THE EFFECT OF SPEED REDUCTION ON CONGESTION

A Microsimulation Analysis

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SUMMARY

Reducing speed in and upstream of a bottleneck is believed to reduce the probability of breakdown and increase capacity. The FOSIM microsimulation model was applied to simulate the effects of reduced speed limits. A single on-ramp was modeled under various operating conditions. Results of the simulation experiments show that there is a trade-off between breakdown probability and queue length. Thus speed reduction creates a situation where either the probability of breakdown with a small queue length is high, or the probability of breakdown with a large queue length is small.

INTRODUCTION

One of the measures that are believed to increase capacity and solve or postpone congestion is the reduction of the speed limit. In the Netherlands this measure has only very recently been introduced in a pilot project on a 7-kilometer stretch of motorway. The signs of the congestion warning system that is installed on a large part of the Dutch motorway system are used for the different speed limits. So this measure will confront the road user with a speed limit, shown on matrix signs above the road. To ensure that users adhere to the speed limit, policing will take place. Due to this, it is expected that the fluctuations in speed of different cars will be reduced and the flow becomes more homogeneous. An algorithm using data on speed and flow collected by dual inductive loops as input, will provide the appropriate speed limit for the signals.
However, there is little knowledge on the influence of the actual value of the speed limit on the probability of breakdown. Thus it is not clear whether the algorithm that was used in the pilot, where under certain conditions a certain speed limit is chosen, can be improved.

Ferrari (5) showed that the driving behavior of individual drivers influence motorway reliability. He proved that it is possible to improve motorway function by imposing speed limits when traffic approaches conditions of instability. Persaud and Elefteriadou (6,7) showed that capacity is not static, but a probabilistic event, dependent on circumstances as road and weather conditions, but showing a stochastic behavior.

This paper presents the results of a microsimulation study, which uses speed limits, which are not flow dependent but time dependent. For different traffic regimes, percentage of trucks and speed limits congestion indicators, such as probability of breakdown, queue length and moment of first congestion were examined. Bottleneck throughput and speed-flow relations in the bottleneck were monitored to provide extra explanation on the performance of the different variants of the indicators. First the FOSIM model and its adaptation are described followed by the setup of the simulations, the results and the conclusions.

THE FOSIM MODEL

Model history

The FOSIM (Freeway Operations SIMulation) model was developed in The United States (*1*), but was extensively modified to deal with the Dutch traffic situation. The model was validated and calibrated for parts of the Dutch motorway network as ramps and weaving sections (*2*) and is permanently maintained by the Transport Research Centre (AVV) from the Dutch Ministry of Transport, Public works and Watermanagement.
FOSIM is a microsimulation model; it simulates a traffic flow on the level of individual drivers and their vehicles. The simulation time is divided into time steps and for every new time step a new position of every vehicle is determined, beginning downstream and working it's way up. In general each driver reacts to the driver in front. The new position of a car depends on it's former position, driver and vehicle characteristics, positions of other vehicles and road geometry. In FOSIM traffic flows can be varied per lane and in time.

Current update

The FOSIM model was chosen since it describes the processes in motorway traffic very accurately and is capable of handling different speed limits. Unlike AIMSUN2 or INTEGRATION the model is unable to handle dynamic, flow dependent measures. To simulate the effects of flow dependent speed limits a range of static speed limits varying over time is simulated. For this simulation FOSIM was updated to deal with lower speed limits. The version was called FOSIM 4.1 DYVERS (dynamic reduction of speed limits on motorways, although it was a series of static speed limits varying over time).

SIMULATION SETUP

Network

An on-ramp to a two lane motorway was modeled (Figure 1).

