CALIBRATION OF A TRAFFIC GENERATOR FOR HIGH DENSITY TRAFFIC

USING THE DATA COLLECTED DURING A ROAD PRICING PROJECT

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ABSTRACT

Microscopic traffic simulation is often used to investigate phenomena that can not be measured in real traffic. In our case, the Dutch Government has employed such a simulation to investigate the performance of several prototype road pricing systems before they were actually implemented on a road site.

In the end, only a few number of prototypes were actually tested on real traffic. During these tests, a separate system recorded not only their outputs, but also the measurements of a reference system. This was an inductive loop system, which is the standard source of most validation sets for traffic simulation. It gave the opportunity to combine two independent measurements that resulted in a data set unique in its reliability and detail.

Key Words: random traffic generation, microscopic traffic simulation, electronic toll collection.

INTRODUCTION: CONTEXT OF THE STUDY

The Dutch Government has the intention to increase the capacity of the existing road infrastructure by stimulating an intelligent use of this infrastructure. Their hope is on fast introduction of the techniques of Intelligent Transport Systems and they strive to be the forerunner with this sort of techniques in Europe, if not the world (1).

Road pricing is foreseen as one of the most effective techniques to stimulate intelligent use of the road infrastructure, which does not necessarily mean that it is one of the most popular techniques. The systems are not allowed to impose any constraints on the traffic flow, which means that the techniques have to be used which can cope with cars performing lane changes while travelling with high speeds. Road pricing based on short-range communication was originally planned to be introduced around the major cities in 2001. Currently they plan to introduce nation wide road pricing in 2006, based on the overall travelled distances.

There are many aspects that need attention in the implementation process of road-pricing. Economic effects, effects on congestion, time-of-day, route choice, mode choice, etc, etc, are just some of these short or long term aspects that are of importance. We concentrated on the technical performance of the systems. The random traffic generator described in this paper was especially designed for this aspect. This aspect is discussed in more detail in the next chapter.

Why building a Random Traffic Generator?

Microscopic simulation is often used to investigate statistical traffic data that can not be measured in real traffic. Reasons for using simulation as an analysis tool can be that the situation one wishes to observe does not yet exist in real traffic (e.g. intelligent transportation systems that have not yet been implemented), because the phenomenon is too rare to find sufficient occurrences in measured data.

With rare phenomena however, like the failure of electronic debiting systems for road pricing, many cars have to be simulated if statistically significant conclusions have to be drawn. Simulation then requires huge amounts of traffic measurements as input data, which is usually not available. Another benefit of simulation is that rare events can be reproduced, when the same seed is used. The logging at the time of that rare event can be extended to determine the precise circumstances that triggered the event, which increases the insight in the system.

What can be learned from the development and calibration of the RTG?

Although the form of traffic distributions is in principle known (2), the parameters of those distributions have to be derived from measurements. The distributions for vehicle types, interarrival times and vehicle speeds have been studied and are presented in this paper.

As shown, determination of the vehicle type is the first step in the generation process. Errors in the vehicle type distribution have severe consequences for calibration of the next steps in the generation process, because both interarrival time and speed are a function of the vehicle type. In this study we combined the measurements of two independent systems, which resulted in a much better vehicle type classification. As a consequence, the interarrival time and speed generators could be calibrated more accurately.

What is the scope of the results?

The road pricing system was meant to operate during the morning rush-hours (week-days between 7 and 9), so the traffic generator was calibrated with passages from this period and validated with another set from this period. The traffic situations during this period can be classified as flowing at very high densities (volumes of around 86% of the road capacity). Our random traffic generator could also be used to generate traffic for other volumes, by scaling the model parameters appropriately. The precise scaling is outside the scope of this article, but at the end of the article we will show to what extend the results presented here could be extrapolated to other domains.

