1 **DYNAMIC MODELING OF VISSIM CRITICAL GAP PARAMETER AT UNSIGNALIZED**
2 **INTERSECTIONS**

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1 **ABSTRACT**

2 Critical gaps are essential parameters in the modeling of traffic operations at unsignalized intersections and
3 roundabouts, and they are main determinants in the calculation of intersection capacities. In microscopic
4 simulation tools, they are basic vehicle-related variables, and their values and variations among the
5 population are user-defined. Errors or oversimplifications of these basic variables may yield unrealistic
6 results in terms of total throughput, queue lengths, waiting times, etc.

7 In this study we propose a method to calibrate the critical gap parameter in microscopic simulations based
8 on individual travel time observations, and a simple formulation for the calculation of critical gap
9 parameters that takes into account the increasing risk taken by drivers on the minor street with increasing
10 volumes on the major road. This new formulation allows a better match between accepted gaps observed in
11 reality and the actual traffic conditions.

12 The new methodology and model formulation have been used for calibration and validation of the
13 minimum gap parameter of the software program VISSIM using data taken from several unsignalized
14 intersections in the city of Leuven, Belgium. The results show clear outperformance of the volume-
15 dependent model with respect to the conventional constant critical gap parameters.

16

1 INTRODUCTION

2 The capacity and service times at minor streets of unsignalized intersections depend on the probability for a
3 vehicle to have sufficient space between vehicles of the higher prioritized streams to pass the conflict areas
4 safely. This probability is function of the vehicle inter-arrival times (or, inversely, the volume or flow rate)
5 on the major streams, as well as it is function of both individual drivers' and vehicle characteristics, which
6 define each individual gap acceptance behavior.

7 A main difficulty when analyzing gap acceptance behavior at unsignalized intersections is that it mixes
8 drivers' risk taking behavior and perceptions with the randomness of vehicle inter-arrival times. We can in
9 fact consider the gap acceptance process consisting of two basic elements: 1) the smallest time interval
10 drivers accept when attempting to enter the intersection, so it is driver-dependent; 2) the gap time
11 distribution, which depends on the traffic pattern of the conflicting streams. According to the driver
12 behavior model usually assumed, no driver will enter the intersection unless the gap between vehicles in a
13 higher priority stream is at least equal to the critical gap. In practice, it is not easy to identify the critical
14 gap, as there is no way to measure it directly. This justifies the different definitions and estimation
15 procedures proposed for this parameter.

16 Despite the variety and complexity of operations at unsignalized junctions, conventional models assume a
17 rather simplified gap-acceptance process, based on a characteristic parameter: the minimum or critical gap
18 parameter. This parameter defines the boundary between small and unacceptable gaps, and those gaps
19 considered sufficiently safe. In many capacity models (e.g., in the Highway Capacity Manual, HCM [1]),
20 the critical gap parameter differs only by type of conflict and vehicle operation. Moreover, all drivers are
21 assumed to be homogeneous and generally the gap-acceptance function does not change with time. Gap
22 acceptance models are also adopted in microscopic simulation programs, such as the widely used software
23 VISSIM [2]. In these models the critical gap parameter can change from driver to driver (by specifying
24 different user classes or by drawing the individual parameters from a random distribution), but once the
25 vehicle is loaded in the system it will not change anymore. This assumption, however, does not comply
26 with real driving behavior. Critical gaps do not vary because of differences among drivers only (e.g., age,
27 gender, driving manners, etc.), but additionally, individual drivers have a different tolerance toward risk
28 while waiting in queue that a sufficiently safe gap is available. This risk tolerance, furthermore, depends on
29 the waiting time in queue and then while at the stop-line. Thus the longer a driver waits, the more he is
30 willing to accept risk and the likelihood for accepting shorter gaps increases [3].

31 An accurate calibration of critical gap parameters has great impact on the validity of simulation results. Too
32 long critical gaps may lead to longer delays and queue lengths than those observed in reality, while too
33 short accepted gaps will result in the opposite behavior and an overestimation of the intersection capacity.
34 The results that can be more easily observed is that a mistake in the calibration of critical gaps will reflect
35 in discrepancy between observed and simulated travel/waiting time distributions.

