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Traffic Operations at an Entrance Ramp of a Suburban Freeway First Results

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Abstract

Within the general framework of updating the French design guidelines for urban freeways, some studies are conducted for building of a new model for traffic operations at on-ramps. One of them, described in this paper, aims to gather general knowledge on the merging process, from the analysis of microscopic traffic data collected on an instrumented suburban freeway segment. This equipment delivers vehicle trajectories, sampled at a 50 m interval. In a first step, empirical evidence on lane use and operating speeds has been established. Then, vehicles interactions have been studied, so as to compute risk indicators at merging locations, and to model the merging probability as a function of the traffic environment. On-going works and perspectives are presented to conclude.

Keywords: on-ramp; merging behavior; merging probability; speed profile; surrogate safety indicator

1. Introduction

1.1. Aim of the study

Traffic models are widely used by engineers in the design process of highway elements, for they are tools helping them to choose a layout and to assess expected capacity, delays and level of service. Some of them are the basis of some recommendations, in particular about lengths, given in the ICTAVRU, the French design guidelines for urban freeways (CERTU, 1990, CERTU, 2003). Within the general framework aiming to update this document, a study has been planned to develop a new traffic model for merging areas, the former one being based on a very earlier version of the U.S. Highway Capacity Manual (HCM). Before building such a model, this study includes several tasks, including a literature survey, an inventory of existing layouts, and a collection of traffic data. For this last one,

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** Sections 4.2 and 4.3 summarize a part of the MSc thesis in Statistics of P. Conde-Céspedes during her internship at the LEPSIS.

several sites have been selected for being observed. One of them is a well-equipped merging area, where microscopic traffic data have been gathered and analyzed, allowing for establishing some first empirical evidence about traffic operations, and for developing a merging probability model. This study is currently going on in order to complete and precise the first elements given in this paper.

1.2. Background

A number of models deal with on-ramp operations modeling. Fundamental algorithms are speed adjustment, lane-change, and gap-acceptance. Speed adjustment by merging vehicles aims to reach a speed allowing for taking a gap, while contributing to create it. Lane-change can be mandatory, for the merging vehicle, or discretionary, for through vehicles overtaking a slower one or facilitating a merging maneuver (the courtesy lane-change). Classical gap-acceptance models developed for unsignalized intersections have to be modified, for the available gap and the interactions between vehicles involved are dynamic, and merging from an on-ramp is not strictly competitive. It can also be cooperative, with discretionary or courtesy lane-changes by through vehicles, or forced at high traffic levels, leading to a priority reversal which can be possibly modelled by the so-called limited priority merge (Troutbeck and Kako, 1997). Existing models may be dedicated to one of these functions, or may embed some of them in a single model, like *e.g.* in Ahmed *et al.* (1996), for there are obvious links between them. Surrogate safety indicators derived from basic traffic data can also be estimated, firstly to quantify a risk (Uno *et al.*, 2002), but also to be used as variables explaining drivers behaviors (Kita, 2000). The preliminary works described here aim to get empirical knowledge on some of these points.

2. The experiment

2.1. The experimental testbed

The experimental testbed SAROT (a French acronym) is located on the suburban four-lane divided freeway A87N in the east side of Angers, a medium sized town in western France. The speed is limited to 90 km/h, but there is no nearby speed enforcement camera. With a daily traffic of around 23 000 vehicles for the direction concerned with about 15 % of heavy vehicles, and 4 300 vehicles on the on-ramp, it operates without recurrent congestion, even during peak hours. During the past ten years, about 2 accidents occurred per year on this segment.

