Impact of Active Speed Limiters on Traffic Flow and Safety

Simulation-Based Evaluation

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Speed limiters, which control the maximum speeds of vehicles so equipped, have been proposed in recent years as speed management tools. A simulation-based evaluation is described of the impact of a wide installation of speed limiters on traffic flow characteristics and on safety. Microscopic traffic simulation is used; it models the driving behavior of individual vehicles in detail and so captures not only the impact of speed limiters on equipped vehicles but also the interaction between equipped and unequipped vehicles and the resulting impact on the latter. In the experiment, the impact is evaluated of preset speed limiters for two limiter-set speeds, 100 km/h and 120 km/h, at various desired speed distributions and congestion levels. The simulation results show that speed limiters can reduce average traffic speeds up to 10% and that the variability of traffic speeds may also be lowered. Consequently, a significant reduction in accident rates might be achieved.

Numerous studies have shown a strong relation between speed and accident risk, at both the individual and aggregate levels [see the review by Stuster et al. (*1*)]. Most of these studies relate safety to the average speed (*2, 3*). A typical value often cited in the literature is that a decrease of 1 km/h in average speed causes a reduction of 2% to 3.5% in injury accidents and 5% to 6% in severe injuries and deaths (*4, 5*). Reductions in the variability of traffic speeds have also been shown to improve traffic safety (*6, 2, 7–10*). The classic means to control speed include determination and posting of speed limits and visible enforcement of these limits. However, studies have found that in many cases these measures cause an abrupt reduction in speed but do not have a significant effect over time and space (*11–13*).

Speed limiters, which control the maximum speeds of equipped vehicles, have been proposed in recent years as speed management tools. Several designs, which differ in the way they operate and the technologies they use, have been proposed. Speed limiters may be classified on the basis of several important characteristics (*11, 13*):

1. Advisory or active systems. Advisory systems provide drivers with audio and visual warnings when the limiter-set speed is exceeded. Active systems directly control speed by applying a counterforce on the gas pedal or through the engine fuel injection system.

2. Preset or dynamic limiter-set speeds. Preset systems use a fixed set speed. Dynamic systems, or intelligent speed adapters (ISAs), use real-time information to adapt the set speed to posted speed limits in various road facilities and to road and weather conditions. Although ISAs provide better control of speed, they also require communication between the vehicle and roadside beacons or the use of the Global Positioning System in order to obtain the dynamic speed limit information. These systems therefore require more expensive road infrastructure and installations in the vehicle.

3. Continuous or voluntary systems. Speed limiters may be designed to operate continuously or to allow drivers to turn them on or off.

Several European states are currently considering legislation that would mandate installation of active speed limiters in various types of vehicles, especially commercial ones. For example, in the United Kingdom, all vehicles with more than eight passenger seats and goods vehicles with design weights over 3.5 tons would be required to be equipped with speed limiters by 2008 (*14*). With the current costs of the various technologies and related infrastructure, a wide installation of speed limiters is likely to be feasible if it is based on simpler preset systems rather than ISAs.

Field studies have showed that speed limiters are effective in controlling speed, with up to 8% reductions in the average speeds of equipped vehicles (*15–18*). Speed limiters also were shown to reduce the variability of speed (*16, 17, 13*). However, mixed results were obtained for their impact on other aspects of driving, such as behavior toward other road users, smoothness of driving, headway keeping, gap acceptance, and intersection negotiation. Some of the inconclusive results may be attributed to compensatory behavior (*12, 19*). Comte (*11*) used a driving simulator to study the impact of speed limiters. The results also showed reductions in the average speeds and in the variability of speed. Both the field studies and the simulator study were conducted with relatively small samples that could not capture the networkwide impact of speed limiters. A wide installation of speed limiters would affect not only the equipped vehicles but also the behavior of other vehicles. Comte (*11*) and Várhelyi and Mäkinen (*13*) point out that a networkwide evaluation of speed limiters would require large-scale field tests, which may be prohibitively expensive.

Comte (*11*) proposes traffic simulation modeling as an alternative evaluation platform that can capture the complex interactions among equipped and unequipped vehicles. In a recent study, Liu and Tate (*20*) used a microscopic traffic simulation model to evaluate the impact of ISAs on driver behavior, congestion, and vehicle emissions in an urban network during the a.m. peak and off-peak periods. They found that both average speeds and the variability in speeds decrease when the penetration rate of speed limiters increases. The decrease in average speeds was larger during the off-peak period compared with

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the a.m. peak period. The authors suggested that the effectiveness of speed limiters decreases with congestion because there are fewer opportunities for the speed limiter to influence speeds. However, they did not quantify the relation between the level of congestion and the speed limiter's impact. They also found that speed limiters caused reductions in fuel consumption but had no significant impact on emissions.

This study evaluates the potential impact of a wide installation of speed limiters on traffic flow characteristics and safety. This evaluation requires detailed models that capture not only the impact on the behavior of drivers in equipped vehicles but also their interactions with unequipped vehicles, so that the impact on the latter can be captured. In the analysis, a microscopic traffic simulation model is used that incorporates a detailed representation of the behavior of all vehicles in the traffic stream. In contrast to the study by Liu and Tate (*20*) as well as most field tests, which studied urban traffic, the focus here is on the impacts on freeway traffic, which is the main target of current legislative initiatives.

TRAFFIC SIMULATION MODEL

Overview

MITSIMLab (*21*) is a microscopic traffic simulation model that simulates in detail the dynamic interactions between drivers on a road network. Travel demand is input in the form of time-dependent origin-to-destination flows, which are translated into individual vehicles wishing to enter the network. Behavior parameters (e.g., desired speed, aggressiveness) and vehicle characteristics are assigned to each vehicle driver. Once on the network, vehicles are moved according to detailed driving behavior models, most notably for acceleration and lane changing. The acceleration model consists of several regimes. A car-following model is used when subjects are close to their leaders. A free-flow model describes the behavior of vehicles that are not close to their leaders. Emergency behavior is invoked in near-collision situations. In addition, separate models describe the accelerations that drivers apply in order to facilitate lane changing. The lane-changing model incorporates both mandatory and discretionary lane changes and consists of two decision levels: the choice of a desired target lane and gap acceptance to complete a lane change. Merging, drivers' responses to traffic signals and signs, posted speed limits, incidents, and tollbooths are also captured. A detailed description of driving behavior models implemented in MITSIMLab may be found elsewhere (*22*). MITSIMLab has been extensively validated and used in a wide range of applications (e.g., *22–24*).

Modeling Speed Limiters

Installation of speed limiters with preset maximum speeds is assumed. It is further assumed that 10% of all the vehicles are equipped with speed limiters, which roughly corresponds to a policy of mandating installation of speed limiters in all commercial vehicles (including light goods and service vehicles) in Europe.

