studies have not yielded conclusive results, where some studies show negative impacts ([6],[7],[8]), while others indicate positive impacts [9], and in some cases little or no impacts ([10],[11]). Studies by Johnson and Pawar [12] and Johnson and Murray [13] have found that in certain DSL jurisdictions the compliance rate is low (e.g. similar speed distributions as a similar USL state), while other DSL states have higher compliance rates. One of the flaws of the statistical-based approach is that the researchers are limited by the data collected (usually only accident and volume data are available). Saccomanno et al. ([14]) provide strong evidence for freeways that microscopic traffic simulation can be used to evaluate the safety effects of mandated truck speed limiters in cases where sufficient before and after data is not available [14].

The implication of DSL may have two different effects on safety of an overtaking manoeuvre. On one hand, passenger cars can overtake slower trucks faster and easier. This can reduce the time that the overtaking vehicle occupies the opposite lane, which will improve safety. On the other hand, higher variation in speed, due to DSL, may lead to more frequent passing, which can increase the risk of accidents. Hauer [15] has shown that increases in the number of overtaking manoeuvres correlates with increases in accidents probability.

The objective of this study is to use a two-lane microscopic simulation platform to evaluate the changes in number of overtaking manoeuvres and the associated risks from the aforementioned effects. The surrogate safety measure used in-lieu of accidents to assess the impacts on road safety is the number of overtaking manoeuvres and the residual gap (distance between the overtaking vehicle and the opposing vehicle at the time when the overtaking is completed).

The discussion in this paper is organized into two basic sections: 1) presentation of the overtaking gap acceptance model, 2) evaluation of the safety effects of differential speed limits for different traffic scenarios and assessing its impact on safety.

2. PROPOSED OVERTAKING MODEL

The characteristics of the traffic stream on two-lane highways are affected by traffic from the opposing direction. The overtake behaviour is influenced by factors such as available gaps in the opposing traffic stream, sight distances, traffic composition, width of road and shoulders, driver characteristics, etc. Some of these factors are affected by other external factors such as weather condition (restricted visibility and pavement wetness).

In spite of advances in modelling driving behaviours, our understanding of overtaking on rural two-lane highways has not kept pace with our understanding of other driving regimes, such as, car-following, gap acceptance at intersections, and lane-changing. Most current microscopic traffic simulation platforms have focus on uninterrupted freeway. For instance, VISSIM (PTV), AIMSUN (TSS), PARAMICS (Quadstone), and INTEGRATION currently have no specific overtaking logic in their algorithm. The complexities of traffic flow of two-lane highways and the difficulty in collecting reliable field data for validation and calibration have been ongoing issues that have inhibited progress in this area.

Figure 1 provides a snapshot of an overtaking situation. A complete overtaking manoeuvre comprises five driving stages: Catch-up, Desire to overtake, Gap acceptance, Passing, and Returning. The catch up stage refers to the interval of time during which the following vehicle (FV) approaches the slower moving or the lead vehicle (LV). During this phase FV drivers feel somewhat restricted with respect to their desired speed by the presence of the LV, altering their behaviour from the free-flow to car-following and decelerating.

