

Chapter 14

Microscopic simulation models

This chapter consists of a general part about simulation (definition, general description, developing and use of a model) and a specific part concerning the microscopic model FOSIM for traffic operation at motorways.

14.1 General aspects of simulation models

14.1.1 General description of simulation

We will restrict ourselves to microscopic simulation models; however, this does not mean that macroscopic simulation models are not important. A microscopic simulation model of a traffic stream can be defined as:

It is a description of the movements of individual vehicles that are considered to be a result of:

- characteristics of the drivers and the vehicles
- interactions between the driver-vehicle elements
- interactions between driver-vehicle elements and the road characteristics
- conditions (weather, light)
- control (static, such as a fixed speed limit; and dynamic, such as: traffic lights; motorway signalling systems; on-ramp control; and, policemen)

In general this process is so complex and the number of factors so large that it can not be handled by analytical methods. The only method that remains is to imitate the process with a computer. The program calculates the position, speed and all other ‘state variables’ of a vehicle every time step Δt . An often used value for this time step is 1 second. However, in a good model this time step should be an input parameter that makes it possible to use other values. It’s obvious that a smaller time step will lead to a longer computer time and that it should lead to a more precise description of behaviour.

14.2 Applications

Many simulation models have been developed in the transportation field. They are used for analysis of existing systems that need modifications and for the design of new systems. In general the use of a simulation model as a tool to solve problems is indicated when the system considered is complex and its components interact.

Examples:

- Traffic operation on motorways with a lot of on-ramps and off-ramps.
- Traffic operation on weaving sections of a motorway.
- Pedestrian flows at airports and railway stations.
- Design of control of isolated signalized intersections.
- Design of control for a network with controlled intersections.
- Two-lane roads with varying road characteristics and extra overtaking lanes.

14.2.1 Parts of the model

- Submodels for the interactions between Driver Vehicle Elements (DVE's).

Examples are submodels for overtaking, lane changing, car-following, submodels for interactions between DVE's and other factors. Examples: Effect of road width, curves, grades, weather, speed limit

- Input

For one, the characteristics of DVE's need to be established. Examples are type of car, free speed of vehicle, maximum acceleration used on grade, acceleration used when accelerating to free speed, critical gap when overtaking, preferred distance headway at car-following, type of driver (calm, aggressive), etc.

Other input consist of road characteristics (number of lanes, width, radius and length of curve, grade, etc.)

- Output

The most complete output consists of all characteristics of all vehicles on the road at every moment of time. This consists of an enormous quantity of numbers that are difficult to handle. It is mostly only useful when developing the model, looking whether it behaves as intended. A graph of the vehicle trajectories can be a good help. A sequence of 'views from the air' (snapshots) of the road with the vehicles moving over the computer screen (animation) is a good tool for demonstrations and also for checking the correctness of the model.

- Random processes

Most models have chance processes to model the fluctuations that are part of reality. The input very often is stochastic; e.g. the type of vehicle and its desired speed are drawings from a probability distribution of which the parameters are given. Also during the process on the road probabilities can play a role. Differences between drivers or even within one driver at different moments can be modelled in this way.

- Generation of random numbers

Most computers have built-in generators of pseudo random numbers that are uniformly distributed between 0 and 1. From these one can generate all types of drawings from other probability distributions. In the past this element of the models was considered to be the most important, leading to the name 'Monte Carlo' simulation.

Remark 65 *The random number generator of a PC can be controlled by a so called seed, usually an integer number. If the seed of a run is the same, the sequence of random numbers is exactly the same. This is a useful property, one can change a deterministic element of the model and by keeping the seed the same, the random elements of the model are the same.*