36 The goal of the research described in this paper is to provide a method to calibrate critical gap functions
37 that are consistent with observed travel times for passing the junction at different traffic conditions. To do
38 so, we propose a new calibration procedure that uses directly simulated and observed travel times,
39 calculated from the moment a vehicle is at the front of the queue until it completes the maneuver.
40 Moreover, we propose a new critical gap function that is traffic flow-dependent. The latter is proposed to
41 capture the changes in risk-taking behavior that drivers show with increasing waiting times in front of the
42 queue due to a reduced chance of acceptable gaps.

43 This paper is outlined as follows. In the next section we provide a state of the art on estimation methods for
44 both unsignalized intersections and roundabouts, and the different definitions of critical gaps proposed,
45 focusing on those used in microsimulation programs. A description of the new estimation methodology
46 follows. Next, data collected from different intersections in the city of Leuven, Belgium, is presented and
47 analyzed, and different critical gap functions are compared when calibrated with this data. The paper is
48 finally concluded with a discussion on the limitations of the current study and a summary of
49 recommendations and further steps in this research direction.

STATE-OF-THE-ART

Many studies have been conducted on gap acceptance based on the concept of critical gaps, both at unsignalized intersections and at roundabouts. In these studies, different definitions and estimation procedures for the critical gap have been proposed, given the difficulty to measure this parameter directly.

The techniques used to estimate critical gap parameters fit into essentially two different groups. The first group is based on regression analysis of the number of drivers that accept a gap against the gap size. If there is a continuous queue on the minor street, then the regression technique produces acceptable results because the output matches the assumptions used in a critical gap analysis. The first empirical studies based on regression analysis proposed different statistical meanings for the critical gap. An early approach suggested by Greenshields et al. [4], used the definition of the “acceptable average minimum time gap” which can be interpreted as a first definition of critical gap. Raff and Hart [5] defined it as the lag for which the number of accepted shorter gaps is equal to the number of rejected longer ones, while analogously Drew [6] suggested that the critical gap is that for which an equal percentage of traffic will accept a smaller gap as will reject a larger one. More recently, Brilon et al. [7] benchmarked different statistical estimation procedures for critical gaps at unsignalized intersections, reporting more than 30 different ways to define and estimate the critical gap parameter, all leading to different capacity calculations. In their study, they argued that critical gaps should not depend on the observed traffic conditions, so that the estimation results can be applied to any unsignalized intersection in undersaturated conditions.

It is important to stress out that the regression method can be applied only when there is a queue waiting at the intersection. Only in this case one can be sure that the critical gap and follow up times are independent from the vehicles arrival times. A probabilistic or behavioral approach must be used otherwise. Traditional models of this type are the ones of e.g. Tian et al. [8] and Troutbeck [9]. An exception in this research stream is the work of Wu [10], which is based on the equilibrium between accepted and rejected gaps and does not necessary require a constant waiting queue at the minor street approach.

Although simple time and demand independent critical gap parameters based on regression analysis have been adopted in most of the official capacity guides, like in the Highway Capacity Manual [1], simulation models, which are programmed to model traffic operations under different traffic conditions and for different goals, require more refined behavioral models. That explains the development of different models for the gap acceptance behavior (e.g., Mahmassani and Sheffi [11], Daganzo [12] Hewitt [13] and Teply et al. [14-15]). Although many studies such as Teply [14-15] reported a general variation of gap acceptance behavior with traffic conditions and especially on the waiting time for an acceptable gap, they concluded that using this dependence in the modeling of unsignalized intersection would be an unnecessary addition of complexity.