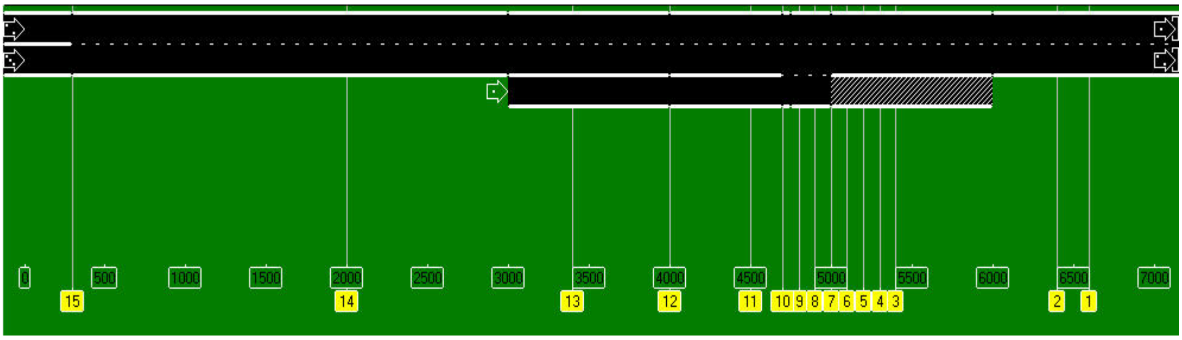

FIGURE 1 Network

The length of the motorway section is seven kilometers: 4.7 kilometers upstream of the on-ramp, 300 meters of on-ramp and 2.0 kilometers downstream of the on-ramp. The on-ramp has a feeding lane of 1.7 kilometers, before the traffic can merge onto the right lane of the motorway. The long lengths upstream of the merging section are used to let the uniform distributed traffic evolve into realistic rates of arrival.

Simulation time and flow regimes

Being stochastic, the outcome of a single FOSIM run does not give enough information to draw conclusions. Two flow regimes were chosen and for each flow regime 100 runs were simulated. The flows of the first regime were determined in such a way that in 30 out of 100 runs breakdown occurred. This regime was called B_30. The second flow regime was created to result into congestion in 70 out of 100 runs and called B_70. The total simulation time equals two hours, which was divided into pieces with their own flow generation. Traffic generation on all lanes and for all time periods is presented in Table 1a for the B_30 regime and in Table 1b for the B_70 regime.

		Simulation time step (sec)				
		0	500	2300	5900	6500-7700
Traffic generated	On-ramp	400	550	650	650	400
	Left lane motorway	1040	1430	1690	1690	1040
	Right lane motorway	800	1100	1300	1300	800
Total		2240	3080	3640	3640	2240

TABLE 1a Flow rates at 30 percent congestion level

		Simulation time step (sec)				
		0	500	2300	5900	6500-7700
Traffic generated	On-ramp	400	550	675	675	400
	Left lane motorway	1040	1430	1755	1755	1040
	Right lane motorway	800	1100	1350	1350	800
Total		2240	3080	3640	3640	2240

TABLE 1b Flow rates at 70 percent congestion level

The traffic generation on time steps in between the time steps mentioned is found through linear interpolation. The first 500 seconds are used to fill the network and were *not* part of the actual simulation.

Five categories of vehicle types are distinguished (Table 2).

Vehicle types	Passenger car classes			Light trucks	Heavy trucks
Class number	1	2	3	4	5
Vehicle length FOSIM(m)	4,5	4,0	4,0	8,0	14,0

TABLE 2 Vehicle class lengths

Table 3 shows the distribution of the vehicle types over the two lanes and the on-ramp.

Traffic composition	Passenger cars (cat. 1, 2, 3)	Light trucks (cat. 4)	Heavy trucks (cat. 5)
On-ramp	92 %	4 %	4 %
Left lane motorway	100 %	0 %	0 %
Right lane motorway	80 %	10 %	10 %

TABLE 3 Distribution of traffic on lanes

Speed limits

Four different speed limits were simulated. The 120 km/h regime, which means no reduction of the current legal speed limit, and three reduced speed limits of 70, 80 and 90 km/h. The speed limits were implemented through altering the desired flee flow speed of the vehicles and thee standard deviations of the desired speeds for the different vehicle types were added (Table 4). The speed limits were in place over the complete time span of the simulation.