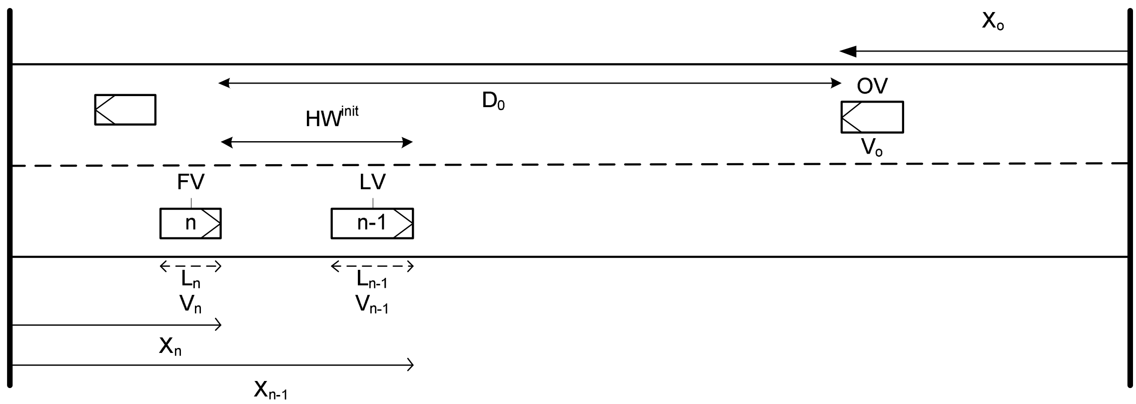


Figure 1 - An Illustration of vehicles involved in an overtaking decision process

A thorough understanding of how drivers respond to vehicular gaps with on-coming vehicles or available sight distance is central to modelling overtaking on two-lane highways. The gap defined in the overtaking models is the distance available between two consecutive vehicles in the opposing traffic stream (D_0). Overtaking gap acceptance behaviour is also dependent upon type and speed of the overtaking and overtaken vehicles, available gap type (sight distance or opposing vehicle), and manoeuvre type

(accelerated or flying), etc at the time of pulling out. For example, accepting a 300-meter gap while overtaking a slow vehicle is more likely than overtaking a fast vehicle with the same gap size. This is due to the higher speed differential between overtaking and overtaken vehicles, which results in shorter overtaking time for the former case.
The potential overtaking driver considers the available gap along with other influencing factors to initiate an overtaking manoeuvre. The gap acceptance is known to be a stochastic process meaning that there is always a chance that a particular gap to be accepted by a particular driver. Various methods have been investigated for modelling overtaking gap acceptance logic, and these depend primarily on how the overtaking driver perceives the time required to safely completing the overtaking manoeuvre (i.e. pulling out, accelerating and passing, and returning to original travel lane). Since decision to overtake depends on various factors, this has led to dealing with different acceptance probability functions for each possible overtaking case that might happen on a road segment

Different studies have considered some or all of these possible combinations, such as St John and Kobett [16] (TWOPAS model), Ahman [17] (VTI model), and Troutbeck [18] (TRARR model). Since some of these factors are continuous variables, mathematically an infinite number of functions are required to cover all possible combination; although, in practice few probability functions have been usually assumed. This complexity has made the calibration task very difficult since a numerous observation is required to calibrate those functions. In our proposed modelling approach, this problem has been resolved i.e. only few calibration parameters of a single gap acceptance function are required to be determined.

In order to consider a gap acceptance model that includes both single and multiple vehicle overtakings, we define a platoon of vehicles with a platoon leader and platoon followers. All vehicles in the platoon are assumed to have a uniform speed, $v_{n-1}(t)$, and critical time-headway (less than 3.0 secs). In the initial decision to overtake, the overtaking driver in the platoon must overtake all or none of the vehicles ahead. The return phase will permit cut-backs to the original travel lane prior to completing the overtaking of the entire platoon, if available gaps and traffic conditions so warrant.

The decision to overtake either a single or multiple LV depends on the following:

- Speed of the overtaken vehicle, v_{n-1}
- Length of the overtaken vehicle, or length of overtaken platoon (in case of multiple overtaking), l
- Length of overtaking vehicle, L_n
- Reaction time, T_n^{react}
- Initial distance between the overtaking vehicle and the oncoming vehicle at the time of pulling out, D_a
- Initial distance headway between the overtaking vehicle and the overtaken vehicle or the platoon leader at the time of pulling out, HW^{init}
- Speed of the oncoming vehicle, v_o
- Acceleration profile of the overtaking vehicle during the passing process

To take into account all these variables, a *residual gap* term is defined as the “perceived” distance between the overtaking vehicle and the opposing vehicle at the time when the overtaking is completed (i.e. overtaking vehicle returns back to the right lane). The overtaking driver is assumed to estimate the residual gap prior to initiating the overtaking manoeuvre based on various traffic and road geometric inferences. In practice the perceived residual gap is unknown, but we can estimate this gap directly from vehicle dynamics for different vehicles in the traffic stream at the time of the overtaking. Since the perceived residual gap is unknown, the probability of acceptance must be related to the observed residual gap for the overtaking vehicle, and that differences between actual and perceived accounted for in the estimation of the gap acceptance function parameters.