The distribution of desired speeds, which is the maximum speed at which drivers would choose to travel if uninterrupted by other vehicles, is an important input to the acceleration and lane-changing models in MITSIMLab. Desired speeds depend on the characteristics of the road (e.g., curvature, number and width of lanes), weather and visibility conditions, and characteristics of the driver and the vehicle. In the simulation model it is assumed that the desired speed distribu-

tion is normally distributed with parameters that are linked to the posted speed limit. On the basis of results reported by FHWA (*25*), the mean of the desired speed distribution is set 10% higher than the posted speed limit, with a standard deviation of 15% of the posted speed limit. Thus, the desired speed distribution is given by

$$V_{des} \sim N(1.1\text{SL}, 0.15\text{SL}) \tag{1}$$

where V_{des} is the desired speed and SL is the posted speed limit.

The desired speed distribution is used to capture the impact of speed limiters on drivers' behavior. The installation of speed limiters affects this distribution in two ways: it reduces the mean desired speed, and it distorts the shape of the distribution, as all equipped vehicles whose desired speeds are higher than the limiter-set speed will be constrained to the limiter-set speed. To illustrate this effect, Figure 1 shows the cumulative distribution of desired speeds, assuming that 10% of the vehicles are equipped and that the posted speed limit is 130 km/h (and so the mean desired speed is 143 km/h), for three levels of limiter speed settings: no limiting, 100 km/h, and 120 km/h. The spikes in the cumulative probability of desired speeds around the limiter-set speeds reflect those drivers of equipped vehicles who would have had higher desired speeds but are constrained by the limiter-set speed. In the simulation input files, the desired speed distribution is parameterized by dividing the population of drivers into 10 classes and assigning drivers within each class with desired speeds based on the corresponding percentiles. Thus, 10% of the drivers who have the lowest desired speeds would be assigned the value of the 5th-percentile desired speed; the next 10% would be assigned the 15th-percentile desired speed; and so on.

SIMULATION EXPERIMENT

Study Network

The network used in the evaluation is a 5-km section of I-93 southbound in Boston, Massachusetts. This section is shown schematically in Figure 2. In addition to the detailed geometric layout, information on the peak-hour travel demand was available in the form of time-dependent origin-to-destination trip matrices. Traffic operates at capacity with this level of demand.

Experimental Design

The impact of speed limiters is expected to depend on various factors that determine the frequency at which they will be activated and the extent of the impact on equipped and unequipped vehicles. In this experiment the following factors were considered:

1. Level of congestion. Traffic conditions determine the frequency of opportunities drivers have to exceed the limiter-set speed. In the experiment the level of congestion is expressed as a percentage of the peak-period demand.
2. Distribution of desired speeds. The desired speeds depend in the model on the posted speed limit as discussed earlier. Four levels of posted speed limits and the corresponding desired speed distributions are considered. It should be noted that higher speed limits (and desired speeds) may represent not only speed regulations but also differences in highway design characteristics and standards.
3. Maximum speed allowed by the speed limiter. A base case in which speed limiters are disabled is considered and two cases in which the limiter speed is set to different values.
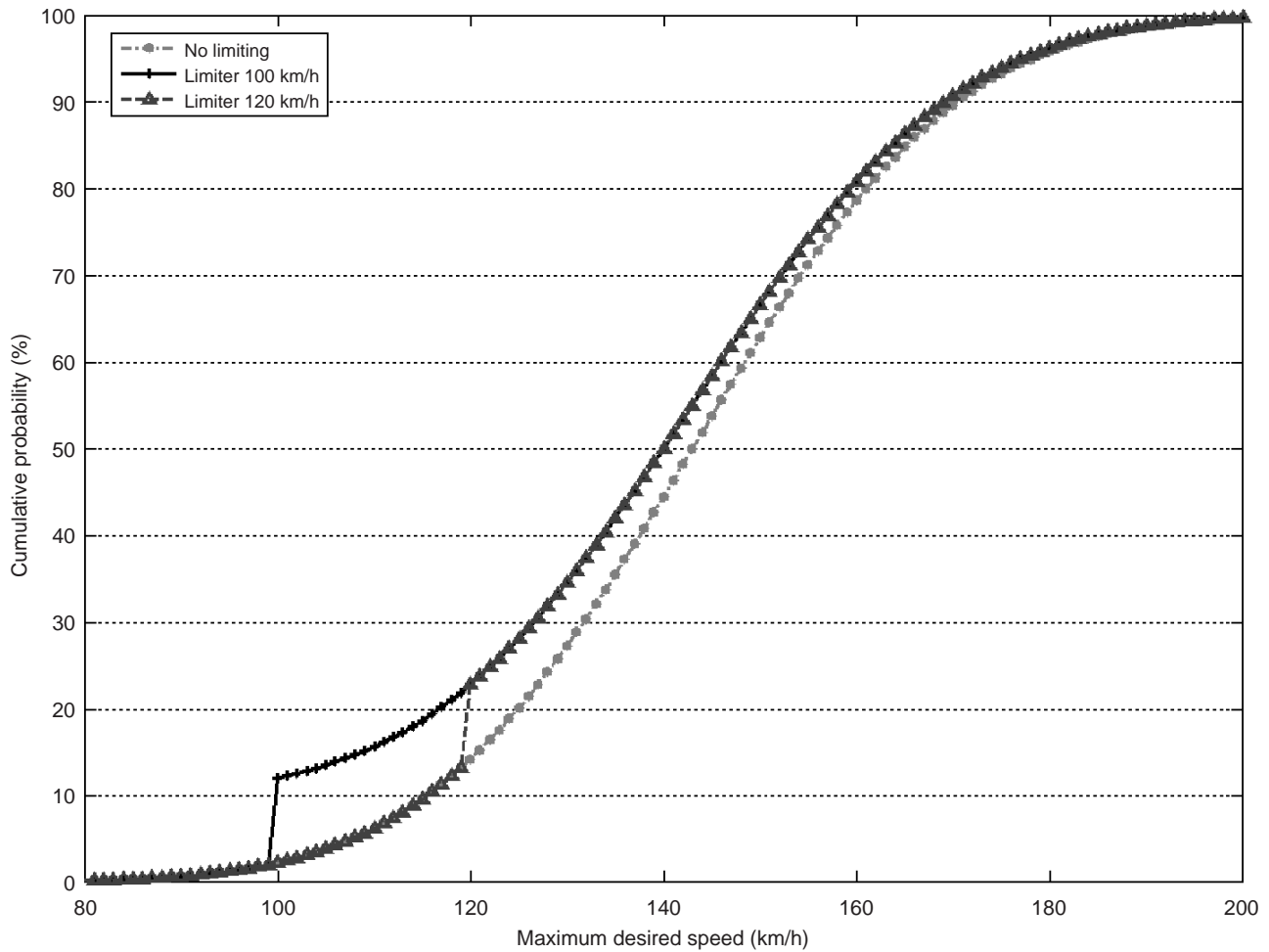
FIGURE 1 Desired speed distribution in presence of speed limiters (speed limit = 130 km/h; speed limiters in 10% of vehicles).

Table 1 summarizes the levels considered in the experiment for each of these factors.

A full factorial experiment was used in which all 60 possible combinations of factor levels were tested. The traffic simulator is stochastic, and so 10 replications were made in each case, for a total of 600 simulation runs. Each run simulated 75 min. The initial 15 min was not used in the analysis in order to eliminate the impact of the initial conditions.