Although this call for modeling parsimony may have modeling advantages, it seems counterintuitive given the observed changes in risk attitude of drivers found in other studies, such as Kittelson and Vandehey [16], which found drivers to accept shorter gaps with increased front-queue delays, and Kaysi and Abbany [17], who found statistically significant changes in drivers’ risk-taking behavior with traffic-related parameters such as number of rejected gaps, total waiting time at head of queue, and major-traffic speed. This type of behavior was argued to be relevant when modeling traffic operations, since it may result in lower total delays at the expense of higher risks. Under certain circumstances, drivers from the minor street may decide to take very small gaps, sometimes forcing the drivers from the main street to decelerate and by doing so they can reduce their waiting time at the junction. Capturing this behavior may be relevant if one investigates the safety and operations under dense traffic conditions. Accordingly, modeling of similar types of intersections depends highly on the behavioral characteristics of minor street drivers, and advanced types of models that incorporate aggressive driver attitudes and traffic stream interaction are more appropriate than the basic gap acceptance model. For the same reasons more refined behavioral models that incorporate these changes in the critical gap have been proposed in the last two decades. Cassidy et al. [18] tested different Logit models to estimate the critical gap parameter in simulation programs. They found these models to be highly sensitive to the choice of the critical gap parameter, and recommended adopting different values for different intersection layouts and traffic conditions, in discordance with the earlier recommendations of Brilon et al. [7], and Teply [14-15].

Polus et al. [19-20] focused on the impact of waiting times in the critical gap parameter at roundabout. They reported that such impact causes critical gaps to be significantly lower than the ones suggested by the

HCM guide [1]. They recently also suggested to correct this issue using a Logit model with its mean parameter to be a decreasing linear function of the average waiting time [21]. Similarly, Romano [22] used drivers' delay to determine their tendency to take a risk when entering the main road at a roundabout. In this model the critical gap parameter depends on numerous factors such as the flow on the prioritized stream, the speed of the circulating vehicles, the vehicles mechanical characteristics, the geometry of the entry arms, and the environmental conditions. In analogy with the study presented in this paper, a correlation is found between the critical gap interval and traffic conditions at the roundabout. A model based on the empirical gaps collected on a roundabout in Villaricca (Italy) was used to give a functional form to this correlation. A different microscopic decision model for driver gap-acceptance behavior was proposed by Pollatschek et al. [2]. The model is based on evaluation of the risk associated with not accepting small gaps against the potential benefit of their acceptance, which is the amount of time saved as a result of shorter waiting at the entry line.

Although behavioral models have been adopted in simulation to better model traffic operations and for safety analysis, all the above studies have reported significant improvements in the calculation of the intersection capacity, despite the earlier studies striving for parsimony (e.g., [7] and [14-15]) and the recommendations from the official capacity guides (e.g. [1]). For this reason, in this paper we aim to investigate the effect of different traffic loads on the critical gap parameter, and to develop a model that can help improving the results of the widely used microscopic simulation program VISSIM [2] without the need to introduce complex behavioral assumptions to incorporate the change in risk attitude of road drivers.

METHODOLOGY

Modeling assumptions

The total delay experienced by the users at unsignalized intersections consists of two components. A first part of the delay is experienced from the moment they join the back of the queue until they arrive at the queue front, and a second component is the time needed to accept a sufficiently large gap to enter the conflict area. Distinction must be made since the first component depends on the (cumulative) gap acceptance behavior of the users positioned ahead in the queue, as well as on the length of the queue itself, while the second is directly related to users' (individual) gap acceptance behavior and the traffic flow rate at the major traffic stream. The focus of this paper is on the calibration of the critical gap parameter so the main contribution of this study is the development of a calibration procedure that does not consider the effect of delays while in queue but only those while waiting for an acceptable gap.

In the software program VISSIM, depending on the traffic conditions each vehicle has two basic conditions in its gap-acceptance behavior:

- Minimum headway (distance)
- Minimum (critical) gap time

As rule of thumb, for the free flow traffic on the main road the minimum gap time is the relevant condition. For slow moving or queuing traffic on the main road the minimum headway becomes the most relevant condition. In this paper we consider only low-dense traffic conditions on the major street.

The critical gap time as defined in this paper follows the definition given in VISSIM, which is different from the critical gap time specified for instance in the Highway Capacity Manual. Essentially, the HCM measures the gap time from the rear of the last vehicle that has passed the junction and the front of the next vehicle arriving at the intersection in the major stream. In VISSIM the priority rule is instead regulated by the distance between the front of the vehicle arriving and the beginning of the intersection. The difference is therefore dependent on the size of the intersection and the mean speed on the major stream. In general, the values provided by the HCM are systematically higher than those given in this paper.