3. GAP ACCEPTANCE OVERTAKING MODEL FORMULATION

In representing the entire overtaking logic, the gap acceptance stage is followed by the passing and the return to original travel lane stages. If the gap is accepted, the driver pulls out into the opposing lane and begins to accelerate to a desired overtaking speed. The overtaking vehicle continues at this speed until it passes the slower vehicle(s). After a safe headway gap with the overtaken vehicle, the overtaking vehicle returns to the original travel lane and the gap acceptance logic is applied to the next overtaking opportunity. By using D_{Res}, we are able to unify different overtaking types into a single acceptance probability function.

The residual gap can be estimated from vehicle dynamics, such that each phase of the overtaking manoeuvre is considered separately (Figure 2).

Phase 1: Distance travelled by the LV (overtaken vehicle) during the FV driver reaction time, D_1

When a new gap becomes available, the LV keeps moving for the time duration of $t_1 = T_n^{react}$ (reaction time) and; consequently, travels D_1 distance:

$$D_1 = v_n^{ini} \times t_1$$

where, v_n^{ini} is the initial speed of the LV. At the same time, the overtaken vehicle travels $D_1^{'}$ with constant speed of v_{n-1}., and this distance is estimated as:

$$D_1^{'} = v_{n-1} \times t_1$$

Phase 2: Distance travelled by the overtaking vehicle (FV) from pull out to time it reaches its overtaking desired speed (v_n^{des-ov}), D_2.

The overtaking desired speed is assumed to be higher than the desired speed under normal free flow driving. The time required to achieve the desired speed after pulling out can be derived from non-constant acceleration motion equations as:

$$t_2 = -\frac{v^{max}}{a^{max}} \times ln\left(\frac{v^{max} - v_n^{des-ov}}{v^{max} - v_n^{ini}}\right)$$

where, v^{max} and a^{max} are maximum achievable speed and acceleration of the vehicle respectively.

The distance travelled by the overtaking vehicle during t_2 can be calculated as:

$$D_2 = v^{max} t_2 + \frac{v^{max}}{a^{max}} \left(v^{max} - v_n^{ini}\right)(e^{-\frac{a^{max}}{v^{max}} t_2} - 1)$$

At the same time, the overtaken vehicle travelled a distance during t_2 time which is:

$$D_2^{'} = v_{n-1} \times t_2$$

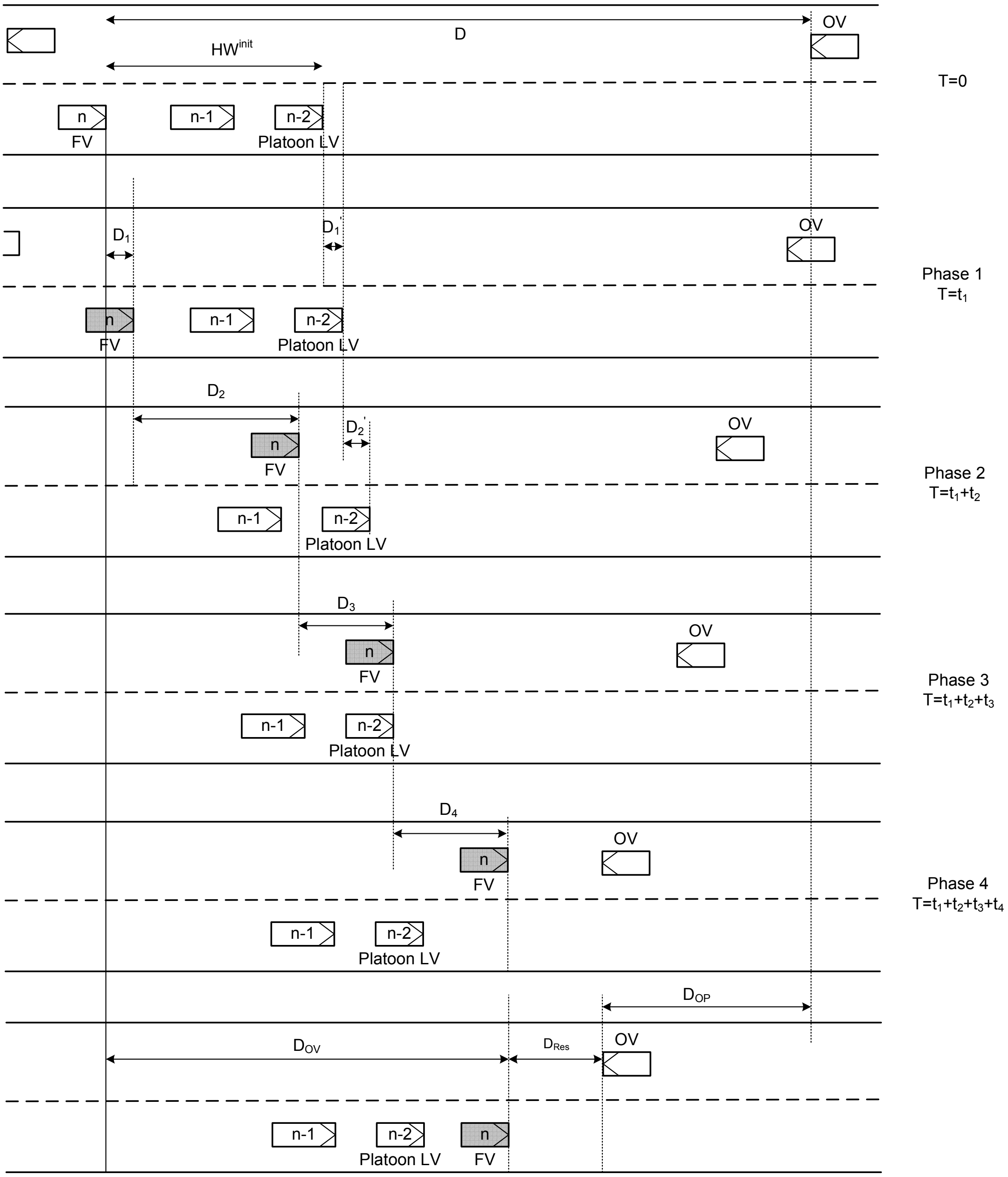


Figure 2 - Passing phases used for estimating a residual gap

Phase 3: Distance travelled by the overtaking vehicle from its point of reaching the desired speed to its abreast position with the overtaken vehicle, D_3.

When the overtaking vehicle reaches its desired speed (v_n^{des-ov}), it continues with that speed for the rest of the overtaking manoeuvre. After t_2, if the position of the overtaking vehicle is still behind the abreast position, it requires t_3 units of time to be in the abreast position. In this case, t_3 is a positive value, but if the position of the overtaking vehicle is already beyond the abreast, then t_2 takes a negative value:

$$t_3 = \frac{HW^{init} - (D_1 + D_2 - D_1^{'} - D_2^{'})}{v_n^{des-ov} - v_{n-1}}$$

Where HW^{init} is the initial distance headway between the FV and the LV or the leader of the platoon at the time of starting the overtaking. Similarly, the corresponding traveled distance is:

$$D_3 = v_n^{des-ov} \times t_3$$

Phase 4: Distance required to keep a safe headway in front of the overtaken vehicle before returning to normal travel lane, D_4