The output collected from the simulation included records on speeds and lane changes for individual vehicles. These were aggregated to calculate four different statistics that were used in the evaluation:

traffic flows, average speeds, standard deviations of speeds, and number of lane changes.

RESULTS

Traffic Flows

The demand levels considered in this study cover the full range of traffic flow below capacity. The change in traffic flow when the limiters were active compared with the base case, when they were not,
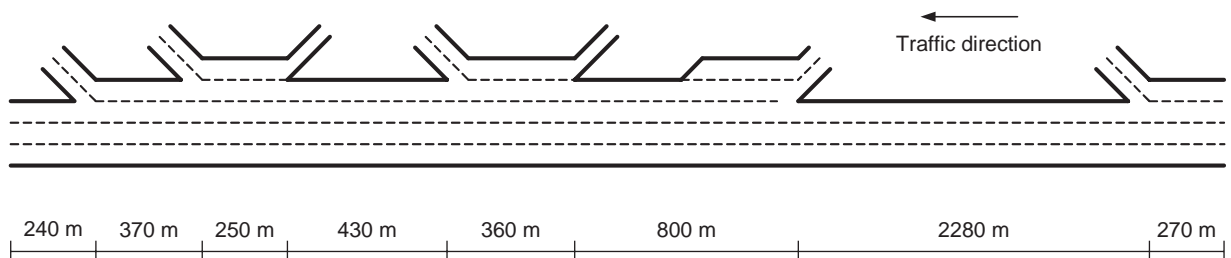

FIGURE 2 I-93 southbound section (Boston) used for evaluation.

TABLE 1 Factors and Their Levels in Experiment

Factor	Levels
Congestion (%)	20, 40, 60, 80, 100
Posted speed limit (km/h)	100, 110, 120, 130
Mean desired speed (km/h)	110, 121, 132, 143
Limiter set speed (km/h)	None, 100, 120

for all demand levels between 20% and 80% was in the range of −0.3% to 0.1%. These values are well within the noise of the simulation results. A larger range of changes, between −0.8% and 1.4%, was found for the 100% demand level. However, no clear pattern could be identified in these changes. This result can be expected, given that traffic operating at capacity is sensitive to small fluctuations in demand. Also, at this level of demand, high speeds are hardly ever attained, and so there is little opportunity for speed limiters to affect speeds. Thus, it may be concluded that the presence of speed limiters had no significant effect on traffic flows in any of the cases.

Average Speeds

Figures 3 and 4 show average traffic speeds with and without speed limiters and the change in average speeds caused by the installation of speed limiters, respectively. The implementation of speed limiters reduces the average traffic speed in all cases except when traffic operates at capacity. Generally, the speed reduction is larger when the speed limiter is more constraining. Thus, the speed reduction is larger when the limiter-set speed is lower and when the mean desired speed is higher. The maximum speed reductions, which were obtained for posted speed limits of 120 km/h and 130 km/h and limiter speed of 100 km/h, are more than 10 km/h at the lowest congestion levels. At the other extreme, when the speed limiter is set too high compared with the desired speeds (limiter set at 120 km/h for the 100-km/h and 110-km/h posted speed limits), the fraction of vehicles that are affected by the speed limiter is very small, and its impact is negligible. The speed limiter is most effective in reducing traffic speeds when drivers have more opportunities to exceed the limiter speed. Thus, the impact decreases when traffic congestion increases and vanishes when flow nears capacity. Interestingly, for all posted speed limits, the largest reductions in traffic speeds were not recorded at the lowest demand levels but at the 40% or 60% levels. This finding may be because at
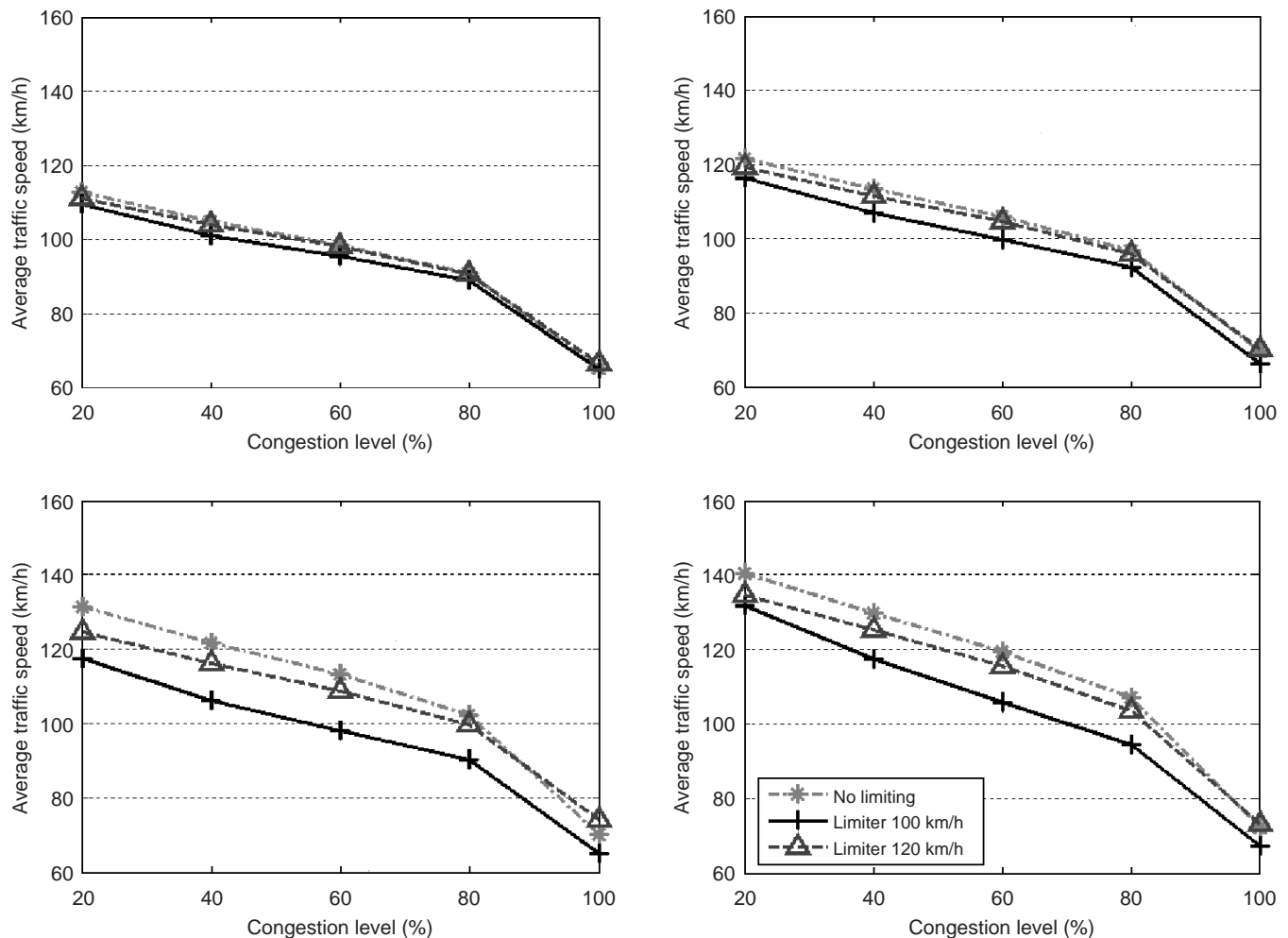
FIGURE 3 Average traffic speeds with and without speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.
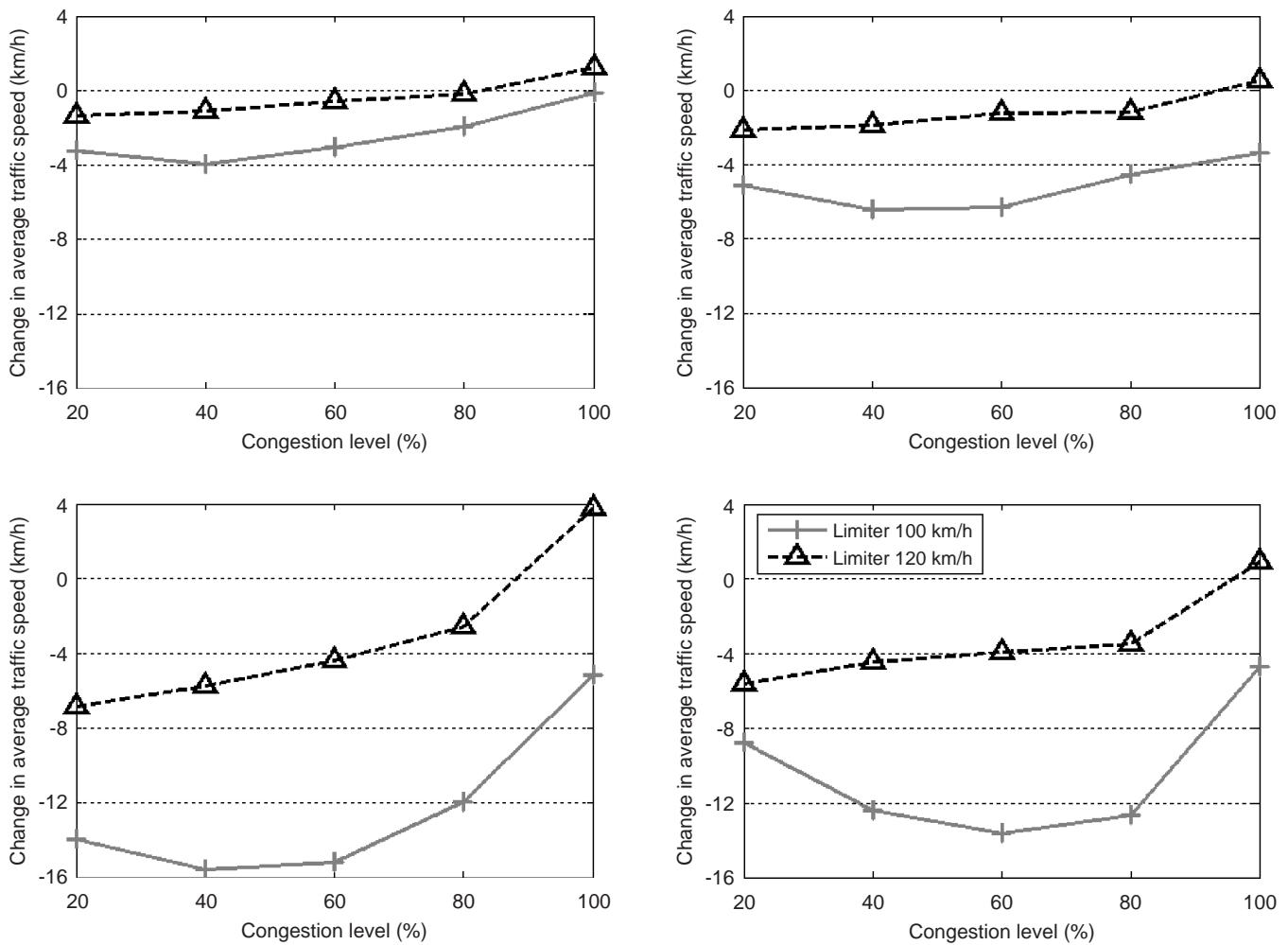
FIGURE 4   Change in average traffic speed due to speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.