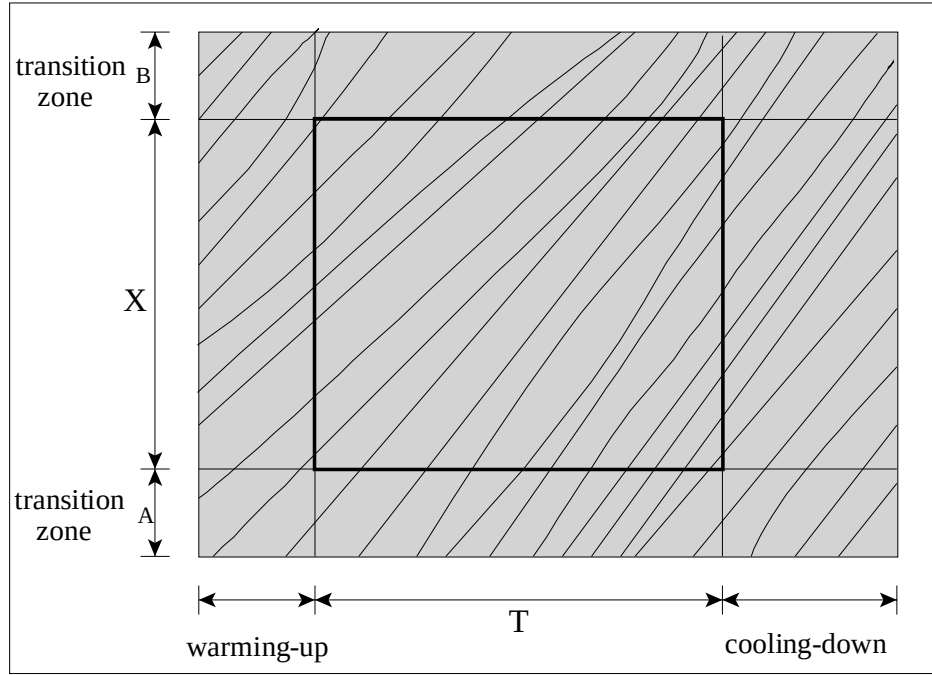


Figure 14.1: Simulation over an area in the road-time plane of size X times T with extra strips to ascertain correct functioning (not to scale)

Using a different seed and keeping all other input the same, is like carrying out observations on two comparable days (same weather, same demand, same truck percentage, etc). The differences in results can then be attributed to the inherent randomness of the traffic process.

The general procedure to generate stochastic variates with distribution F is shown in Fig. ???. The drawing X , from a uniform probability density between 0 and 1, is transformed by $F^{-1}(x)$ and the outcome Y is the required variate. When the calculation of the transformation is not easy, it might take too much computer time. It should be realized that in some models over 1 million of random drawings can be needed for a single run and then it is worth the trouble to use a more efficient method for generation. There are a lot of books discussing methods to generate stochastic variates. A standard trick, that is cheap in terms of computer time, to generate random variables from a Normal Distribution, is the following: Take the sum of a number (say 12) of uniform distributed random numbers. Due to the ‘Central-limit Theory’ this approximates the required Normal variates rather well.

- Warming-up time

In most models the simulation starts with an empty road. This makes the behaviour in the beginning of the simulation not realistic. One should simulate until at least the vehicles have reached the end of the section that is modelled.

The required so called warming-up time can be estimated from the length of the road and a rough indication of the travel speed.

- ‘Cooling-down time’

Some models simulate longer than the period T that is used as an input. This makes it possible to collect characteristics such as the travel time for the total road length for all vehicles that entered the road between time = 0 and the duration of the simulation T ; see Fig. 14.1.

- Transition sections

Many models have an extra length of road at the beginning and sometimes also at the end of the road section considered. This is needed because the entering vehicles are not immediately in a realistic state and need a certain distance to reach more realistic behaviour. At the end of the section, the sudden disappearance of vehicles can lead to unrealistic effects. For both reasons it is useful to have a transition section, at both ends of the section on which the investigation is carried out.

14.2.2 Development of a simulation model

Suppose the decision has been taken that for a given type of problem(s) a simulation model is needed. This does not imply that one should develop a new model. It is worthwhile to consider the alternative of buying an existing model, even when it does not fulfil all requirements. The development of a model is very time consuming.

Suppose one chooses to develop a model, then there are a lot of choices to be made. An important point is: Should one develop a special purpose model, that is as simple as possible and just able to solve the problem at hand; or should one develop a more comprehensive model that can be used for a wider class of problems. All those decisions have implications for costs and benefits, but this point will not be discussed here further because it depends so much on the case at hand.

Now follows a list of points that are important in developing a model.