The remaining time required to pass the vehicle and keep a safe headway in front is given by:

$$t_4 = \frac{l_n + v_n^{des-ov} \times T_n^f}{v_n^{des-ov} - v_{n-1}}$$

And the corresponding distance is:

$$D_4 = v_n^{des-ov} \times t_4$$

Therefore, the overtaking distance can be calculated as:

$$D_{OV} = D_1 + D_2 + D_3 + D_4$$

If we assume that during the overtaking the opposing vehicle keeps a constant speed, the distance travelled by the opposing vehicle is:

$$D_{OP} = (t_1 + t_2 + t_3 + t_4) \times v_o$$

From Figure 2, we can specify the residual gap as:

$$D_{Res} = D - (D_{OV} + D_{OP})$$

The nature of the probability function representing the relationship between the gap acceptance probability and residual gap size can be established experimentally by an S-shape function limited between zero and one. The details of the overtaking model calibration are reported in Ghods and Saccomanno [20].

4. MICRO-SIMULATION FRAMEWORK

A micro-simulation program was developed to simulate the overtaking manoeuvre on two lane roads. The program is able to simulate a straight segment of a two-lane highway where overtaking is permitted. Three types of vehicles are considered in the traffic stream: Car, Recreational Vehicle, and Truck and Normal distribution is used to assign desired speeds to different vehicle class with a mean and standard deviation. A time-base scanning simulation approach is used such that for every simulated time increment (1 second), the position and speed of each vehicle is updated. The following steps are executed for each run:

1) Generate traffic and vehicle/driver attributes.

2) For every time increment the following steps are carried out until the stop time is reached:
   a) Load a vehicle to the road if it is time to do so.
   b) For each vehicle currently on the road update the position, speed and status of the vehicles.
   c) Remove vehicle from the road if it has reached end of the road.
   d) Update the graphical animation.
3) Log the output results if requested.

5. **SIMULATION CASESTUDY**

The simulation study is a six kilometres straight stretch of a two-lane highways where overtaking is permitted on the first 5 kilometres of each direction (Figure 3). The simulation time period is 70 minutes in duration with a 10 minutes warm-up interval. The average of five runs is taken.

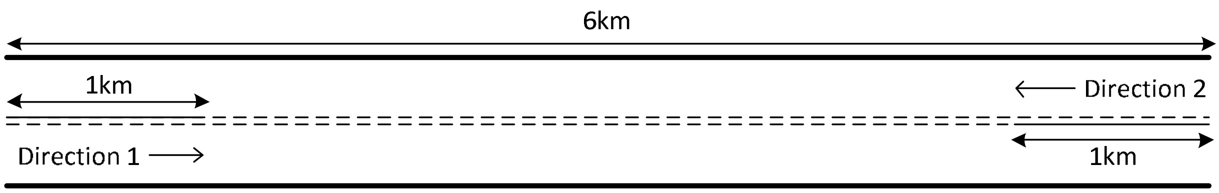


Figure 3: Benchmark Simulation Highway

The two traffic control strategies being considered are: with and without DSL. The number of overtaking manoeuvres by vehicle type as well as average accepted residual gaps for different directional traffic flow are recorded for each simulation run. As noted previously, the number of overtaking can be correlated with accident probability [15]. The residual gap, the "perceived" distance between the overtaking vehicle and the opposing vehicle at the time when the overtaking is completed, can also be correlated with safety performance in that lower residual gaps increases the risk of a head-on collision or doing an evasive manoeuvre. Table 2 presents the percentage of truck and the distribution of desired speed for the without DSL scenario. The coefficient of variation of desired speed is assumed to be 0.14 for both car and truck.

Table 2- Percentage of vehicles and distribution of desired speed for without DSL case

	Cars Percentage (%)		Trucks Percentage (%)	
Value	80		20	
	Mean Desired Speed Cars (km/h)	Desired Speed Standard Deviation Cars (km/h)	Mean Desired Speed Trucks (km/h)	Desired Speed Standard Deviation Trucks (km/h)
Value	100	14	100	14

Table 3 shows the number of overtaking manoeuvres by type and average accepted residual gaps for without DSL case. The same data are reported in Table 4 and Table 5 for the DSL scenario.