Around 1 100 m, including 500 m along an entrance ramp, are observed in detail (figure 1). The installation includes 12 sensor lines (consisting in double inductive loops on each lane), 3 lasers (for performing reference measurements) and 10 cameras (for observing and recording video pictures), 3 of them (over the bridges) allowing for number plate recognition. The sensor lines, numbered from 12 to 1, comprise three double loops between lines 8 to 4, with the on-ramp, and two double loops elsewhere. Three of them (12, 11, 1) are associated with the lasers. Sensor lines 10 to 1 are regularly spaced by 50 m. Guilbert *et al.* (2011) give a detailed description of the site, so as examples of some experiments conducted. A similar instrumented site exists on the M42 motorway in UK, with a loop spacing of 100 m, but where the traffic characteristics are very different (Wilson, 2008).

In order to give to the merging vehicles the prime importance, the space origin in this paper has been fixed at the first sensor line where they appear, *i.e.* line 8, so the distances for the sensor lines are measured from - 100 m (line 10) to + 350 m (line 1), and are used in such a way for presenting the results. The merging lane exists until after + 200 m, *i.e.* after line 4. For negative abscissas, merging traffic is not observed.

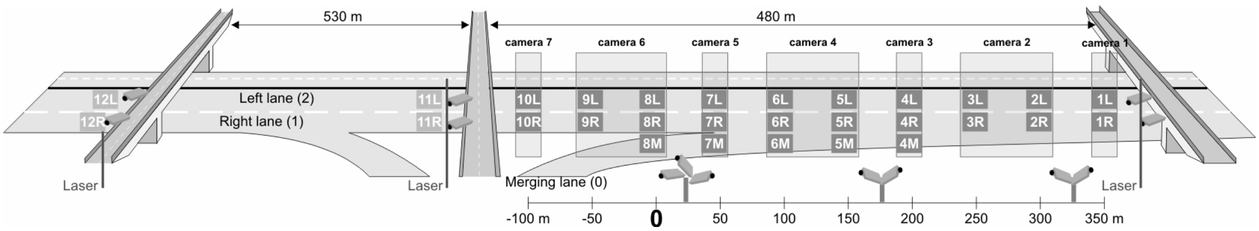

Figure 1: The experimental testbed SAROT

2.2. The data

We used here the data recorded from the inductive loops of lines 10 to 1, and when necessary the video pictures of cameras 7 to 1 for checking and explaining them. The information delivered by a loop consists in speed, passing time, length and vehicle category (the initial categories have been reduced here to only two, cars and heavy vehicles).

These initial data are independent, but the system allows for tracking the vehicles from a loop to the next one, and it delivers aggregated data with 10 information (one per sensor line) for each vehicle, such as a confidence index for the identification for each loop. Vehicle trajectories in the time *vs* distance space are then obtained, sampled at a 50 m interval (figure 2, where the color denotes the lane and the symbol the vehicle category). Other derived information can be easily computed for each vehicle, such as mean speed over 50 or 100 m, speed variation from loop to loop, acceleration...

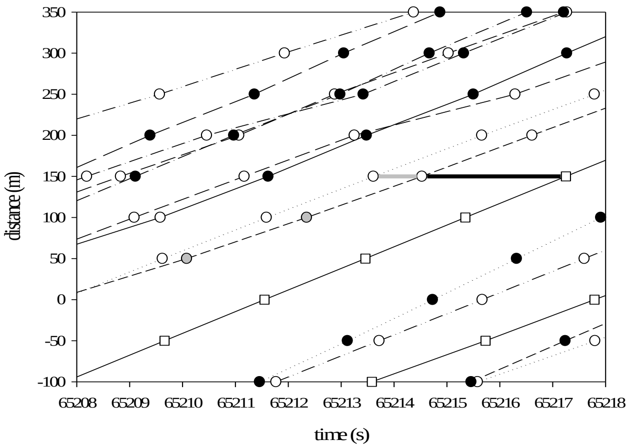

Figure 2: Example of successive trajectories (grey: merging lane, white: right lane, black: left lane; circle: car, square: heavy vehicle)

For the tracking algorithm is imperfect, it is sometimes necessary to check the aggregated data with the video pictures (figure 3), when there exists a doubt concerning the fact that it is the same vehicle which is sampled in such a way. The doubt may come from unrealistic values or abnormal variations in speed, acceleration or vehicle length, or from inconsistencies between the measured spot speed and the mean speed obtained from passing times. The series of mean accelerations on every 50 m subsegment (derived from the spot speeds) appears to be a good criteria for detecting matching errors.