- Define the aim(s) of the model
- Derive from that the type of model that is needed.
- Design the model in broad outline.
- Draw up a general description of the modules of the model
- Work out the modules in flow diagrams
- Choose a computer language or a simulation package
- Program the modules
- Verification
 - Test the modules separately to see that they work as intended.
 - Combine modules in larger parts and verify them.
 - Combine the parts in a complete model.
 - Start with making simple test runs.
 - (A good tactic when verifying and testing can be to eliminate temporary the stochastic element because a completely deterministic model is more easy to check)
- Criterion variables
 - Determine which outcomes of the model are crucial for the application; e.g. for a certain application travel time might be an important characteristic and the number of overtakings not that much.
- Sensitivity analysis
 - Determine which parameters are most important for the outcomes of the model.

- Determine how variations in important parameters influence the outcomes. This is a so called sensitivity analysis. The results indicate how precise one should determine the parameters.
 - A comprehensive model very often has too many parameters (say > 25) to calibrate and validate them all. Most of them have to be based on existing knowledge and engineering judgement.
- Calibration
 - Compare outcomes from the model with results of observations in reality.
 - Change parameters to make the model reproduce reality as close as possible.
 - Validation

Compare model outcomes with fresh real data using the parameters as found in the calibration. When the result of this is positive, the model is considered to be valid. However, one should keep in mind that validity is always with respect to a certain field of application. When more cases are used for validation, and the outcome is favourable, the validity of the model increases.

14.2.3 Use of a model

The carrying out of investigations with a simulation model as a tool resembles the process of collecting observations in real traffic. The task of designing appropriate runs with the model and analysing the results is often underestimated.

When investigating the effect of (say) 5 factors that can have 4 values, and being interested in 5 different traffic intensities with 2 different percentages of trucks, one has to do $5 \times 4 \times 5 \times 2 = 200$ runs. If the effect of randomness is large one might wish to do each simulation 10 times, which increases the number of runs to 2000. Even if the simulations are cheap, think about analysing the results of 2000 runs.

Consequently there is a need for using techniques from the field of ‘design of experiments’ to reduce the number of runs and the size of the analysis. With those techniques it is possible to choose a specific subset of runs (say 200) and almost get the same information as from 2000 runs.

An other solution, to process the outcomes of many runs, can be to carry out the analysis of the results directly by a computer program of which the simulation model is a module.

14.3 Description of simulation model FOSIM

14.3.1 General

The Transportation Laboratory of TU Delft has developed (since around 1988) - and is continuously extending and improving - a microscopic simulation model with the name FOSIM (Freeway Operations SIMulation). This model simulates the traffic operation on motorways and has been successfully applied at several types of road configurations: weaving areas; sections with on-ramps; and, sections with road works. See: [39], [47], [46], [48]. FOSIM is a microscopic simulation model, i.e. the behaviour of a traffic stream is imitated on the level of individual driver-vehicle elements. The simulation period is divided in time steps of 1 s (other time steps can also be used but in general 1 s is a suitable value). Each time step the positions and other dynamic characteristics of the vehicle are updated, starting with the most downstream vehicle. The new position of the vehicle depends on its previous position, the properties of the driver and the vehicle; the interactions with other road users; and, the characteristics

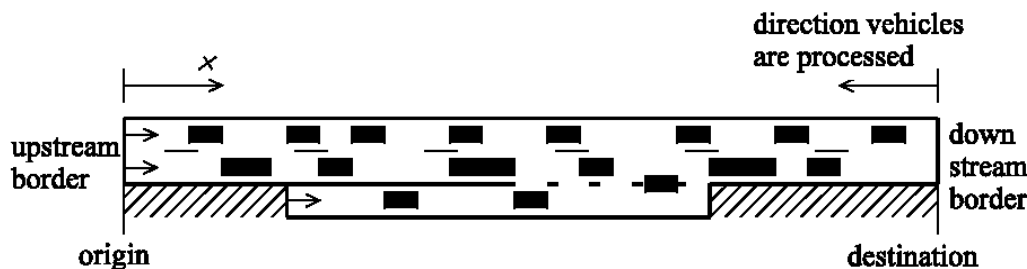


Figure 14.2: Schematisation of a roadway section with an on-ramp

(mainly geometrical properties) of the road. The new position is calculated taking into account the expected position after a few time steps, representing the anticipation of the drivers.

Using FOSIM it is possible to define a large variety of road configurations. A simple example is the roadway section with an on-ramp, depicted in Fig. 14.2. It is assumed that the road sections have no grades and the horizontal curves are so smooth that they do not influence vehicle behaviour. These assumptions are not very restrictive for Dutch motorways.