Table 3- Number of overtaking manoeuvres and average accepted residual gaps for different directional traffic flow without DSL case

Flow Direction 1 (veh/h)	Flow Direction 2 (veh/h)	Number of Overtaking Manoeuvres					Average accepted residual gaps
		Car-Car	Car-Truck	Truck-Car	Truck-Truck	Total	
100	100	30.4	27	0.4	0.2	58	893
200	200	68	57.6	0.6	0.8	127	578
300	300	89	80.8	0.2	0.8	170.8	398
400	400	99.2	81.2	0.8	0.4	181.6	333
500	500	94.2	95	0.8	0.8	190.8	338
600	600	102	97	1.6	1	201.6	409
700	700	110	109	1	0.6	220.6	277

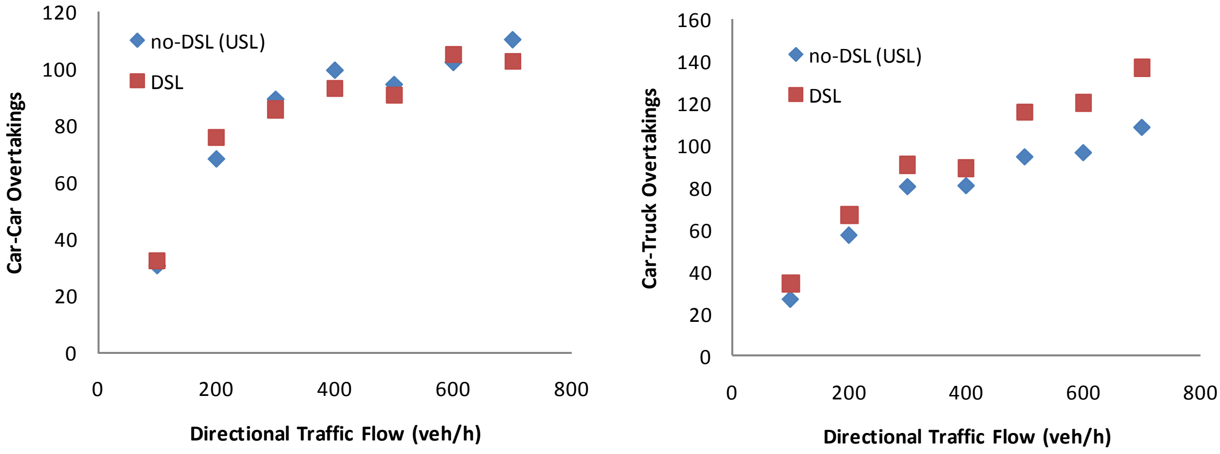
Table 4- DSL Scenario, percentage of vehicles and distribution of desired speed

	Cars Percentage (%)		Trucks Percentage (%)	
Value	80		20	
	Mean Desired Speed Cars (km/h)	Desired Speed Standard Deviation Cars (km/h)	Mean Desired Speed Trucks (km/h)	Desired Speed Standard Deviation Trucks (km/h)
Value	100	14	80	12.6

Table 5- Number of overtaking manoeuvres and average accepted residual gaps for different directional traffic flow with DSL case

Flow Direction 1 (veh/h)	Flow Direction 2 (veh/h)	Number of Overtaking Manoeuvres					Average accepted residual gaps
		Car-Car	Car-Truck	Truck-Car	Truck-Truck	Total	
100	100	32.4	34.4	0.4	1	68.2	786
200	200	75.8	67	1.4	1.4	145.6	652
300	300	85.5	91	1.5	1.75	179.75	356
400	400	83	89.2	0.6	1	173.8	334
500	500	90.75	116	0.25	1.25	208.25	305
600	600	105	120.4	1	1.4	227.8	334
700	700	102.5	137	1	0.25	240.75	331

The number of car-car overtaking manoeuvres and car-truck overtaking manoeuvres are illustrated graphically in Figure 4.