these demand levels, there are more interactions among the vehicles, and so the impact on the speeds of unequipped vehicles is larger.

Variability of Speeds

Figures 5 and 6 show the standard deviation of speeds among simulated vehicles and the change in the standard deviation of speeds caused by the installation of speed limiters, respectively. In all cases, the variability in traffic speeds was highest when traffic operated at capacity and is significantly lower in free traffic conditions. The implementation of speed limiters generally reduces the variability of speeds in the medium and high demand levels. The reduction is larger when the limiter speed is set at 100 km/h compared with when it is 120 km/h. It also is larger for higher posted speed limits, where speed limiters truncate some of the very high speeds that otherwise occur. Similar to the impact on average speeds, when the speed limiter is set too high, its impact vanishes. In free traffic conditions (20% and 40% demand levels) a reversed impact (i.e., an increase in speed variability) is observed. The reason is that the speed limiters cause the speed distribution to become bimodal with one mode centered on the limiter-set speed and the other on the mean desired speed. As the

difference between the two modes increases, the overall variability of speeds increases, as can be seen in the cases of posted speed limits at 120 km/h and 130 km/h and especially for the 100-km/h limiter-set speed.

Lane Changes

Figures 7 and 8 show the rates of lane changing per vehicle and the change in lane-changing rates due to speed limiters, respectively. Generally, lane-changing rates decrease when the posted speed limit is higher. This result may be because the free space drivers require to change lanes depends on the time headways between vehicles and so increases with higher speeds. Lane-changing rates are lowest for the low demand levels (20% and 40%) because the interaction among vehicles is limited, and so the need to change lanes does not arise frequently. As congestion increases, two phenomena with opposite effects occur. On the one hand, the interaction among vehicles increases and with it the desire of faster vehicles to overtake slower ones. Furthermore, lower speeds make it easier for drivers to change lanes when a suitable gap is available. On the other hand, when congestion increases, suitable gaps for lane changing are increasingly
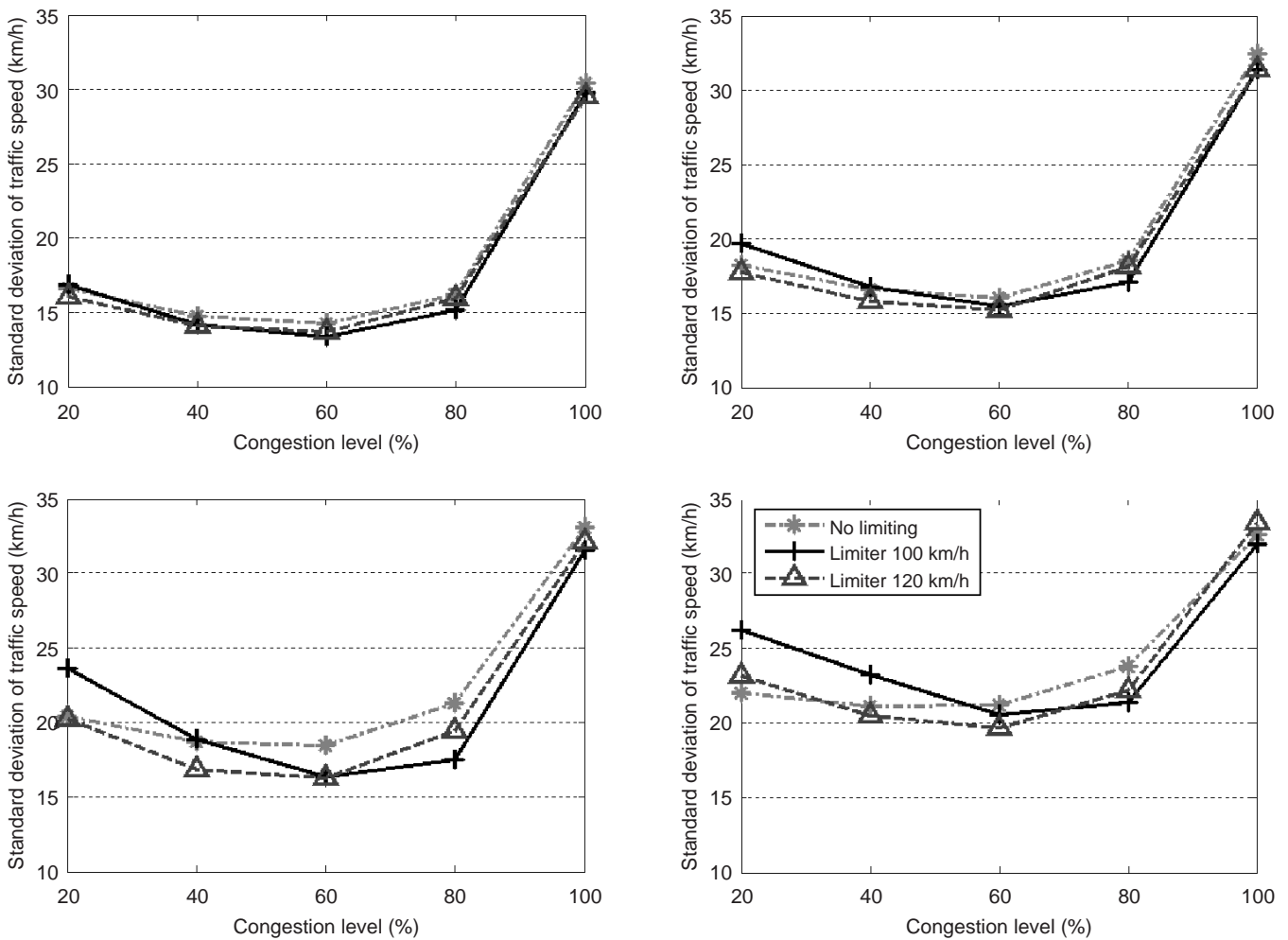