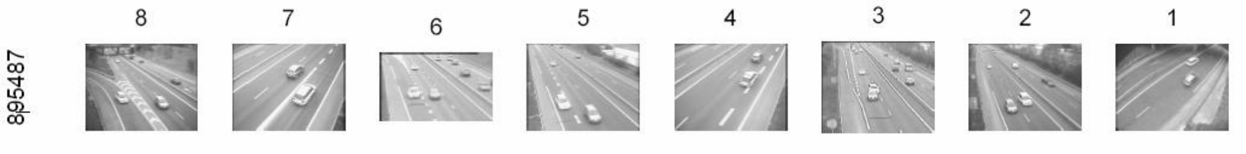

Figure 3: Example of checking the tracking of a merging vehicle with video pictures

These data have two limitations, which are that they are sampled with a 50 m interval, and that the information on the lateral position is not more precise than the lane where the vehicle is considered to be. These discretizations imply that the exact merging point of a vehicle driving from the on-ramp is not known, and is considered to be at the end of a 50 m subsegment. The computed distance and time needed for merging are then slightly overestimated.

Trajectory data, which contain much more information than usual traffic data, have known a growing interest during last years, partly due to the availability of the NGSIM data. Their interest, such as the way to derive traffic variables, are described *e.g.* by Knoop *et al.* (2009), in the case of video aerial observations, which deliver data more continuous than ours. However, if some parameters are not accessible here (*e.g.* relative to car-following), their discrete character is not an hindrance to the treatments that we applied. And a prime advantage of such an instrumented site if the possibility to get as many observations as needed.

For this study, we used the first data collected at a large scale, during the spring 2010, which concerned mainly peak hours. So, the traffic flow conditions are quite homogeneous (with around 2 200 vehicles per hour and per way on the main carriageway and 350 vehicles per hour on the entrance ramp), and the results obtained must be considered to be valid for this volume. The effect of the volume will be assessed in the next step of the study (§ 5).

The initial dataset (called here the full dataset) contains all the 50 000 trajectories (including more than 6 000 trajectories of merging vehicles) collected during these peak hours. It allows for studying the interactions between successive vehicles. A selection has been done in order to retain car trajectories fully validated, which led to retain more than 21 000 of them (including more than 3 000 trajectories of merging cars), their collection being called here the reduced dataset. Similar data have also been selected for heavy vehicles, with less strictness on the criteria, in order to conduct some comparisons between vehicle types. Because of these selections, the reduced datasets do not allow for studying the interactions between successive vehicles.

The data analysis was twofold. Firstly, from the reduced dataset, the trajectories have been studied independently of one another, producing some empirical evidence on general traffic patterns such as lane use, merging locations, speed profiles and other derived variables (section 3). Secondly, from the full dataset, the interactions between merging and through vehicles have been addressed in two ways: basic risk indicators involving a merging vehicle, its follower and its leader have been computed (section 4.1), but the main task has been the detailed analysis of the behavior of merging vehicles, along with the nearby traffic environment (sections 4.2 to 4.3). All of these works are still in progress, and the section 5 gives some indications on planned researches.

3. Some empirical evidence

3.1. Lane use

The lane distribution is quite constant all along the segment under study, before, along and after the on-ramp, without any noticeable variation (less than 2 %): about two thirds on the right lane, and one third on the left one. Of course, this balance between lanes is only valid for the traffic volume observed.

As expected, merging cars use mainly the right lane after insertion, but there are 11 % of them on the left lane at the end of the on-ramp, and 16 % at the end of the area observed (figure 4).