(a) (b)

Figure 4 – Number of overtaking manoeuvres versus directional traffic flow

Figure 4(b) clearly shows that at higher traffic flows, the number of car-truck overtaking manoeuvres increase significantly with directional traffic flow when DSL is introduced. The number of car-car overtaking manoeuvres does not change significantly between the no-DSL and DSL scenarios. Paired t-test were undertaken to verify whether these samples were statistically significant. For the car-truck samples, a t-value of -4.76 was estimated (the t-critical value for a two-tailed is 2.44 at the 95% confidence level). Therefore, we can reject the null hypothesis that the mean of the samples are the same. Hence, road safety expressed in terms of number of OT manoeuvres can be compromised with the introduction of DSL.

Figure 5 illustrates the average accepted residual gaps for the non-DSL and DSL scenarios. In general, the relationship is negative exponential in nature, between average residual gap and directional traffic flow.

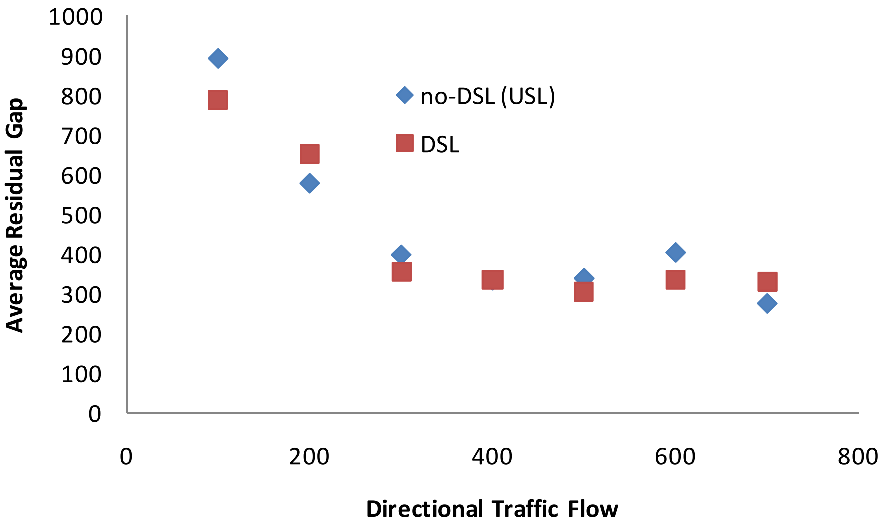


Figure 5 – Average accepted residual gaps versus directional traffic flow

A t-test comparison between the curves in Figure 5 for DSL and non DSL cases proved to lack significance. Hence there is no evidence to suggest the introduction of DSL has resulted in a significant increase in the average residual gap size for similar flows. Hence there does not appear to be a change in safety based on the 'accepted residual gap' metric. The presence of DSL imposes higher speed differentials, which increases the chances of vehicle platooning. If platoons exist then the overtaking vehicle has to join the platoon and undertake single or multiple accelerated overtakings which requires more time and leads to smaller residual gaps, and this has a significant effect on safety.

6. CONCLUSIONS

A microscopic simulation overtaking model was described and applied to assess the safety impacts of imposing differential speed limits on trucks. The two surrogate safety measures used in the study were the number of overtakings and the available accepted residual gaps. Two scenarios were tested for different traffic volumes with and without DSL. It was found that the presence of DSL had no significant impact on the accepted available residual gaps and the number of car-car overtaking manoeuvres. However, there was a statistically significant increase of car-truck overtaking manoeuvres; and this could compromise safety on two lane highways. This supports the negative safety impacts of DSL found in some of the literature based on observational before-and-after accident analysis.

Only one aspect of overtaking was considered for this study, that of the gap acceptance overtaking stage. All aspects of the overtaking process will need to be considered before a full understanding can be obtained regarding the safety on two lane highways of mandated truck DSL.