	Standard deviation in desired speeds (km/h)		
Speed limit	Passenger cars (cat. 1, 2, 3)	Light trucks (cat. 4)	Heavy trucks (cat. 5)
No reduction of speed limit (120 km/h)	13	11	6
70 and 80 km/h	6	6	6
90 km/h	6	6	6

TABLE 4 Standard deviation of desired speeds per vehicle category

CONGESTION INDICATORS

Three main congestion indicators were monitored during the simulation runs: breakdown probability, queue length and time of initial congestion. To clarify the results found by these indicators bottleneck throughput and speed flow relations were monitored. The definition of breakdown which was used is: if detector 11 (Figure 1) shows a speed below 40 km/h for a period of 60 seconds then we declare the section to be congested. As a sensitivity analysis this was repeated for 15 km/h instead of 40 km/h. The locations of the detectors determine the locations where spill back (or queue length) could be measured. The time of first congestion was also determined using output information of detector 11. Bottleneck throughput was monitored on detector 8, halfway on the on-ramp, and on detector 3 downstream of the bottleneck. Speed flow relations finally were plotted to explain the results of the three congestion indicators.

RESULTS

The results of both traffic flow regimes, B_30 and B_70, show a relation that can best be described by: low breakdown probability is found in combination with high queue length and high breakdown probability is found in combination with short queue length (Figure 2a and 2b).

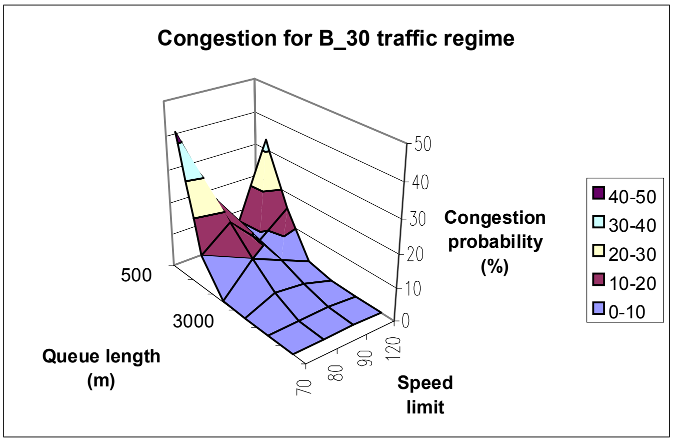

FIGURE 2a Breakdown probability and queue length for all simulated speed limits for the 30 percent congestion level

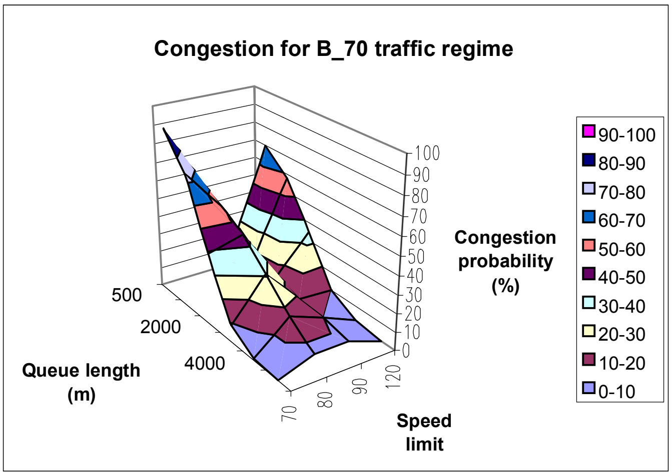

FIGURE 2b Breakdown probability and queue length for all simulated speed limits for the 70 percent congestion level

Figure 2a and 2b show for each combination of speed limit and distance upstream from the bottleneck how many out of 100 simulations result in congestion on a specific location. Detector 11 is on 500 meters from the middle of the on-ramp. Under the B_70 regime and the 120-km/h speed limit the congestion probability is 70%. This is how the B_70 regime was constructed. With a 70-km/h speed limit the congestion indicator results are similar to the results of the 120-km/h speed limit: high breakdown probability in combination with short queues. The 80-km/h and especially the 90-km/h speed limit simulations show low breakdown probabilities in combination with long queues. When the two criteria, queue length and breakdown probability, are combined, the 90-km/h speed limit comes out as best under both traffic regimes (Figure 3).