Several driver-vehicle elements can be distinguished. Their main characteristics are:

- vehicle length
- accelerative power
- declarative power
- free speed (or desired speed)
- parameters determining the car-following behaviour
- origin lane and destination lane
- When a vehicle enters the model, it is assigned a destination lane in a random way, taking into account the origin-destination matrix. Also the properties that are assigned to a driver-vehicle element (e.g. the desired speed) have some random elements. Consequently the repetition of a run, with a different random seed will produce a different outcome.

In general one has to repeat the simulation several times in order to get a reliable mean outcome and an impression of its variability (standard error). Intensities at the entrances can be varied per lane. The results of the simulation (intensities, speeds and densities) can be collected at detectors at the sections at arbitrary positions.

14.3.2 The vehicle process

The decision process that each driver has to go through at each time step, is called the vehicle process; see Fig. 8.4. The first step is to compare the actual lane with the destination lane. If the destination lane and the actual lane are different, this can lead to a desired lane change, dependent on the position of the vehicle (if the vehicle is still far from its destination, the destination lane has little influence).

If a driver does not have to change lane to reach the destination, he/she can decide to overtake a slower vehicle in front. If a lane change is desired, FOSIM checks the possibilities to carry it out in the actual time step. If the outcome is positive, then the vehicle is placed on the new lane and its new position is calculated. If the lane change is not possible, then the vehicle becomes a car-follower.

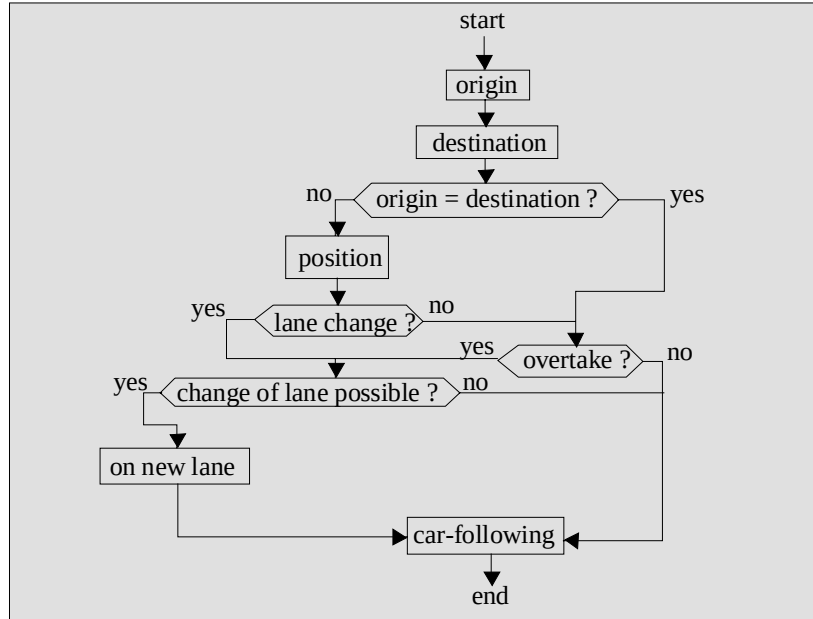


Figure 14.3: The vehicle process in FOSIM

14.3.3 The car-following model

In FOSIM each driver will always try to maintain or go back to his/her desired speed. If a vehicle in front is present (at a distance headway that is relevant), FOSIM calculates an acceleration that aims at reaching an acceptable distance headway.

Fig. 14.4 depicts the car-following situation; vehicle a is the leader and vehicle b the car-follower

The headway distance the vehicle is aiming at, is given by:

$$d_i = L_j + z_1 + z_2 f_j v_i + z_3 v_i^2 \quad (14.1)$$

with:

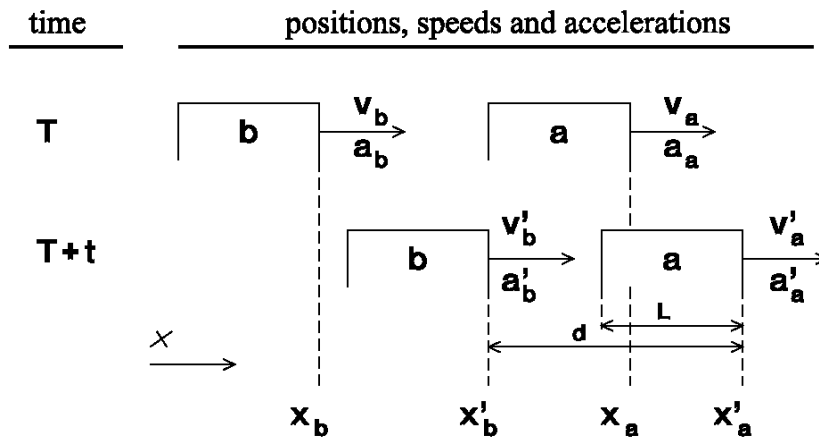


Figure 14.4: Two vehicles at successive moments

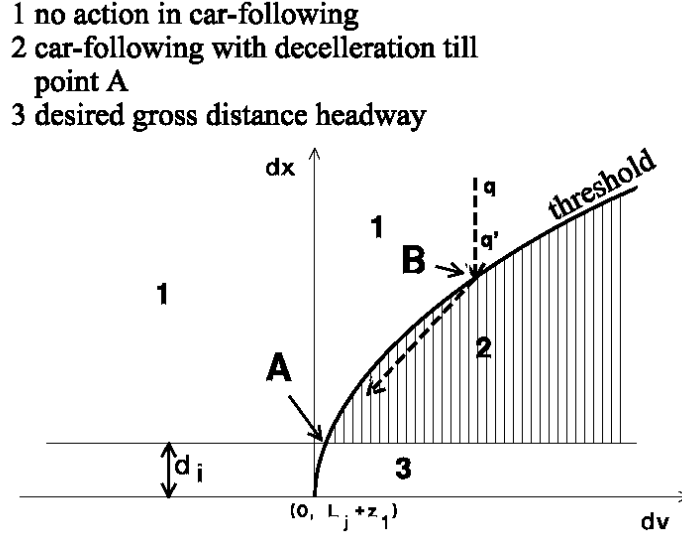


Figure 14.5: Anticipation threshold at approach of vehicle in front

i, j	—	index of vehicle i, j
d_i	m	target gross distance headway
L_j	m	length of leader
f_j	s	follower specific car-following parameter
v_i	m/s	speed of car-follower
z_1	m	general car-following parameter
z_2	m/m	general car-following parameter
z_3	s^2/s	general car-following parameter

If a vehicle catches up a vehicle in front along line $q-q'$ (see Fig. 14.5), then it will decelerate if the combination of relative speed and distance headway requires it.

The threshold function of FOSIM is given by:

$$dV = ((dx - L_j - z_1) / 50)^2 \quad (14.2)$$

where dV = speed of car-follower - speed leader, and dx = distance headway of car-follower. After crossing the threshold in point B, an acceleration is determined that will lead to the situation in point A. As an extra check the possibility of a collision is investigated and the acceleration will possibly be adapted to prevent that.

14.3.4 Lane change model

In FOSIM are distinguished: mandatory lane changes; desired lane changes; and, overtaking movements; see Fig. 14.6 and Fig. 14.7. The desired lane change between cross-sections a and b is carried out in order to get into a better starting position for the mandatory lane change between positions b and c. The driver is willing to take a greater risk at a mandatory lane change than at a desired lane change. This risk is translated in the deceleration a driver accepts to make the lane change possible.

In some cases, e.g. at weaving, FOSIM allows extremely short headways (these do occur in reality too) by halving the anticipation time.

In the case a *vehicle blocks an intended lane change*, the driver can change his speed a little to increase the possibility for the lane change in the next time step. Dependent on the driver type, this will be a speed increase (tactic 1) or a speed decrease (tactic 2). In case of tactic 1, the vehicle that blocks the lane change can possibly cooperate by decreasing its speed and, so to speak, give priority to the lane changer.