To analyze the effect of traffic conditions on the critical gap, we here identify concurrent reasons for observing differences in drivers' gap acceptance behavior. Some factors that affect this behavior are [23]:

- Factors related to the infrastructure
 - o type of conflict/movement
 - o slope
 - o number of lanes

- intersection layout
- speed limits
- Traffic related factors
 - percentage of heavy traffic
 - mean speed on the major stream
 - inter-arrival distribution
 - presence of protected flows (cyclists, pedestrians,...)
- External factors
 - weather conditions
 - visibility
- driver related factors
 - gender
 - age
 - aggressiveness
 - perception heterogeneity
 - compliance to driving rules
 - perception of danger
 - purpose of trip
 - presence of passengers.

While infrastructural, traffic and external factors can be objectively observed during the data collection process most of the driver-related factors remain unknown. This will also be the case in this study.

Estimation procedure

The developed estimation procedure is based on a 'basic unsignalized intersection', which consists of a T-shaped intersection such as in Figure 1 and on travel time measurements instead of the more conventional vehicle inter-arrival times. The travel time measurements used are the times needed for the minor street vehicles to enter the major street. The calibration parameter in this procedure is the critical gap parameter and its variation depends on the demand observed on the major street and the one on the minor street, which are used as input in the VISSIM simulation program, together with the (observed) average traffic composition and the relevant infrastructure-related factors (e.g. speed limit, slope, etc.).

Figure 1: Basic unsignalized intersection and travel time measurements defined in this study.

Travel times are recorded from the yield-sign until the vehicle entering from the minor street has reached a fixed location downstream of the main road. This location was chosen at different distances from the junction to make sure that vehicles merging into the major stream had completed the acceleration phase.

In the proposed estimation procedure the distribution of travel times is the key performance measure. This of course has a direct relationship with the traffic conditions on the main street: the higher the flow rate, the longer waiting times will be expected and therefore the longer travel times from the front of the queue to some point downstream of the junction. The choice of the waiting time parameter is in line with research done on roundabouts and described in the previous section [20-22].

Description of the basic cases

The case studies have been accurately chosen to control the impact of the factors listed in the methodology section. More specifically we made these choices on the basis of the following characteristics:

- T-shaped intersections, to guarantee always one conflict point;
- small impact of non-motorized traffic (pedestrians, bicycles, etc.);
- no signalized intersections in the neighborhood, which could create regular gaps for the drivers, platooning effects, etc.
- single lane approaches, to avoid drivers competing for the available gaps;
- clear visibility;
- different traffic conditions (i.e. traffic intensities)

On the basis of these characteristics we have identified five different unsignalized intersections in the area of Leuven, Belgium (See also Table 1 for the specifications of the traffic characteristics of each case):

1. Case 1: Blijde Inkomstraat - Herbert Hooverplein –traffic on minor road turns left to join the main street, which is one-way; low presence of heavy vehicles and speed limit of 30km/h on both roads;
2. Case 2: Westlaan – Wilgenstraat –traffic on the minor road turns right to join the main street, which is one-way; similar conditions as above, but with higher flows on the main street;
3. Case 3: Bondgenotenlaan – Justus Lipsiusstraat –similar as case 1 but with significantly high share of heavy loaded vehicles;
4. Case 4: Naamsestraat – Parkstraat –similar as case 2 but with a positive slope on the minor street;
5. Case 5: Naamsesteenweg – Koning Leopold III-laan - traffic on the minor road turns right to join the main street, which is a two-way road; speed limit is here fixed to 50 km/h.

Data collection strategy

To guarantee a correct interpretation of the results and comparison with the VISSIM simulations it is important to collect the data both in real life and in the simulations in the same way.

The real measurements consist of two types: we collected the volumes from the major and the minor streams, including also the share of light and heavy duty vehicles and we measured each individual travel time of the vehicles in the minor stream. This operation was done manually using a chronograph.

To guarantee a relatively small impact of external factors we collected the data on days with stable good weather and during working days only. All measured data have been collected with a 0.1s accuracy.

VISSIM simulations

We used the same infrastructure layouts, traffic rules, as well as volumes, mean speeds and percentage of light and heavy duty vehicles in VISSIM. We defined four types of vehicles in the simulations, i.e. cars, vans, busses and trucks. Vehicle lengths, speed and acceleration profiles of each type were chosen according to the default parameters suggested by the program developers. To obtain reliable results we also used ten different random seeds in the simulation program for simulating different random arrivals at the intersection. The minimum gap times modeled were also varying from driver to driver according to a Normal distribution. The distribution interval of gap times utilized was tested to be at the 95% significance level similar to the one measured in reality.