3.2. Merging locations

Figure 5 reports the cumulative percentage of vehicles having merged at a given location, noticing that a completed merge is recorded only at the end of the 50 m subsegment where it has been done, as explained before. Less than 1 % of cars have completed their maneuver at + 50 m, 16 % have done it between + 50 and + 100 m, 52 % between + 100 and + 150 m, 28 % between + 150 and + 200 m, and the remaining 4 % in the last subsegment of the on-ramp. Heavy vehicles insert later (previous figures become respectively 0, 10, 36, 44 and 10 %). Half of the cars have completed their maneuver at 135 m and 85 % at 180 m (respectively 155 and 195 m for heavy vehicles).

The mean time needed for completing a merge (starting from line 8) is 8.2 s, with a standard deviation of 2 s.

3.3. Speed profiles

Figure 6 shows the mean speed profiles for different flows. The mean speed of through cars is quite constant along the merging area, around 86 km/h on the right lane and 98 km/h on the left lane (cars changing lane have intermediate speed profiles, consistent with expectations). If looking at the mean speed of merging cars at their merging location (the dark points), there is a difference of 5 to 10 km/h with the mean speed on the right lane. On this right lane, the mean speed of merging cars just reaches the mean speed of through vehicles at the end of the segment (*i.e.* 150 m after the end of the on-ramp). The 85th percentile speed profiles lead to similar conclusions, with curves lying 6 to 9 km/h higher. But it is also interesting for addressing the risk, to compare the quickest through vehicles to the slowest merging vehicles. If we choose the 85th and the 15th percentiles to do it, it appears that there is a difference of 30 km/h between through and merging cars using the right lane (the same difference is twice less for through cars only). Though these figures are not relative to individual differences but are mean values, they show however that the different speed patterns of the two flows involved in merging operations are likely to induce a risk.

Figure 7 reports the speed profiles of merging cars, along with their merging location. There exists a strong link between the merging location and the mean speed profile. The acceleration occurs within the last subsegment before merging, following a lower speed increase. It can be supposed that cars merging later have encountered impeding traffic on the right lane, and have adjusted their speed, with a clear decrease of their initial acceleration, in order to find a convenient gap. This is particularly obvious for cars merging at the end of the lane, whose mean speed is quite constant over 100 m in the central part of the merging lane. That is what Yi and Mulinazzi (2007) call the "challenged merge", *vs* the "free merge" of unimpeded vehicles.

Instead of choosing in such a way the criteria for distinguishing different kinds of speed profiles, we tried also to classify them automatically, using the dynamic clusters analysis method. Different input variables were tried, as speed, normalized speed, speed difference, acceleration, merging location, which showed that several families of speed behaviors had to be considered, which exhibit noticeable differences. The reasons of these differences, due to the traffic environment encountered, are still to be analyzed, but will be a source of information to model the way that drivers adjust their speed to contribute to create a gap.