Technical Evaluation

The reliability of a road pricing system should be very high. To prove such high accuracy requires millions of passages. This number can be obtained in the field, but not under controlled circumstances, which makes the results difficult to interpret. It was concluded that performing only field tests in this respect is unfeasible (3). Instead, the Dutch Government chose a three stages approach. Three different type of tests were done, each for their own purpose:

- A field test using micro scenario's (4) where only a couple of vehicles are used for testing. An example of a micro scenario is given in figure 1. The specific purpose of this micro scenario was to see the response on lane switching of motorcycles in stop & go traffic. Other micro scenarios tested other difficult conditions: high speeds, vehicles between high trucks, and start, crawl and stop manoeuvres.

Figure 1: Example of a micro scenario

- A computer simulation (5) to predict and evaluate the performance of the systems. The behaviour of the different components of the system, whose characteristics were known from previous tests, are made explicit via the code for the simulation. By evaluating millions of simulated passages one can see if unexpected combinations of behaviour occur. With this tool, statistical information about the quality of the systems can be calculated.
- Road tests to validate the overall behaviour of the system (6). These tests can be used to check if there are no important aspects that were overseen in the modelling phase. These tests are very important for the final judgement of the system, but require a huge effort. Since the circumstances on the road cannot be controlled, it is difficult to interpret what the actual situation was and if the system reacted appropriately. Hence, the insight gained by modelling and simulation is very valuable at that moment.

Simulation environment

To be able to simulate a road pricing system we need to generate traffic with enough detail. In this section we will give some examples of details needed for this application.

The road pricing system prototypes that were evaluated, detect the passage of a vehicle using an optical system, e.g. a row of laser curtains. These systems are sensitive to the shape of the vehicles themselves and the distance and shape of the surrounding vehicles. Furthermore, the evaluated prototypes use short-range microwave communication for the payment. In one of our studies we have explored the effects of multiple cars trying to communicate at the same time and the effects of reflections at large surfaces (7). Thus, the performance of this subsystem also depends on the surrounding traffic.

This means that we need to generate traffic on a microscopic level that is not often needed in traffic simulation. To add more details to a simulation model is not difficult; the real challenge is in validating those new features with measurements. In this project, there was a unique opportunity to validate, because during the road tests the traffic was monitored both by the road pricing system and a reference system and all differences were resolved manually by looking at a video-recording that was also running in parallel. This made it possible to validate this simulator at a very high accuracy and reliability.

As mentioned before, the road pricing system was meant to be only operate during the morning rush-hours (week-days between 7:00 and 9:00), so the traffic generator was calibrated with a set of approximately 5000 passages from this period and validated with another set from this period. During this period, at that location, the traffic reached high densities, but remained flowing at high speeds. A much larger set of measurements is available on our project site (8), documented in accordance with the recommendations of the Dutch Platos initiative (9).

In the next chapter we will show the structure of our random generator, followed by the calibration and validation results.

TRAFFIC GENERATION

Generating traffic for a microscopic traffic simulation model comes down to simulating the registrations that would be made by measurement systems along the road: inductive loop detectors in the road pavement or road pricing systems installed on gantries above the road. New vehicles should be generated from a random distribution per lane, with the instantiation of the following features:

- the vehicle type: car, lorry, van, motorcycle. This will immediately define the vehicle's length;
- the interarrival time (IAT) between the newly entering vehicle and its predecessor: this interarrival time implicitly defines the exact moment of arrival at the entrance, since the arrival time of the predecessor is known, as well as its length and speed (determining the clearance time);
- the speed of the entering vehicle.

One could wonder whether it would be sufficient to determine each feature independently from a measured statistical distribution. Considering the innumerable interactions in daily traffic, especially during the rush hours, it is easily understood that this procedure will not hold. We have assumed that these three features are highly coupled, and are also dependent on the characteristics of the predecessor. That is why the order of instantiation is important. Our model is based on the model used in the Mixic-simulator (10).

Basic structure of the Traffic Generator

During execution the random Traffic Generator consequently generates vehicles for a single lane and assigns type (including vehicle length), interarrival time and speed for the newly generated vehicle in a fixed order (as is shown in the flow chart in figure 2). This serial process implies that a generator subroutine further down in the chain can use vehicle attributes that were generated by a subroutine that was executed earlier in the chain but not vice versa. For example the Speed Generator can build on vehicle type and interarrival time of the new vehicle j in determining the new speed, while the Inter Arrival Time Generator can only use the type of the new vehicle.