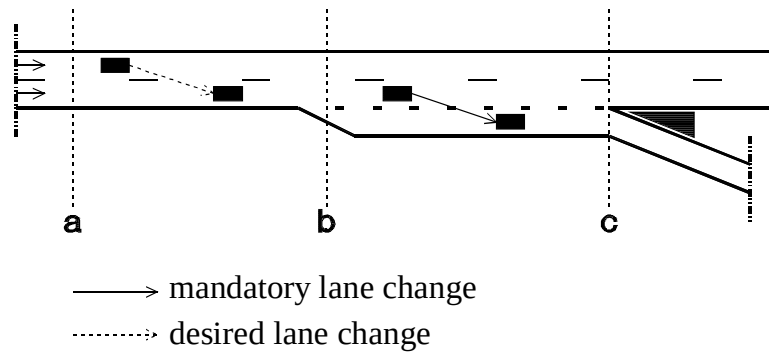


Figure 14.6: Mandatory and desired lane change

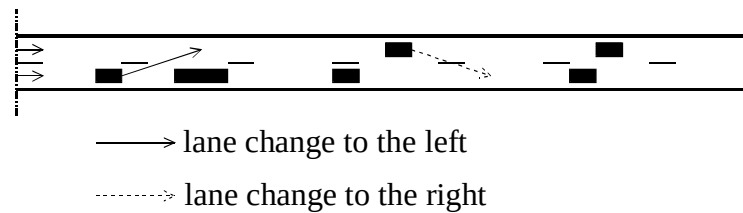


Figure 14.7: Lane changes at an overtaking

An *overtaking*, see Fig. 14.7, will primarily be carried out to maintain the desired speed or deviate less from it. The overtaking consists of two parts: a lane change to the left and one to the right. These are more or less independent manoeuvres.

A *lane change to the right* is carried out if there is no speed advantage in staying on the actual (non-right) lane. This will in general be the case if the vehicle drives at its desired speed.

14.3.5 Calibration and validation

Before a simulation model can be applied, one should be reasonable sure that the model resembles reality sufficiently for the relevant aspects. FOSIM has been calibrated for several configurations: weaving sections; sections with on-ramps; roadways with temporary lane reductions due to road works. The main aim was to use the model for capacity analyses and estimations. For that case the car-following behaviour is most decisive and consequently the focus of the calibration were the parameters of that process. Criteria for the calibration were:

- capacity
- distribution of roadway intensity over the lanes
- location of the start of congestion
- location of the lane changes
- mean speeds per lane

The outcome is that FOSIM is considered to be (sufficiently) valid for:

- weaving sections of the type 2+2 and 2+1 lanes;
- road works of the type 2→1, i.e. a two-lane roadway has one lane dropped over a given distance;

- roadway section with on-ramp.

In fact the calibration of a model such as FOSIM is an ongoing process. Recently the car-following behaviour module has been modified: the parameters now used are different for non-congested and congested traffic; see [16].

14.4 Application of FOSIM

In the Second Transport Structure Plan (SVV-II) several measures are proposed to make a Better Use of the Existing Infrastructure. Several of these measures are new, their effects are unknown and at least an estimation of the potential benefits is needed before they will be applied. The effects of these measures can be estimated by applying: general theory about traffic behaviour; studies with instrumented vehicles; studies with vehicle simulators in laboratories; and, last but not least simulation models.

Two measures have been studied: (with truck percentages of 5% en 10%)

- Introduction of no overtaking periods for trucks on motorways (truck overtaking ban);
- Prohibition for trucks to use motorway sections at periods congestion is frequent (truck ban).

Four scenarios have been investigated:

- One-lane on-ramp at a two-lane roadway
- Permanent lane reduction at a roadway from 3 to 2 lanes with the most left lane falling off
- Weaving section of the type 2+1 lanes
- Weaving section of the type 3+1 lanes

For each scenario the effect of the measure on the capacity has been investigated and per alternative situation 50 simulations were carried out; see [48] for more details.

14.4.1 Truck overtaking ban

Relevant differences between trucks and cars are:

- larger dimensions of the truck (vehicle width and length unto 18 m);
- lower speed (the official speed limit for trucks on motorways = 80 km/h, in reality truck speeds at free flow are 85 to 100 km/h);
- lower accelerative power.

Because differences of desired speed of trucks can be small, overtakings between trucks can last long and lead to temporary blocks for other vehicles. Large speed differences between cars and trucks can lead to sudden and unpredictable speed reductions of cars. To reduce the negative impact of trucks at busy hours the measure considered was to introduce no overtaking periods for trucks. This will result in platoons of trucks on the right lane of the roadway behind a slow vehicle (which could also be a slow car). The longer this situation persists, the longer will become the platoon; see Fig. 14.8.