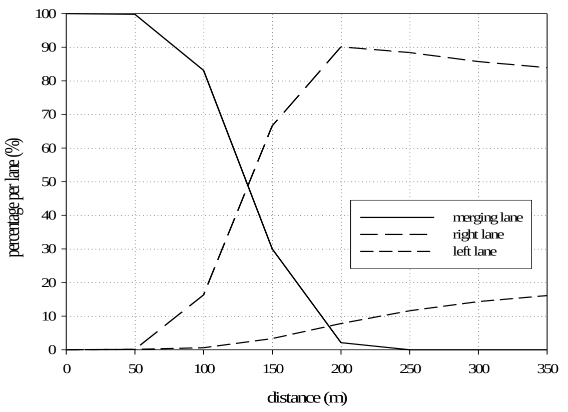

Figure 4: Lane distribution for merging traffic

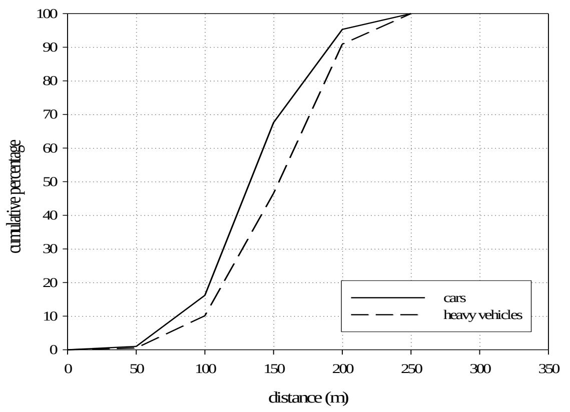

Figure 5: Cumulative percentage of performed merging maneuvers

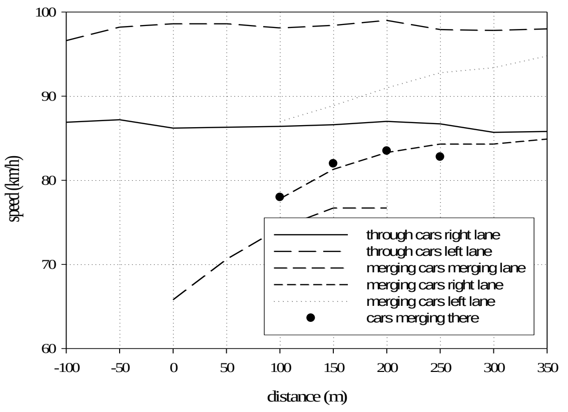

Figure 6: Mean speed profile of through and merging cars

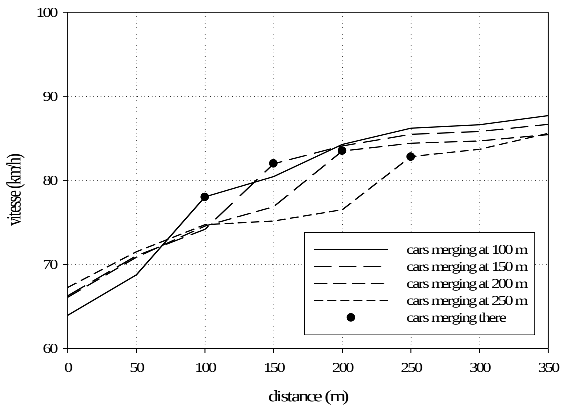

Figure 7: Mean speed profile of merging cars along with their merging location

4. Analysis of the interactions during a merge

First, we shall assess the risk induced by a merging maneuver, focusing on the instant of occurrence. Then, we shall consider the neighbors of merging vehicles. For that, we shall define the notion of "partner vehicle" and observe the behavior of merging vehicles according to the behavior of their partners. Finally, we shall present a method (and its results) to estimate the probability of merging as a function of the surrounding traffic parameters.

4.1. Risk indicators

To quantify the risk induced by a merging maneuver, classical indicators have been computed. It should be remembered that a merging maneuver is recorded only at a sensor line, but has been really completed in the preceding 50 m subsegment. So, any indicator computed in such a way is likely to underestimate the risk, for the vehicles involved already had the opportunity to adjust their behavior to reduce it.

For each merging vehicle in the full dataset, *i.e.* more than 6 000 observations, it has been identified the next one appearing at the sensor line where the merge has been recorded, so as to compute the net headway h_n and the time to collision (TTC) at the merging location. The net headway (or time gap) is the time between rear to front passing times and the TTC is the time for a rear-end collision if both vehicles go on with the same speed, when the second one runs quicker. We have considered rear net headways and TTCs (related to the follower of the merging vehicle) and front net headways and TTCs (related to its leader). The horizontal lines in figure 2 represent respectively the rear and front headways, between front to front passing times. We did not consider the case when the follower or the leader, was also a merging vehicle, and following comments concern the car *vs* car interaction, unless noted.