REFERENCES

1. FHWA. (2008). *Highway statistics.* Federal Highway Administration
2. TAC. (1990). *Canada's roadway infrastructure.* Ottawa: Roads and Transportation Association of Canada
3. Lamm, R., A. Beck, T. Ruscher, T. Mailaender, S. Cafiso, G. La Cava, and W. Matthews. (2006). How to make two-lane rural roads safer. *Scientific Background and Guide for Practical Application*.
4. FHWA. (1994). *The magnitude and severity of passing accidents on two-lane rural roads (HSIS summary report).* Federal Highway Administration, FHWA-RD-94-068.
5. Transport Canada. (2006). *Canadian motor vehicle traffic collisions.*
6. Garber, N.J., and Gadiraju, R. (1989). Effect of truck strategies on traffic flow and safety on multilane highways. American Auto Association Foundation for Traffic Safety.
7. Garber, N.J., and Gadiraju, R. (1991). Impact of differential speed limits on highway speeds and accidents, Department of Civil Engineering, University of Virginia, Charlottesvile, Virgina.
8. Council, F.M., Duncan, C.S., and Khattak, A.J. (1998). Applying the ordered probit model to injury serverity in truck-passenger car rear-end collisions. Transportation Research Record, Vol. 1635 pp 63-71
9. Neeley, F.W. and Richardson, L.E. Jr. (2009). The effect of state regulations on truck-crash fatalities. American Journal of Public Health. Vol 88, No.3, pp 408-415.
10. Garber, N.J., Miller, J.S., Yuan, B., and Sun, X. (2003). Safety effects of differential speed limit on rural interstate highways. Transportation Research Record, Vol. 1830, pp 56-62
11. Garber, N.J., Miller, J.S., Sun, X., and Yuan, B. (2006). Safety impacts of differential speed limits for trucks and passenger cars on rural interstate highways: A modified empirical bayes approach. Journal of Transportation Engineering, Vol 132, No. 1, pp 19-29
12. Johnson, S.L., and Pawar, N. (2007). Analysis of heavy truck and automobile speed distributions for uniform and differential speed limit configuration on rural interstate highways. Proceedings of the Transportation Research Board Conference, paper #07-2949.
13. Johnson, S.L, and Murray, D. (2010). Empirical analysis of truck and automobile speeds on rural interstates: impact of posted speed limits. Proceedings of the Transportation Research Board Conference, paper #10-0833.
14. Saccomanno, F., Duong, D., Cunto, F., Hellinga, B., Philp, C., and Pierre, T. (2009). Safety Implications of Mandated Truck Speed Limiters. In Transportation Research Record, Vol. 2096, pp 65–75.
15. Hauer, E. (1971). Accidents, overtaking and speed control. Accident Analysis and Prevention, Vol. 3, pp 1-13
16. St John, A. D., and D. R. Kobett. (1978). *Grade effects on traffic flow stability and capacity.* US Transportation Research Board. National Cooperative Highway Research Program, 185.

17. Ahman, K. I. 1972. Omkorningar av lastbilar. *Trafikstudier Statens Vag-Och Trafikinstitut* Raport 6 .
18. Troutbeck, R. J. (1981). *Overtaking behaviour on Australian two-lane rural highways.* Australian Road Research Board, Special Report SR20.
19. Carlsson, A. (1993). Beskrivning av VTIs trafiksimuleringsmodell (description of VTIs traffic simulation model, in swedish). *VTI Notat T* 138 .
20. Ghods, A.H., Saccomanno, F.F. (2012). A micro-simulation overtaking model for rural two-lane highways", Transportation Research Board (TRB) conference, Washington D.C., United States, (submitted).
21. Gazis, D.C., Herman, R., and Potts, R.B. (1959). Car-following theory of steady state traffic flow. Operations Research, Vol. 7, No. 4, pp 499-505.