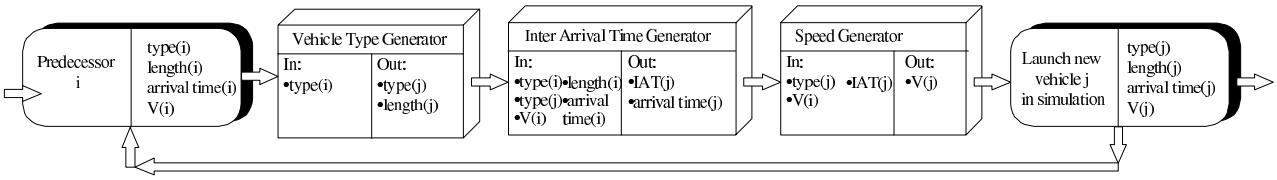


Figure 2: Basic structure of the Random Traffic Generator for Free Flowing traffic. The newly generated vehicle is indicated by the index j; its predecessor is indicated by i.

At the end of the series the new vehicle j is launched into the simulation and its attributes can be used as input for the generation of the next vehicle.

The simulation environment then calculates the vehicle's trajectory over a stretch of road. Both lateral and longitudinal dynamic behaviours are modelled. This dynamic behaviour can be switched off at the beginning and end of the road to prevent effects as, for instance, acceleration near the exit because no vehicles are left in front.

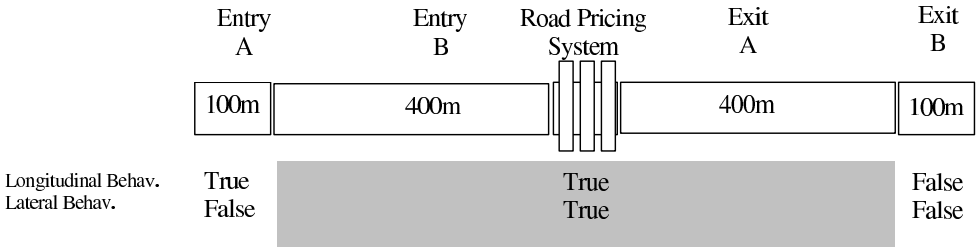


Figure 3: The simulated stretch of road. At the middle three sections, full dynamic behaviour is simulated.

CALIBRATION AND VALIDATION OF THE TRAFFIC GENERATOR

In this chapter the subroutines of the Traffic Generator will be explained in more detail and the calibration and validation results will be presented.

Vehicle Type Generator

The determination of the vehicle type is done using a 4 x 4 one step transition matrix for each lane. This matrix contains the conditional probabilities P(type(i) | type(j)), where (i) is the index of the predecessor, and (j) the index of the following vehicle. Normally the transition matrix is calibrated using only inductive loop detector measurements under various conditions and the measured length is then used to distinguish vehicle types. In our case we had access to both inductive loop detector measurements and laser curtain measurements. With a laser curtain the width and the height are known. We have combined the measurements of both detection systems in several combinations and found out that classification purely on the inductive loop length is not always correct. For instance, by setting a threshold of 6 meters on the length 4% of the trucks are missed and a considerable amount of false positives are generated: cars and vans are classified as trucks (19%). When the classification is based on the laser curtain height and width measurements no cars or vans are classified as trucks (for a 5 min validation interval) and 3 trucks are classified as vans.

Hence, for this article the transition matrix is in principle calibrated with the height and width from the laser curtain measurements. Only for the sporadic cases (<1‰) that no laser curtain measurements were available, we have used the length from the inductive loop measurements. The used inductive loop system was also quite reliable (missed passages < 1%) and the chance that both systems missed a passage is very small (~2 10^{-5}). The combined chance is slightly larger than the product of both independent chances, which indicates that the chances are correlated. The most likely source of the correlation are motorcycles, from which it is known that they are poorly detected by inductive loop systems and also more difficult to detect for laser curtains.