FIGURE 5 Standard deviation of vehicle speeds with and without speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.

difficult to find. As a result, lane-changing rates level off or even decrease at higher demand levels (60% and 80%). The highest lane-changing rates are recorded at capacity as queues form and drivers change lanes in order to avoid these queues. For a given posted speed limit, the lane-changing rates are higher when speed limiters are implemented and especially when they are set to 100 km/h. As was the case for the speed variability, the cause may be the creation of a bimodal distribution of slow and fast vehicles with a significant speed difference between them. The increase in lane-changing rates due to speed limiters is larger when the posted speed limit is higher. For a given combination of posted speed limit and limiter-set speed, the increase in the lane-changing rates is roughly constant up to the 60% demand level. At higher demands, and especially at the 100% level, the increase in the lane-changing rates is smaller.

SAFETY IMPLICATIONS

As noted earlier, many studies correlate average traffic speeds with the number of highway accidents and related injuries. There is evidence that reductions in the variability of traffic speeds also contribute to reductions in accident rates. However, it is still unclear whether this effect is causal or reflects other factors correlated with speed variation

(*8, 26*). The lane-changing rate has also been shown to be positively correlated with accident rates (*27, 28*). Given that changes in the average speed are considered the main factor affecting traffic safety, this factor was focused on and the safety implications of speed limiters were derived from these statistics.

The Swedish model (*29*) was adopted, which is one of the most researched in this area. This model relates the fraction of change in the number of accidents to the fraction of change in the average speed. It was developed from consideration of energy-related physics laws and validated with real-world data. The predictions it provides are consistent with those of other accident prediction models that have been proposed in the literature (e.g., *30, 31*). Mathematically, the model is given by

$$\frac{n_a}{n_b} = \left(\frac{v_a}{v_b} \right)^m \tag{2}$$

where

n_b and n_a = number of accidents before and after the change, respectively;
v_b and v_a = before and after average speeds; and
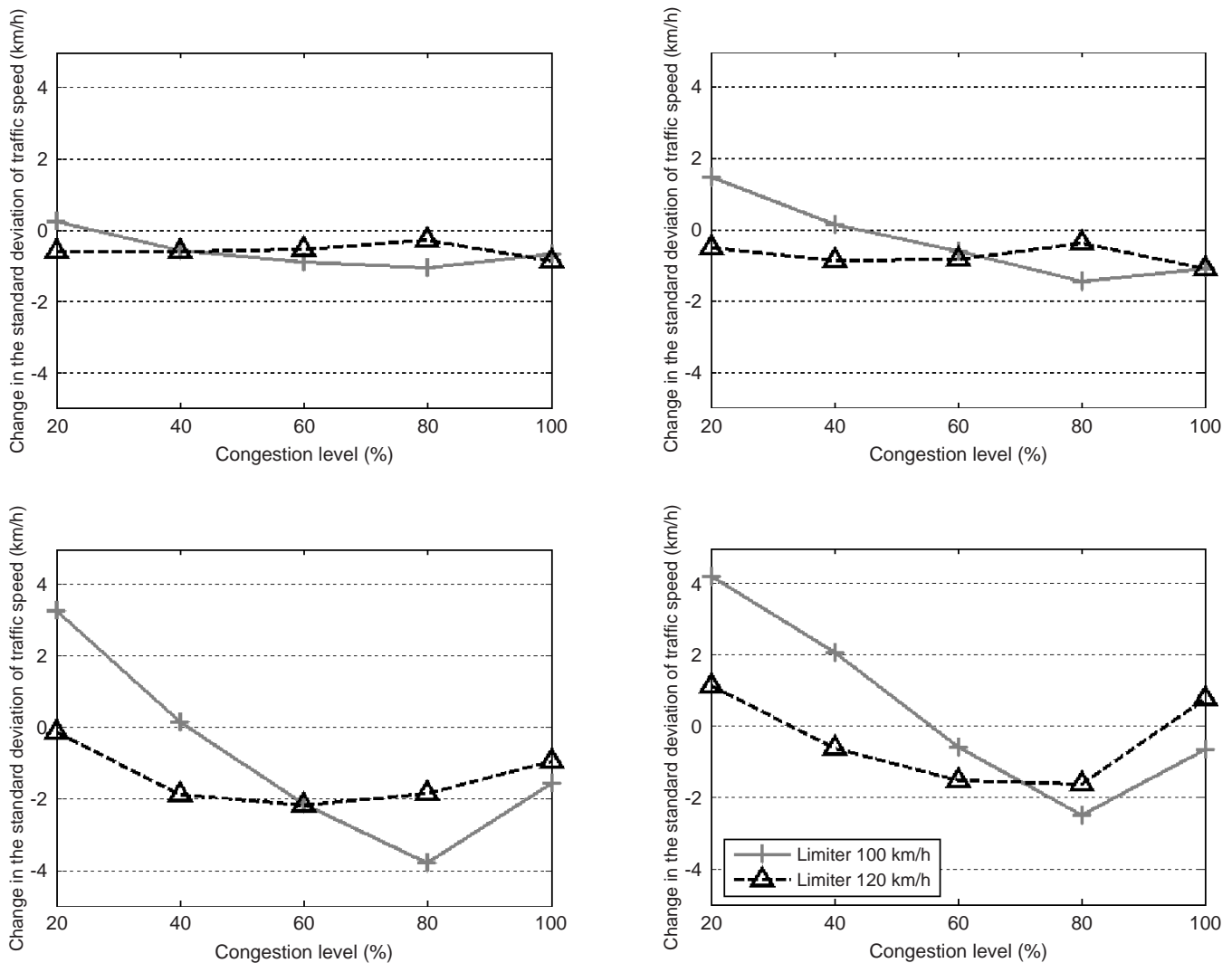m = parameter that depends on type of accident:

FIGURE 6   Change in standard deviation of vehicle speeds due to speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.

$$m = \begin{cases} 2 & \text{all injury and fatal accidents} \\ 3 & \text{serious and fatal accidents} \\ 4 & \text{fatal accidents} \end{cases}$$

Figures 9 and 10 show the percentage change due to speed limiters in the number of all injury accidents and in the number of fatal accidents, respectively. In all cases, the percent reduction in traffic accidents is larger when the speed limiter is more restrictive (i.e., set at 100 km/h compared with 120 km/h). The reduction in accident rates also increases with the difference between the posted speed limit and the limiter-set speed. The impact on fatal accidents is larger compared with all injury accidents because lower speeds reduce both the frequency of accidents and their severity. The results show that fatal accidents may be reduced by up to 40% and injury accidents by up to 25%. However, the Swedish model as well as other research in this area are based on data that do not typically include changes in speed of more than 10 km/h. Thus, the models were not validated for large reductions in average speeds such as the ones that were observed in some of the simulations.

DISCUSSION AND CONCLUSION

A simulation-based evaluation of the impact of a wide installation of active speed limiters on freeway traffic flow, driver behavior, and safety was described. A microscopic traffic simulation model was used, which models the acceleration and lane-changing behavior of individual vehicles in detail and so captures not only the impact of speed limiters on equipped vehicles but also their interaction with unequipped vehicles and the resulting impact on the latter. The simulation study deals with preset speed limiters, which implement simpler technology and relatively low cost compared with ISAs and are the focus of several legislation initiatives in Europe. In the experiment, the impact of speed limiters at various desired speed and demand levels was evaluated for two levels of limiter settings. In developing the simulation model it was assumed that the desired speeds of equipped vehicles are lowered to the limiter-set speed. This assumption may be worth testing in field tests or with driving simulators.