The percentage of rear net headways less than a given threshold (here, 0.5, 1 and 2 s) grows with the merging location, at least up to 200 m (figure 8). An explanation could be that cars merging early do it because there is no through traffic at that time, and cars waiting to perform the maneuver do it when reaching the end of the on-ramp, whatever the traffic environment. An interesting fact is that all merging locations together, cars are more likely to accept a very short gap (less than 0.5 s) in front of a heavy vehicle (10.6 %) than in front of another car (4.2 %), as if car drivers did not wish to be behind a heavy vehicle as soon as they enter the main carriageway, and then managed to avoid it.

The distribution of front net headways at merging is quite different, with a high percentage of short intervals behind the leader (figure 9): a third of the cars adopt a time gap less than 1 s. The proportion of short front time gaps clearly increases with the merging location.

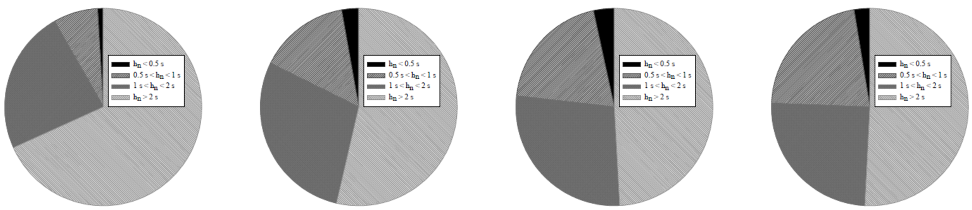

Figure 8: Distribution of rear net headways just after merging, along with the merging location (100 m, 150 m, 200 m, 250 m)

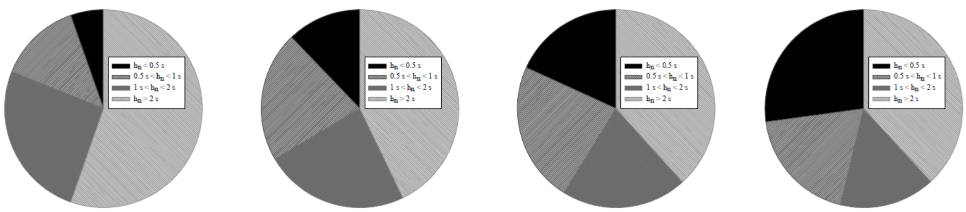

Figure 9: Distribution of front net headways just after merging, along with the merging location (100 m, 150 m, 200 m, 250 m)

When looking at the time to collision, which is a better risk indicator, the percentage of them being less than a given threshold is quite constant along the merging area, either with regard to the leader or to the follower: 5 to 8 % for TTCs less than 10 s and 1.5 % for TTCs less than 5 s, values which do not denote risky traffic conditions (except perhaps for cars merging in front of a heavy vehicle: 4 % of TTCs less than 5 s). This is explained by the fact that the increase of the percentage of short headways when the merging location is further is compensated by the decay of the speed differential. The comparison of net headways and TTCs also shows that when drivers adopt short front or rear intervals, they adapt their speed in the same time.

4.2. Definition of "partner vehicle"

For any vehicle in the merging lane which is at a given point of measure, its partner is the vehicle situated immediately behind it in lane 1. This definition can be spread to vehicles in lane 1, with a partner in lane 2 defined as the partner of the partner.

When a merging vehicle tries to enter the lane 1, its partner is the most affected. The partner has 3 possible choices: change lane, let the vehicle enter or not let it. Generally, a vehicle has several partners during its merging process. Table 1 shows the distribution of vehicles according to their number of partners.

Table 1: Distribution of merging vehicles according to the number of partners

Number of partners	N(vehicles)	Percentage
1	2541	39.9%
2	2504	39.3%
3	1122	17.6%
4	189	3.0%
5	10	0.2%
Total	6366	100%

We identified 4 reasons which justify a partner's change: the partner overtakes the vehicle, a vehicle coming from lane 0 merges between the vehicle and the partner, a vehicle coming from lane 2 moves towards lane 1 in front of the partner, the partner moves towards lane 2 (figure 10). Two reasons (2, 3) have for effect to shorten the current time gap, the others (1,4) to increase it.