A possible negative effect of a platoon of trucks is the temporary reduction of gaps for other vehicles to make a lane change. This could lead to a deterioration of traffic operation at on-ramps and weaving sections. Consequently the measure could have positive and a negative

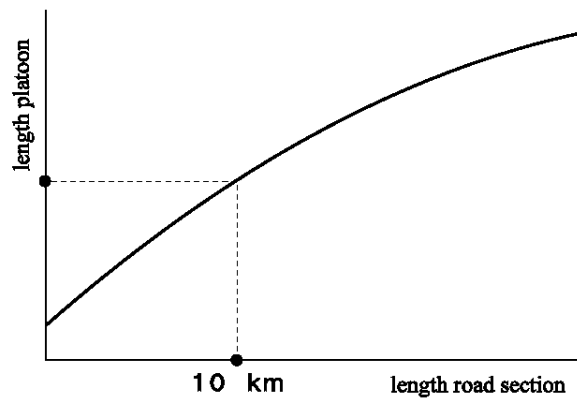


Figure 14.8: Hypothetical growth of platoon lengths as a function of the road section length

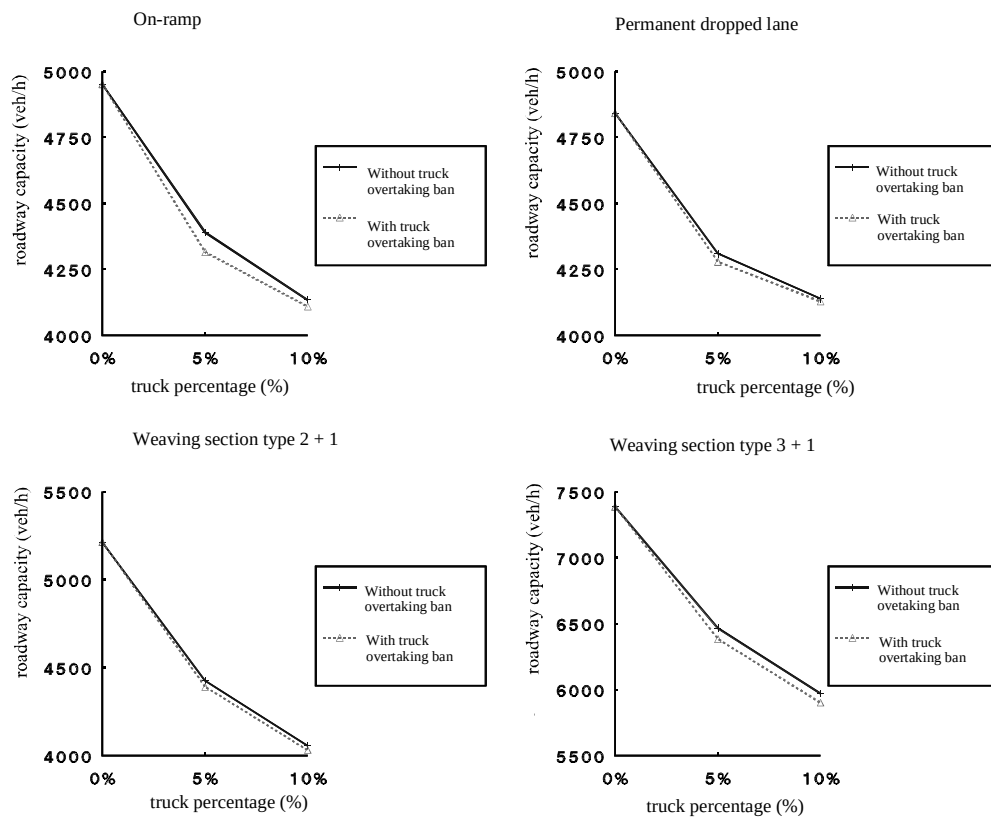


Figure 14.9: Capacity of roadway with and without truck overtaking prohibition

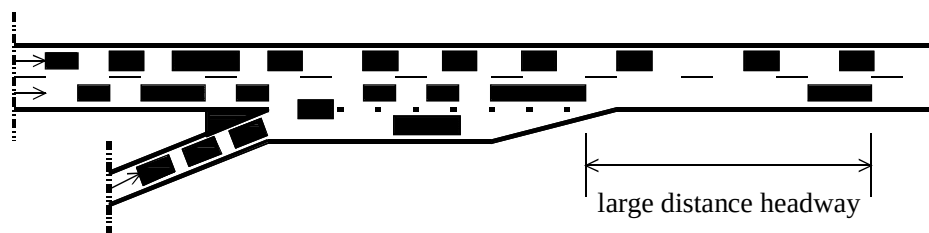


Figure 14.10: Accelerating from a congested region at an on-ramp

effects, both of unknown size. On theoretical grounds it is not possible to determine the overall effect. This is especially a situation in which a simulation model can be a useful tool. The results of the simulations are depicted in Fig. 14.9. From this figure can be concluded that the effect on capacity of the truck overtaking ban is negative but rather small.