When laser curtain measurements were available we used the following rules:

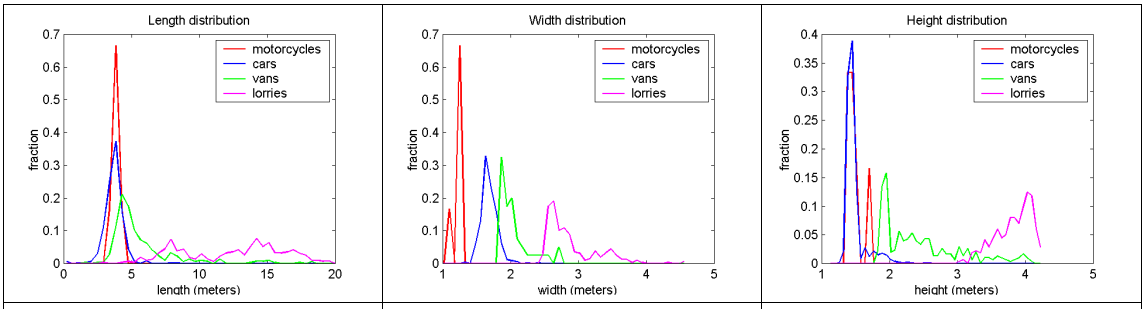
- motorcycle: `width < 1.3 (meter)`
- truck: `height > 3.0 AND width > 2.5 (meter)`
- van: `height > 1.8 AND width > 1.8 (meter)`

When only inductive loop measurements were available we used the following rules:

- truck: `length > 9.0 (meter)`
- van: `length > 6.0 (meter)`

In all other cases we assumed that the vehicle was a passenger car.

The following picture shows the results of the classification. The distribution of the length, width and height are given. The measurements of the validation set are classified using the previous rules. Each vehicle type has its own colour and one can distinguish the different distributions. As one can see, it is difficult to distinguish vans and cars in width, in that case the height is best indication.



Length distribution	*Width distribution*	*Height distribution*

Figure 4: Distribution of the dimensions of the 4 vehicle types.

The following conditional probabilities were obtained by applying the classification rules:

	Slow lane	Middle lane	Fast Lane
Calibration set	$\begin{bmatrix} 0.376 & 0.069 & 0.004 & 0.128 \\ 0.065 & 0.019 & 0 & 0.045 \\ 0.002 & 0 & 0 & 0.001 \\ 0.132 & 0.041 & 0 & 0.117 \end{bmatrix}$	$\begin{bmatrix} 0.827 & 0.064 & 0.006 & 0.011 \\ 0.064 & 0.009 & 0 & 0.001 \\ 0.004 & 0.001 & 0 & 0.001 \\ 0.012 & 0 & 0 & 0.001 \end{bmatrix}$	$\begin{bmatrix} 0.949 & 0.022 & 0.004 & 0 \\ 0.022 & 0.001 & 0 & 0 \\ 0.004 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
Generated set	$\begin{bmatrix} 0.384 & 0.067 & 0.009 & 0.129 \\ 0.059 & 0.016 & 0.001 & 0.039 \\ 0.012 & 0 & 0 & 0.001 \\ 0.134 & 0.032 & 0.003 & 0.113 \end{bmatrix}$	$\begin{bmatrix} 0.802 & 0.060 & 0.012 & 0.016 \\ 0.060 & 0.010 & 0.002 & 0.002 \\ 0.013 & 0.002 & 0 & 0.001 \\ 0.015 & 0.003 & 0.001 & 0.002 \end{bmatrix}$	$\begin{bmatrix} 0.912 & 0.027 & 0.015 & 0 \\ 0.028 & 0.001 & 0 & 0 \\ 0.015 & 0.001 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
Validation set	$\begin{bmatrix} 0.417 & 0.056 & 0.002 & 0.129 \\ 0.057 & 0.011 & 0 & 0.035 \\ 0.002 & 0001 & 0 & 0 \\ 0.128 & 0.035 & 0.001 & 0.125 \end{bmatrix}$	$\begin{bmatrix} 0.854 & 0.054 & 0.006 & 0.011 \\ 0.055 & 0.004 & 0 & 0 \\ 0.005 & 0.001 & 0 & 0 \\ 0.010 & 0.001 & 0 & 0.002 \end{bmatrix}$	$\begin{bmatrix} 0.936 & 0.028 & 0.004 & 0 \\ 0.028 & 0.002 & 0 & 0 \\ 0.004 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$

Table 1: Transition matrices showing the probability whether a vehicle is of a certain type when the predecessor was a car, van, motorcycle, or lorry respectively.