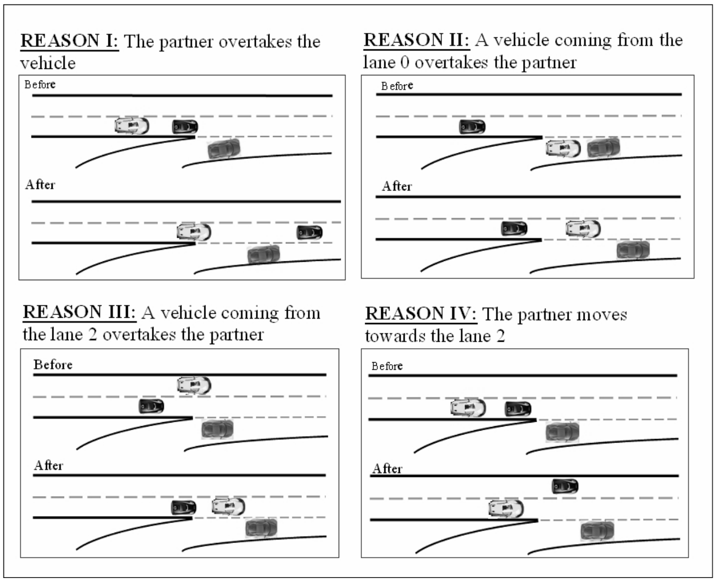

Figure 10: Reasons of partner's change

Table 2 shows the distribution of vehicles according to the reason of partner's change. The reasons 1 and 4 are especially observed in the beginning of the lane. In reality, there is a link between the reason of partner's change and the point of measure. As for those of table 1, these percentages are valid for the traffic volume observed.

Table 2: Distribution of merging vehicles according to the reason of partner's change

Reason	N(vehicles)	Percentage
1	2916	45.8%
3	1719	27.0%
3	166	2.6%
4	929	14.6%
Total	6366	100%

The time gap (rear to front) between two vehicles is also a crucial variable in the decision of the partner. Figure 11 shows a box plot of the time gap according to the reason of the change. We notice that the time gap is low when the partner overtakes the vehicle (reason 1). If the partner moves towards lane 2 (reason 4), the time gap is a little more important, but it remains small with regard to the other reasons.

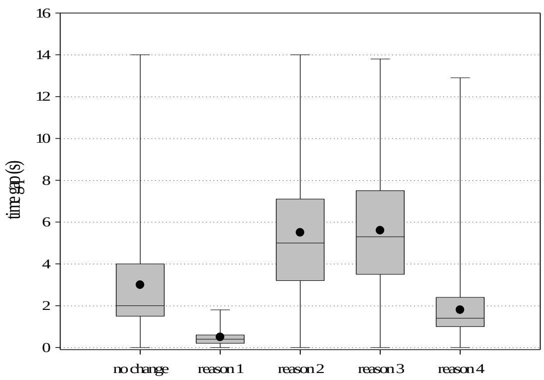

Figure 11: Link between the time gap and the reason of partner's change

4.3. Modelling of the probability of merge by Bayesian Discriminant Analysis

At every point of measure, either the vehicle decides to merge or it decides to wait for another opportunity. Our objective is to estimate the probability of a merge knowing a vector X of variables describing the traffic. The variables which we considered are:

- speed of the vehicle in the merging lane;
- speed of the partner;
- time gap (vehicle - partner);
- position (distance from the sensor line 10).

We suppose X known. Bayesian Discriminant Analysis aims to predict the probability of insertion (or not) given the predictor variables X. This probability is given by the Bayes theorem formula:

$$P(G_k \mid X) = P_k \, f_k (X) \,/\, \Sigma \, P_i \, f_i (X) \qquad (1)$$

where:

- G_0 and G_1 represent the non merging and merging event respectively;
- P_i is the probability of G_i in the whole population (*a priori* probability);
- f_i (X) is the conditional density of X according to group i.