14.4.2 Truck ban

Because trucks have a much smaller accelerative power than cars, they can substantially decrease capacity in the case of congestion, when vehicles have to accelerate (compare with trucks after a stop at a traffic light). Fig. 14.10 illustrates this situation; trucks can have a large empty space in front in such conditions, which represents a loss. To circumvent this problem it has been proposed to forbid trucks to use busy road sections during peak periods.

Remark 66 *On the other hand special facilities for the benefit of truck traffic are under construction, e.g. the truck traffic lane at the Rotterdam orbital motorway.*

Simulations with FOSIM have resulted in effects, depicted in Fig. 14.11.

The general effect of the banning of trucks is substantial. At 5% trucks the capacity gain amounts to 7.0%-13.4% and at 10% trucks the increase is 14.9%-22.1%. The effect of the truck ban is smallest at the case with the lane reduction. This makes sense because the left lane, without truck traffic, is disappearing. For other cases the gains are approximately the same.

It can also be concluded that the capacity gain is relatively smaller at higher truck percentages; the law of diminishing returns seem applicable here. Inspecting the effects per lane, it is evident that the effect is largest at the right lane, mostly used by trucks.

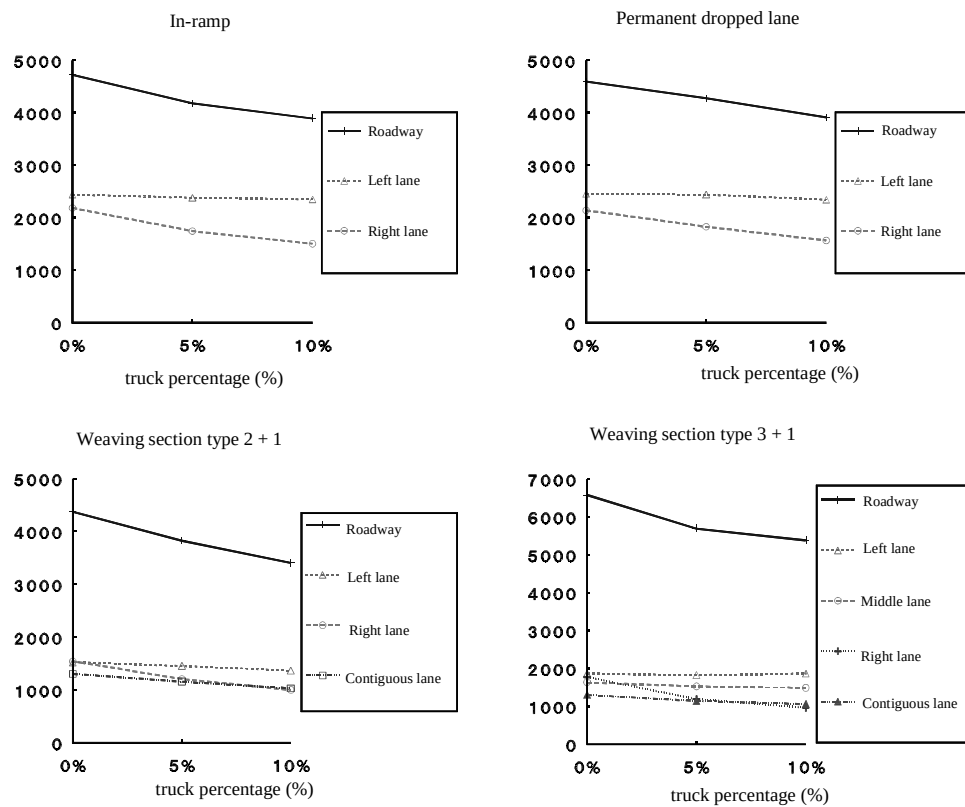


Figure 14.11: Queue discharge rate of roadway per type of roadway section