The simulation results show that speed limiters affect the speeds driven, the variability of speeds and lane-changing rates, but not
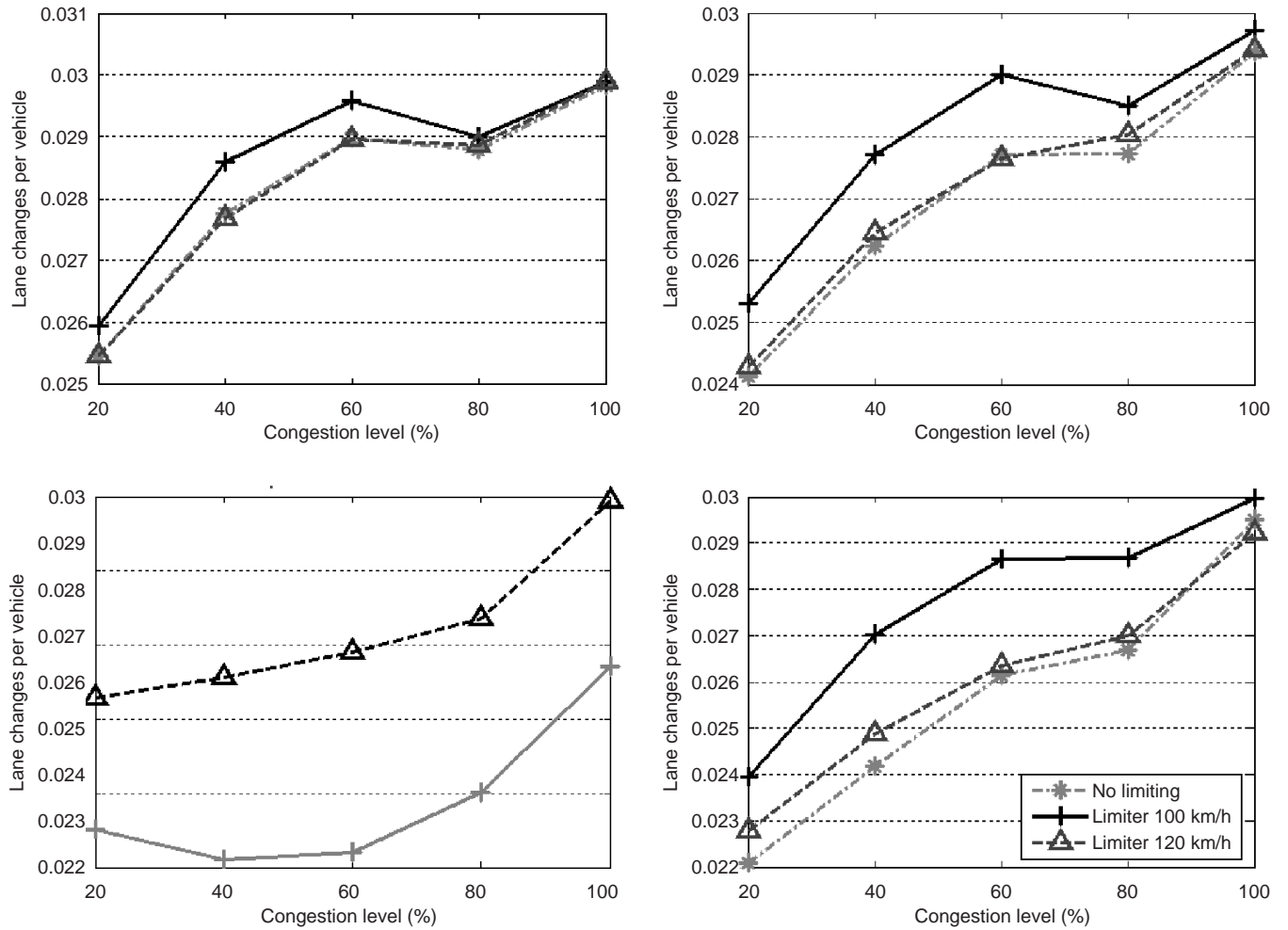
FIGURE 7   Lane-changing rates with and without speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h,
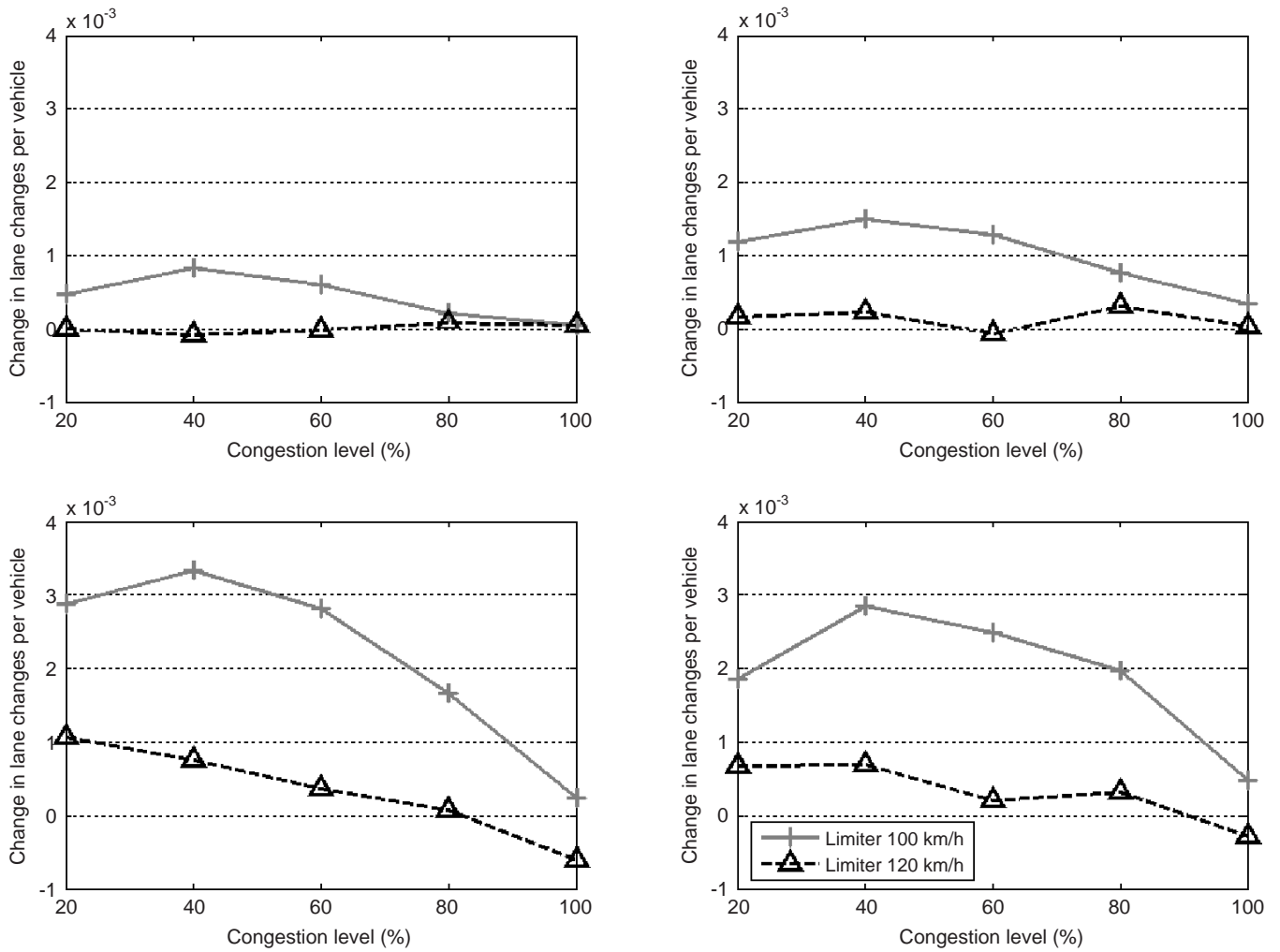(*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.