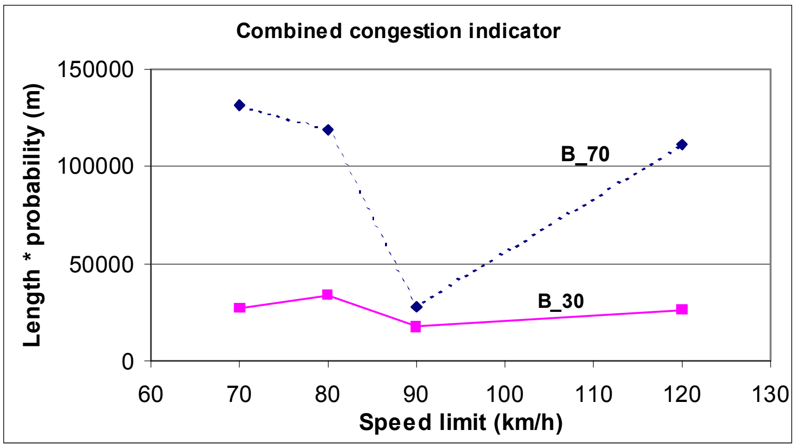

FIGURE 3 Combined congestion indicator

Under the B_70 regime the 90-km/h speed limit performs best. Using the alternative definition of breakdown, 15 km/h on the bottleneck detector instead of 40 km/h shows similar results. The moment of first congestion (Figure 4a and 4b) is in almost all cases not significantly different (on a 95% confidence level). Only the onset of congestion in the B_70 flow regime with the 70-km/h speed limit is about 8 minutes earlier than the onset of congestion under different speed limits with the same flow regime.

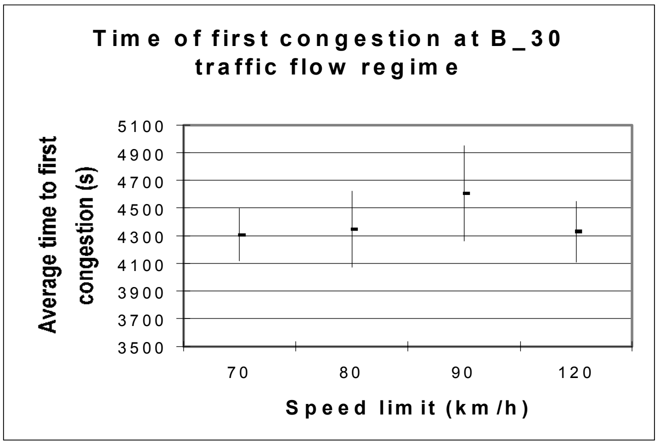

FIGURE 4a Time of first congestion for the 30 percent congestion level

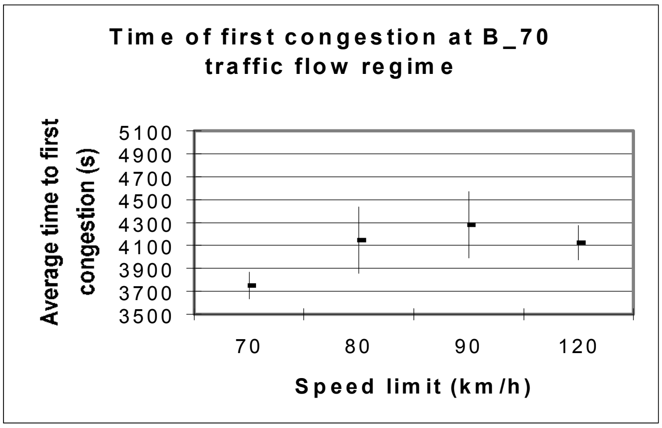

FIGURE 4b Time of first congestion for the 70 percent congestion level

Sensitivity analysis on standard deviation in speeds and pce-factors used for trucks uphold the above results.

CONCLUSIONS

Speed regulation is a measure that influences the probability of breakdown and queue length. The experiments show there exists a trade-off between queue length and probability of breakdown. Therefor, if plans exist to introduce a reduction of the speed limit, the maximum queue length that is still acceptable must be known. If even a long queue does not form an obstacle for any other flow a 90-km/h speed limit may be installed. However, if a long queue has the danger to block other flows it is advisable to install the 70-km/h or the 120-km/h speed limit.

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