Analysis of results

Table 1 gives an overview of the data collected at the 5 locations listed above.

Table 1: overview of recorded data

	<i>Case 1</i>	<i>Case 2</i>	<i>Case 3</i>	<i>Case 4</i>	<i>Case 5</i>
Collection time (minutes)	480	120	120	180	180
Mean intensity (veh/h)	258	496	230	252	242
Recorded speeds (km/h)	25-30	25-30	25-30	25-30	40-45
Light duty vehicles (%)	2.9	2.1	3.9	2.0	2.3
Heavy duty vehicles (%)	0.9	1.4	22.4	3.4	4.3
# vehicle records	487	74	244	34	138

In this case more than 80% of the recorded travel times was less than 5 seconds, as it is shown later in Figure 3. The first case was characterized by the longest collection time period. We subdivided this data into 48 time periods of 10 minutes where we assumed stationary traffic conditions (Figure 2). These intervals were then aggregated into four sub-periods with a characteristic mean volume, which was later used as input to perform the VISSIM simulations.

Figure 2: subdivision of the collection time period of the first case study into four sub-periods.

Figure 3 gives an indication of how the VISSIM simulations reproduced realistic travel times in the first case. We operated the same technique also for the other cases. The second case differed significantly from the first one only for a higher volumes recorded during the study period. We therefore aggregated the results, resulting in the relationship between accepted gap times and traffic volumes as shown in Figure 4.

Figure 3: real data vs. simulated travel times for the first case.

Regarding cases 3 to 5 we reported a significant increase of accepted average gap times due to a higher share of heavy loaded vehicles (around 1.5s longer gaps needed on average), no increase in the case of positive slope (about 5.5% maximum slope), and about 1.0s longer gaps in the fifth case, where the mean recorded speeds are higher.

Analysis of minimum gap times

Figure 4 displays the interval of gap times calibrated on the first two case studies (the middle interval represents the average of the first case over the whole time period). Recall that the goal was to minimize the difference between estimated and observed individual travel times, as shown in Figure 3 so these values

represent the intervals of assigned critical gap parameters that minimize the difference between observed and simulated travel times, such as in Figure 3. Figure 4 suggests that the observed gap times tend to get smaller with increasing volumes. This is intuitive given the lower chance for the drivers to find acceptable gaps, and in line with earlier studies on roundabouts (e.g., [19-22]).

Figure 4: relationship between traffic intensity and accepted gap times for cases 1 and 2.

To further investigate this trend we have performed different simulations in VISSIM using different functional forms for the critical gap parameter (Figure 5). More specifically we have analyzed the results when using the constant default parameter suggested by the VISSIM developers, the one used commonly in Belgium (Constant Model 1) and the one found as best calibration of a constant model using all data at once (Constant Model 2), as well as a linearly decreasing model and two different exponential models.

Figure 5: different functional forms analyzed for the critical gap [24].

To test the goodness of fit we have used different metrics. Table 2 shows the results in terms of average error, its normalized value (Root Mean Squared Error) and the standard deviation. The results of the exponential model are found by calibrating the parameters of the following function:

$$GT = t_{\min} + (t_{\max} - t_{\min}) * \exp^{(-\alpha * (I - I_0))}$$

where

- $t_{\max}$ = $t_{\text{basis}} + t_{c,HV} * PHV + t_{c,G} * G + t_{c,S} * S / 5 + t_{c,C}$;
- $t_{\min}$ = $0,75 * t_{\max}$;
- α = $0,025$;
- I = intensity (veh/h);

- 1 – I_0 = 240 vtg/h (start of exponential behavior);
- 2 – t_{basis} = 3,23 s;
- 3 – $t_{c,HV}$ = 0,07 s (correction factor for heavy traffic);
- 4 – PHV = heavy traffic (percentage);
- 5 – $t_{c,G}$ = 0,10 s (correction factor for slope);
- 6 – G = rising slope (percentage);
- 7 – $t_{c,S}$ = 0,23 s (correction factor for speed);
- 8 – S = speed in km/h faster (+) or slower (-) than speed profile 25-30 km/h;
- 9 – $t_{c,C}$ = correction factor for conflict type based on *HCM*.