As you can see, in the fast lane mainly passenger cars can be found. It should be noted that there is a small variation between the calibration and validation set, in the order of a few percent.

Inter Arrival Time generator

The inter arrival time (IAT) of the new vehicle with respect to its predecessor is defined as the time elapsed between the passing of the rear bumper of the predecessor and the arrival of the front bumper of the new vehicle.

Two different IAT distributions can be distinguished:

- free or *unconstrained* vehicles: vehicles who do not have to modify their time-space trajectory when approaching their immediate predecessor;
- followers or *constrained* vehicles: whose time-space behaviour is influenced by the presence of their predecessor.

For the 7:00-9:00 traffic we have assumed that all vehicles are constrained. The distribution F(IAT) of the inter arrival time of vehicles at a detection point can be described by probability density function (pdf) of the Pearson type III distribution PT3(IAT) (10) :

$$PT3(x) = \begin{cases} 0 & for \quad x < d \\ \dfrac{1}{\Gamma(\beta)} \cdot \alpha^{\beta} \cdot (x-d)^{\beta-1} \cdot e^{-\alpha(x-d)} & for \quad x \geq d \end{cases}$$

Examples of these distributions are given in figure 5. As one can see, for cars in the fast lane the Pearson type III distribution are characterised by an offset of a few hundred millisecond, followed by a sharp rise to a peak slightly above 1 second, followed by a fast exponential decay. For the slow lane, the peak is less sharp and the decay much slower. This effect is even more pronounced for vehicles classified as trucks and lorries. This indicates in the slow lane the existence of relative large gaps between heavy vehicles. Passenger cars are reluctant to fill those gaps due to the speed difference between the slow lane and the other lanes.