To estimate the densities f_0 (X) and f_1 (X), we used 2 methods (Lebart *et al.*, 2000, Saporta, 2006).

The first one is the method of k Nearest Neighbors (k-NN). We recall briefly the principle. Let X be an observation to classify. The target of the nearest neighbors method is to find nearest points of X. Then we classify X in the most represented group.

The *a posteriori* probability is given by:

$$P(G_j \mid X) = g_j / k \tag{2}$$

where g_j is the number of observations in the group G_j amongst the k nearest neighbors.

If k is too small this probability is not significant.

The second method is a nonparametric approach. It is a procedure of local estimation of probabilities in the neighborhood of the observation X (to classify). So the estimator of the density associated with every group is:

$$f_k(X) = \Sigma_Y K(X - Y) / n_k \tag{3}$$

where:

n_k is the size of the group G_k

Y is any observation belonging to the group

K is the kernel.

The kernel K is a function which gives more weight to the observations of Y close to X. The most used kernels are: uniform, normal, Epanechnikov, Biweight, Triweight. Besides the kernel, it is necessary to choose a parameter r of smoothing, called the bandwidth.

In table 3 we compare the performances of the methods employed. The rate of badly classified observations is little sensitive to the choice of the method. The percentage of well classified observations oscillates between 83 and 85 %.

Table 3: Rate of badly classified observations (%)

Method	Neighbors	Uniform	Normal	Epanechnikov	Biweight	Triweight
k or r	k=75	r=1.5	r=0.5	r=1.5	r=2	r=2
Rate of error (%)	15.65	16.37	15.66	15.75	15.84	15.63

5. Conclusions and perspectives

In section 3, we established some empirical evidence on basic traffic patterns. If the numerical values are only valid for the traffic conditions observed, which was homogeneous for the set of observations, the behavioral characteristics observed are valid for free flow conditions. It is known that driver behaviors during congestion are different (Daamen *et al.*, 2010), but the traffic volume on the experimental site SAROT does not allow for observing such conditions. In section 4.1, unexpected results have been found about the risk induced by a merging maneuver, such as the quite high proportion of very short net headways in front of the merging vehicle, or behind it when the follower is a heavy vehicle. In section 4.2, we introduced the notion of partner vehicle, which induces the most the decisions of the merging vehicle, and we showed that several of them had to be considered along the course of a merge. Finally, in section 4.3, we built a model for forecasting the merging probability, which takes into account the positions and speeds of the vehicle and its partners. The rate of well classified observations (more than 83 %), for both methods employed, appears to be satisfying.

As their quality is fundamental for any analysis, there remains some works to do with the data collection and validation. A new algorithm for vehicle tracking is under development, making a better use of the likelihood of a next passing time, estimated from the present one and the speed, and the data checking procedure will be tuned.

The empirical works described in section 3 are going on, from a trajectory dataset of growing size and quality, in order to have an insight on some points not yet addressed, as *e.g.* the effect of the traffic volume (retaining short periods of heavier conditions), the effect of the drivers population (comparing at similar traffic levels, week days with a high proportion of daily commuters, and week-ends and holidays with road users traveling for other reasons and less familiar with the site), the behavior of heavy vehicles, the behavior of platoons. Concerning the merging probability model, new variables will be introduced in the vector X characterizing the traffic environment, relative to the partner of the partner, and to the leader, such as external variables (*e.g.* weather).

These works will also be a basis for analyzing new trajectory data, which are going to be collected on other entrance ramps with a higher traffic, extracted through an innovative video processing (Goyat *et al.*, 2010).

So the present results, with those expected from the on-going developments, will be a valuable source of knowledge for building the merging model to be developed.

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