Table 2: results of the calibration of the different models.

	Constant Model	Linear Model	Exponential 1	Exponential 2
Average error	0.27	0.21	0.19	0.12
Error percentage (RMSE%)	7%	6%	5%	3%
St. Deviation	0.34	0.27	0.26	0.14

The result of the calibration is shown graphically in Figure 6. The proposed exponential model is compared with the result of the optimally calibrated constant model but for different mean volumes, and the calibrated linear model. We would stress that the represented 6 points are based on extensive data collection (more than 1000 individual travel times), and they simply represent the averages of similar demand levels from different intersections.

Figure 6: calibration of the proposed exponential model.

To assess the validity of the calibrated VISSIM parameter and to compare the goodness of fit of the different parametric curves we checked the robustness of the parameter values with respect to the reliability interval, which is defined as the interval between which 90% of the minimum gap time values lie (5%-95% range). All simulated minimum gap times in VISSIM using the exponential model lie into the reliability intervals, as shown in Figure 7. This is not the case if the other functional forms are used [24]. Note that, in the picture, the five different cases have been divided into 11 different datasets of homogeneous volumes:

- 1) Case 1 (199 vtg/h);

- 1 2) Case 1 (251 vtg/h);
- 2 3) Case 1 (258 vtg/h);
- 3 4) Case 1 (275 vtg/h);
- 4 5) Case 1 (313 vtg/h);
- 5 6) Case 2 (496 vtg/h);
- 6 7) Case 3 (198 vtg/h);
- 7 8) Case 3 (230 vtg/h);
- 8 9) Case 3 (274 vtg/h);
- 9 10) Case 4 (252 vtg/h);
- 10 11) Case 5 (242 vtg/h).
- 11

12
13 **Figure 7: reliability intervals and results of the proposed exponential model.**

14 *Model validation*

15 We finally perform validation of the model using a new case study, again from a junction taken in the city
16 of Leuven. Table 3 gives the main characteristics of this junction, while Figure 8 shows a photograph of the
17 junction and its VISSIM representation, together with the permitted traffic operations.

18
19 **Figure 8: junction used for validation in this study (left) and its VISSIM representation (right)**

20 Green arrows represent the operations having priority over the red arrows. We therefore consider three
21 minor streams: vehicles coming from the minor road taking left or right, and the ones from the major road
22 that need to turn left.

23 Table 3 provides also the critical gap values used to compare the VISSIM default parameters, the best
24 calibrated constant parameter and the proposed exponential model, and the results in terms of error
25 percentage between the travel times simulated using the default VISSIM critical gap value and the one
26 using the exponential model. In addition, we show the results using the constant model calibrated using the
27 same data collected for the validation (i.e. the best simulation results using a constant critical gap
28 parameter) and the one done by calibrating the exponential model.

Table 3: main characteristics of the road junction and observed turnings, minimum gap times used in the validation and results of the validation in terms of travel times

	<i>Northbound</i>	<i>Southbound</i>
Data collection time (min)	120	120
Average intensity (veh/h)	207	235
Speed limit (km/h)	50	50
Light duty vehicles (%)	1.7%	2.1%
Heavy duty and buses (%)	1.0%	0.4%
Operation	Right turning	Left turning
# of observed vehicles	112	84

<i>Gap time (s)</i>	<i>Right from minor</i>	<i>Left from minor</i>	<i>Left from major</i>
Default VISSIM	3.0	3.0	3.0
Calibrated constant model	3.4	3.4	3.4
Exponential model	4.2	4.4	2.1

<i>Travel time (s)</i>	<i>Right from minor</i>	<i>Left from minor</i>	<i>Left from major</i>	<i>Total</i>
Average travel time	4.4	error %	6.9	error %
Default VISSIM	3.93	11%	5.95	14%
Calibrated constant model	4.25	3%	7.61	10%
Exponential model	4.61	5%	7.20	4%
Calibrated exponential model	4.64	5%	7.17	4%

As one can see from Table 3, the exponential model performs very well when applied to the turning operations from the minor street. Results from the exponential model set using the proposed exponential function GT are very close to the best constant model for the minor street vehicles, while they are less accurate for the major stream vehicles. This trend is however shown also for the best calibrated models, pointing at a larger discrepancy between reality and the type of operation simulated with VISSIM. Note that the values in Table 3 are simply an average over a certain distribution that the program VISSIM uses to draw the individual critical gaps. The result of loading critical gaps from this distribution is similar to the distribution of travel times represented in Figure 3, thus accurately mimics the real observations.