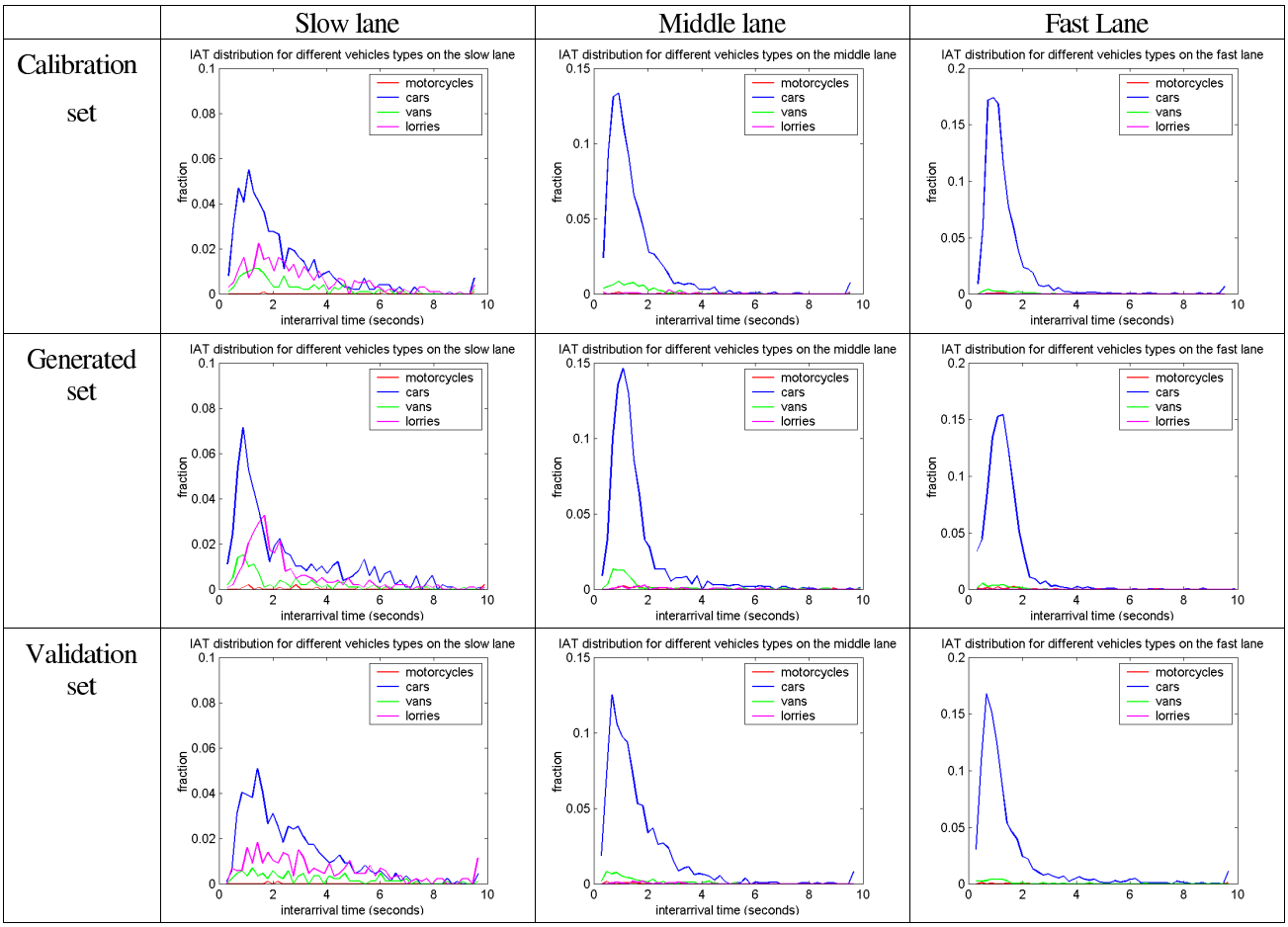


Figure 5: IAT-distributions both measured and generated. Measurements are from the A2 3-lane motorway between Woerden and Utrecht

Drawing Speeds with the Speed Generator

The speed of newly entering vehicles is generated using an empirical procedure. This procedure is based on speed observations and the assumption that the speed of the following vehicle depends on that of its predecessor. There will be a variation in the measured speeds, which we model in principal with a uniform distribution *U*. There will be a little asymmetry in the distribution: the skewness which is a function of the lane, current type and previous type. Furthermore, the variation ΔV will be less for vehicles close by (IAT of 1 or 2 seconds) than for vehicles at larger distances, as depicted in figure 6.

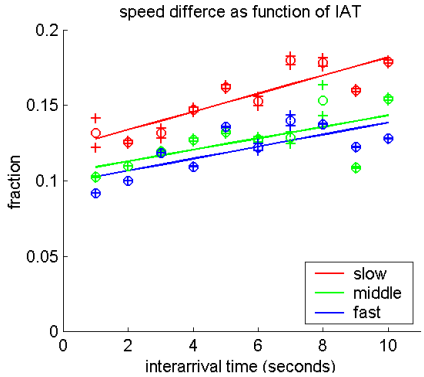


Figure 6: The speed difference ($|\Delta V|/V$) between a vehicle and its predecessor.

Figure 6 is a plot of the average speed difference ($|\Delta V|/V$) between a vehicle and its predecessor. The average differences can be as large as nearly 20%. In the slow lane the speed differences are more dependent on the IAT than in the fast lane.

To summarise, the following model is used to estimate the speed of vehicle j in our model:

$$V(j) = V(i) + \Delta V(lane, type, IAT) \bullet U(skewness - 1, skewness)$$

where *U* is the uniform distribution and ΔV a look-up table. An example of the output of the Speed Generator and the correspondence with measurements has been shown in next figure. The Speed Generator can generate both symmetric (fast lane) and asymmetric speed distributions (slow lane).