FIGURE 8   Change in lane-changing rates due to speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.
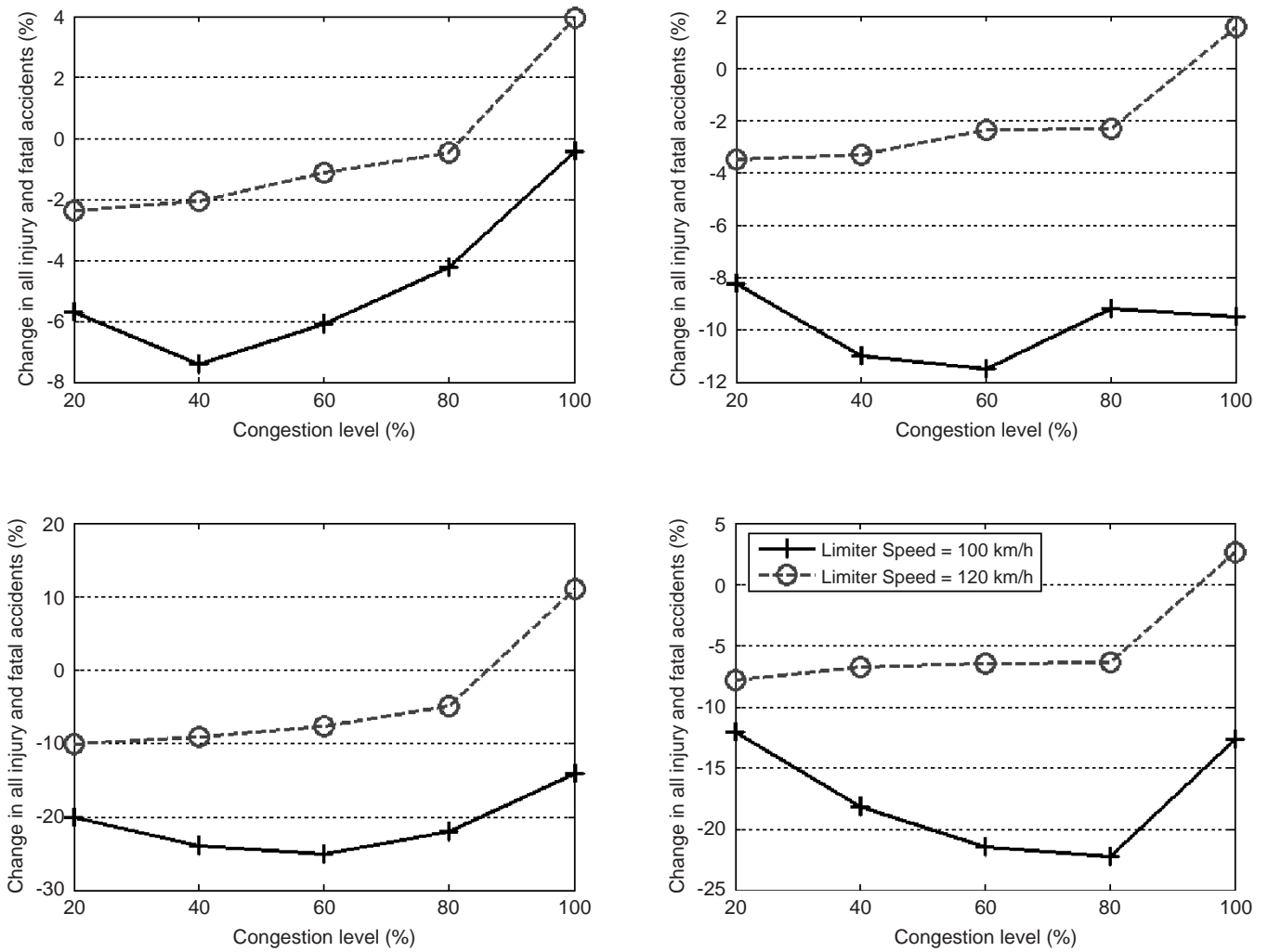
FIGURE 9   Changes in rates of all injury accidents due to speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.
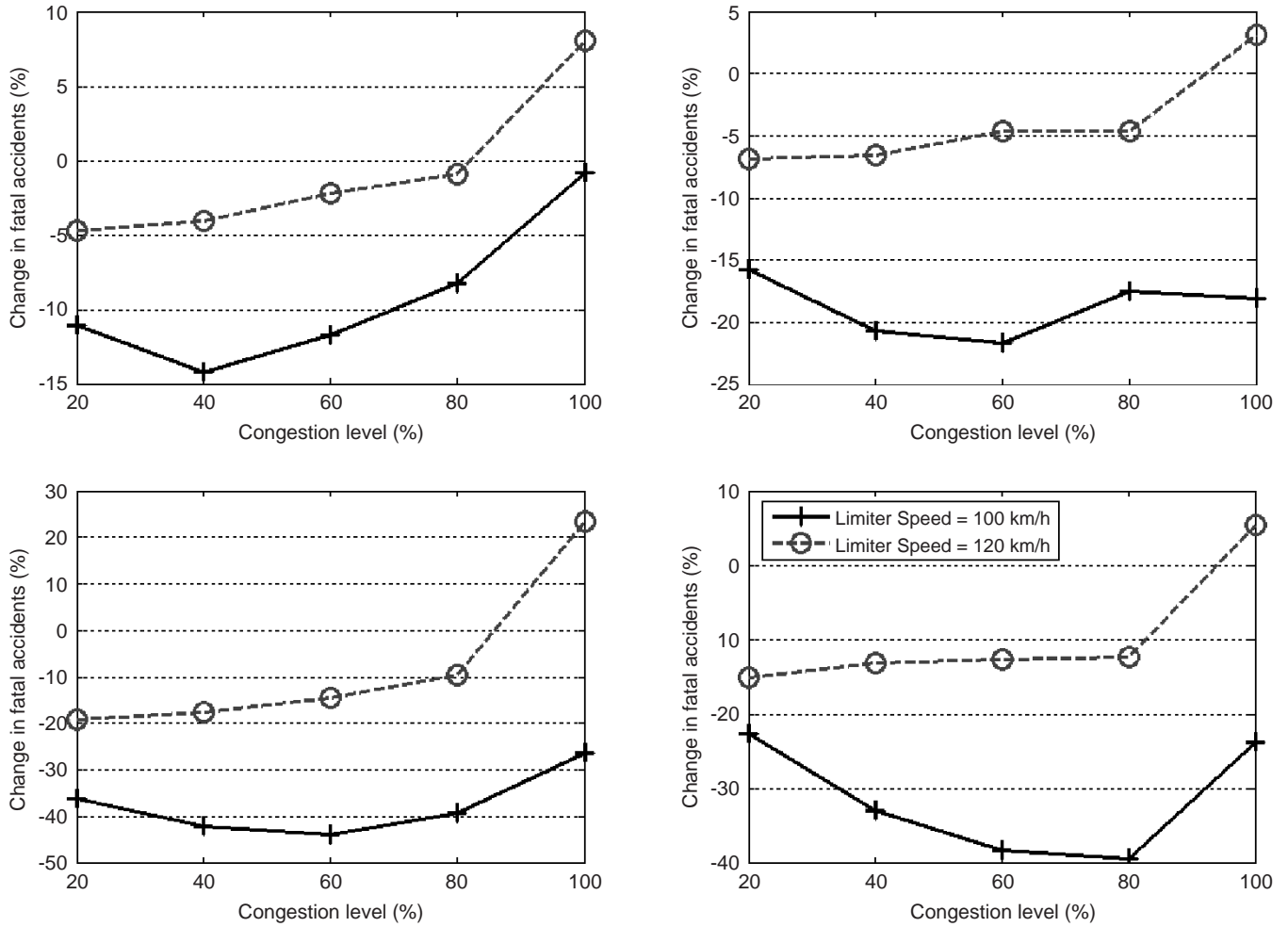
FIGURE 10   Changes in rates of fatal accidents due to speed limiters: (*a*) speed limit = 100 km/h, (*b*) speed limit = 110 km/h, (*c*) speed limit = 120 km/h, and (*d*) speed limit = 130 km/h.

traffic flows. Speed limiters can reduce speeds by as much as 10%. This result is comparable with field evaluations and the simulation study by Liu and Tate (*20*). The variability of traffic speeds also may decrease significantly, especially for the higher desired speeds and demand levels. Speed limiters also affect the number of lane changes drivers undertake. Generally, the impact of speed limiters is more pronounced when their settings are more restrictive compared with uncontrolled traffic speeds in the section. They are also generally most effective in the middle range of demand levels (40% to 80%), where they have a moderating effect not only on equipped vehicles but also on unequipped ones.

Although the results show that speed limiters can be useful in controlling speed and lead to significant reduction in accident rates, their undesirable effects should also be noted. In some emergency cases, drivers have to exceed the preset speed. Furthermore, unsuitable limiter settings may yield no impact or even undesirable impacts on traffic flow and on safety. In addition, some other effects of speed limiters, such as increased travel times, should also be considered.

If a wide installation of speed limiters is sought, it would be useful to evaluate the additional safety benefits that may be derived from ISA systems, which adapt set speeds to various conditions and so may have a more significant positive effect on traffic flow characteristics. Furthermore, it would be beneficial to analyze what the market penetration rates and limiter-set speeds that would yield optimal safety and traffic flow impacts for prevailing congestion levels and speed regulations may be. As demonstrated in this study, traffic simulation models can be effectively used for such evaluations.

ACKNOWLEDGMENTS

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