LIMITATIONS OF THE STUDY AND FURTHER RESEARCH DIRECTIONS

Despite the very promising results shown in the validation section, we are aware that the current dataset used to calibrate the models may not reflect all traffic conditions at unsignalized intersections. The calibration of the exponential model parameters is quite well fitting, as shown with Figures 7 and 8, and the form of the exponential model is intuitive, since one can expect that the users start accepting shorter gap times only above a certain traffic load, which may yields to long expected waiting times. However, more data may suggest other functional forms, like the S-shaped function suggested by Polus et al. [25].

The methodology adopted is rather general. However, the results of the calibration are not, and the values found in this paper may differ significantly from case to case. The choice of the T-junctions has facilitated the calibration process significantly. Different conflict points may induce different behavior for the drivers,

and this may affect the gap parameter values, as well as different factors not included in the study, will have a significant influence, for instance when the visibility is very different from the T-junctions used (left turning from major roads or merging operations with very sharp angles). Further analysis under different conditions and to identify relevant external factors is needed since all conditions considered were with reasonably good weather and visibility. Also analysis on roundabouts may show some differences, especially if one considers the introduction of the circulating flow parameter.

It must also be pointed out that a very important goal for the gap acceptance model is to reproduce well delays and queue lengths observed at minor streets. However, the focus of this study is on the critical gap parameter, its distribution over the population and its variation with different loads on the major street. This is also equally important since critical gap is a main determinant of the intersection capacity and is one of the input parameters that affect gap acceptance behavior. Without a reliable estimation of this parameter, delays and queue length will certainly be erroneously estimated.

For the calibration procedure, total individual delays and queue lengths from the minor street could also be used in our framework. However, using the whole individual delay in the process (i.e. from the moment the vehicle joins the queue until it leaves it and merges the main stream) would introduce much more complications and probably reduce the estimation capabilities of the methodology. To give just a few reasons, the full individual delay would include, and be influenced by, the behavior of the other drivers preceding the vehicle. It would be very difficult to extract the correlation in this data type. Moreover, the estimation results would strongly depend on the queue lengths. These are measures that have relatively weaker influence on the critical gap parameter. The word ‘relatively’ is used on purpose since we expect that drivers joining long queues and experiencing long delays before arriving at the front of the queue may show a stronger risk-taking behavior due to loss of time and patience. This effect is partly considered in our method by considering the minimum gap parameters as function of the traffic load on the major stream. Finally, this paper has focused only on the critical gap parameter, while no regard was given to the analysis, calibration and validation of follow up time parameters. The data collected was insufficient to obtain reasonable results and this will be certainly a direction to undertake in future research.

SUMMARY AND RECOMMENDATIONS

Critical gaps are essential parameters in the modeling of traffic operations at unsignalized intersections. These parameters are also fundamental in simulation studies, which are normally based on gap-acceptance theory. In this paper we have developed and tested on different real cases a new methodology based on individual waiting times at the minor streets to calibrate the minimum gap parameter of a well-known microscopic simulation program, VISSIM. We showed also that significant improvements could be achieved if the simple constant critical gap parameter used in the standard driver model of VISSIM is replaced by a more refined model that is sensitive to the traffic load on the major road. This is in line with past research, who has found evidence of the decreasing average gaps accepted by the drivers with increasing (expected) waiting times.

The values found for five different intersections in Leuven, Belgium, and under 11 different scenarios depending on the specific traffic conditions and compositions has been validated also on an intersection in the same area. The results show that the proposed traffic-dependent exponential model outperforms the simpler constant and linear models. Naturally, the better fitting is done at the expense of extra parameters to calibrate, but the advantage for better estimating capacities at unsignalized intersections or safety and operations under dense traffic conditions supports this choice.

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