Also note that for the Calibration and Validation sets some bins are completely empty. This is an artefact from the used induction loop. Unfortunately, the road pricing system was not designed for speed measurements, so no additional information could be gained from this system.

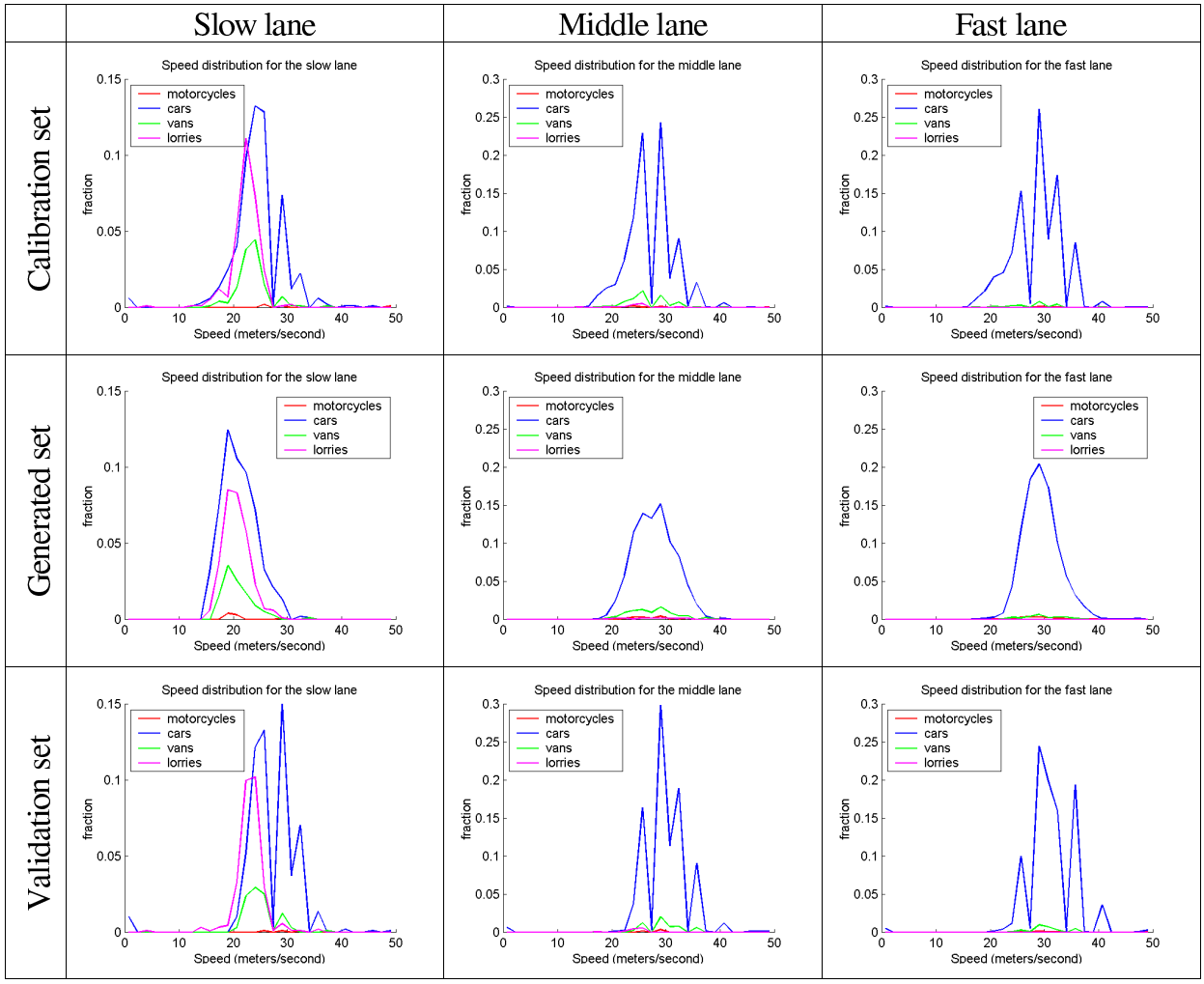


Figure 7: The speed distributions, both measurements and generated.

Volume dependence

All previous parameters are scaled relative to a reference volume (intensity over capacity rate) I/C*. In order to do the validation we have to know what the distribution of the intensities and capacities are over a five minutes interval and do the validation on a consistent set. The used calibration set consists of 3 sessions of 7:00-9:00 traffic. This set had per lane an average intensity of 526±44, and an average capacity of 608±15, which gives our reference volume I/C* of 86±8%.

From these three sessions, we have selected the session with the highest I/C (session 29 with an I/C of 90%). This situation was classified as belonging to the largest class of measurements; situation 2 (diffuse daylight, no precipitation, high density, high speed). In total 25546 passages were classified as situation 2, with an average volume I/C of 66%. Although situation 2 is high-density traffic, it also contains traffic outside the 7:00-9:00 timeslot, which explains a lower average volume than the calibration set used in this article.

To validate the scaling of our parameters outside the 7:00 to 9:00 period, we performed the following test. In total 4 simulation runs were performed, 2 simulation runs with the parameters directly gained from respectively situation 2 and session 29, and 2 runs with the parameters of the other situation/session, this time scaled to the right volume.

Figure 8 shows the results of the test. Note that for the slow lane, the original parameters and the extrapolated parameters match perfectly. For the volume I/C of 66% we have a broad peak, skewed to higher velocities. For the volume I/C of 90% the peak is less broad and more symmetric. For the fast lane, the extrapolated parameters overstate this effect. With the original parameters the speed-distributions have nearly the same mean and deviation, while the extrapolated result clearly shows different speed-distributions.

This means that we have to fine-tune the scaling effect, because the extrapolation was performed in the right direction, but not always with the correct amount.

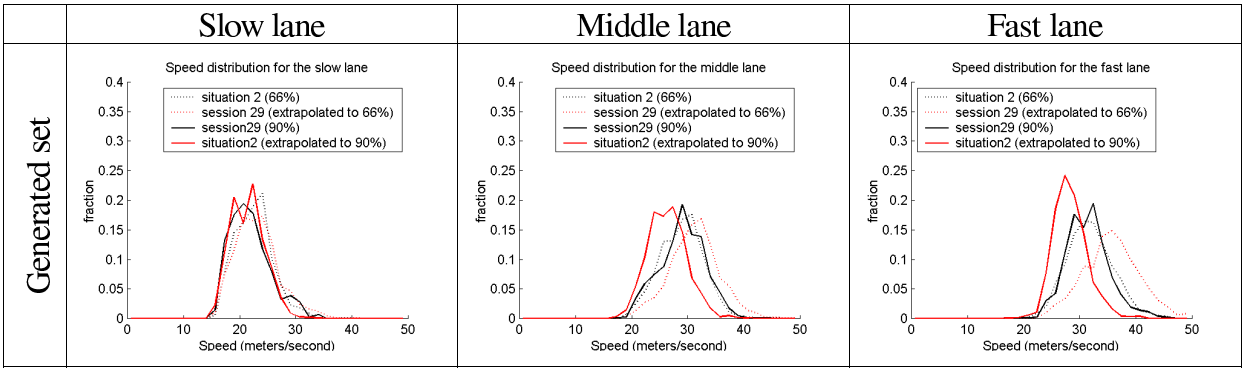


Figure 8: The speed distributions, generated for two volumes I/C.

CONCLUSIONS

The RTG presented in this paper performed well for flowing traffic at high densities. The calibration of such a RTG process at a microscopic level is a labour-intensive job, which requires good models, rich datasets and correct initial estimates of parameter settings (11). In this article we have tried to document our effort as good as possible, so that other researchers could use our experience and dataset. In our view further development of random traffic generators is limited by the availability of well-documented traffic datasets and benchmarks.

Our analysis was unique in the sense that we had two independent measuring-systems, which classified the vehicle types on completely independent features. Because the distributions of both the speed and the distance from the predecessor are highly dependent on the vehicle type, good estimates of the two distributions could be made.

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