# Safety In Rural Intersections: Experimental Research For The Evaluation Of Sight Distance For Stop–Controlled Intersection

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## SYNOPSIS

The objective of this paper is to analyze the methodologies for the control of sight distance for intersections at-grade, and to propose methods mainly adapts to estimate this distance for intersection with Stop control on the minor road.

In all the problems connected with the road safety, the sight distance assumes great importance. Near the intersections, it is important that drivers have to disposition a sufficient sight distance in order to decide, firstly, which manoeuvres to carry out, and, secondly, for being able to complete it reducing the risk of collision. In correspondence of crossroad, it is necessary to define the clear sight triangles, in order to the speed of the approach.

In this paper, we'll proceed with this following phases:

- First phase: analysis of the national and international rules in relation to estimate the sight distances;
- Second phase: field experiences at Stop controlled intersection focused on the behaviour of minor – road drivers, waiting on the minor road, for a gap in the major – road traffic stream, in which to enter or cross the major road;
- Third phase: proposal of a methodology mainly adapted for the evaluation of sight distances at intersections controlled by a stop sign. A procedure, founded on consolidated international recommendations will be proposed, through which it will be possible to estimate, for every manoeuvre (crossing, right–turn, left–turn), the sight distance.

This Research Group, in conclusions, recommends that the evaluation of sight distance at grade intersections controlled by a stop sign, has to be differentiate according to the maneuvers to be executed at junctions. At this purpose, we propose methodology by means of which it's possible to exactly characterize the possible visibility triangles.

# Safety In Rural Intersections: Experimental Research For The Evaluation Of Sight Distance For Stop–Controlled Intersection

## INTRODUCTION

Visibility has a great importance for what concerns all the problems connected with safety driving. Road users must have a good visibility especially nearby road intersections: first to decide what action has to be taken and second to decide how to carry out this action reducing to the minimum the risk of collision with conflicting traffic. It is therefore necessary that all obstacles to visibility are removed nearby intersection, by suitably defining the borders of the visibility triangle, from a planimetric point of view, so to guarantee the above said requirements, with variable dimensions in function of approach speed.
The objective of this paper is therefore to preliminarily analyze the criteria actually present in literature for the control of sight distance for intersections at-grade controlling, and propose methods mainly adapts for the evaluation of sight distances at intersections controlled by a stop sign. In order to reach these objectives, we will make reference to a series of experimental surveys carried out at four intersections in Sicilian extra-urban roads network.

## SIGHT DISTANCE AT STOP-CONTROLLED INTERSECTIONS

The criteria for determination of visibility triangles relevant to the stop-controlled intersections are based, in literature, on two different types of approach: the first one based on the analysis of the acceleration time of the vehicle coming from a minor-street, and the second one, on the contrary, based on the identification of the critical gap of acceptance into the major-street vehicular stream, by the minor-street vehicle waiting at stop sign.
Among the criteria which make reference to the acceleration time of the minor street vehicle, we remember the following ones:

- Procedure AASHTO, case IIIA (crossing)
- Procedure AASHTO, modified, cases IIIB and IIIC (left and right turn))

The methods, analysed in the present study, are on the contrary, based on the determination of the critical acceptance gap and are reported here following:

- Procedure adopted by Highway Capacity Manual 2000 (HCM);
- Procedure recommended by the Report 383 (N.C.H.R.P. Report 383);
- Model recommended by the Green Book 2001;
- Pre-standard study of Roma-Trieste dated 10 September 2001.

Determinations procedures for sight distance (ISD) are summarized in Tables 1 and 2 in a general intersection regulated by a stop sign, on the basis of the above-said criteria.
We reported in tables 3, 4 and 5 all the critical gaps values utilized in national and international procedures which make reference to the scheme of merging, conditioned by the presence of a gap in the major vehicular stream. Each table is referred to each possible maneuver at a stop-controlled intersection.
We can immediately notice that international criteria (HCM, Report 383, Green Book-2001), based on statistic surveys carried out in the United States, consider different values for turn and crossing. Italian standards (Pre-standard study of Roma-Trieste), on the contrary, utilize only one value for critical gap, equal to 6.0 sec., accepted by the drivers for crossing, without any reference to turn.
We have reported in figure 1, for example, the schemes of the visibility triangles relevant to the procedure recommended by AASHTO (schemes based on the acceleration).
On the contrary, we reported in figure 2, the general representation of the visibility triangles connected to the calculation of gap acceptance on the major stream (HCM, Report 383, Green Book, Italian Pre-standard Study).

**Table 1: Determination criteria of sight distance for stop-controlled intersections, based on the acceleration time of the minor street vehicle**

| CRITERIA BASED ON THE ACCELERATION TIME OF THE MINOR STREET VEHICLE |
|---|
| **PROCEDURE AASHTO, CASE IIIA: CROSSING**<br>ISD = 0,278 V x (J + $t_a$);<br>V = design speed of the major street [km/h];<br>J = total time of perception-reaction and time requested to engage the gear [sec];<br>$t_a$ = time requested to accelerate and drive the distance necessary to free the intersection [sec]. |
| **MODEL AASHTO MODIFIED, CASES IIIB AND IIIC: TURN MANEUVERS**<br>ISD = Q - h;<br>Q = distance run by the vehicle on the major street while effecting deceleration nearby the intersection until reaching a speed equal to the speed of entry of the minor street vehicle [m];<br>h = distance run by the vehicle on the major street during the time used by the minor street vehicle to travel from the medium point of the turn-left lane to the representative point of the maneuver conclusion [m]. |

**Table 2: Determination criteria of sight distance for stop-controlled intersections, based on the critical gap acceptance in the vehicular major stream by the minor street vehicle**

| CRITERIA BASED ON THE GAP ACCEPTANCE IN THE MAJOR STREAM |
|---|
| **PROCEDURE ADOPTED BY HCM**<br>ISD = 0,278 V x G;<br>V = design speed of the major street [km/h];<br>G = gap of acceptance [sec]. |
| **PROCEDURE RECOMMENDED BY REPORT 383**<br>ISD = 0,278 V x G;<br>V = design speed of the major street [km/h];<br>G = gap of acceptance [sec]. |
| **PROCEDURE ADOPTED BY GREEN BOOK - 2001**<br>ISD = 0,278 V x G;<br>V = design speed of the major street [km/h];<br>G = gap of acceptance [sec]. |
| **PRE-STANDARD STUDY OF ROMA - TRIESTE - 10/09/2001**<br>ISD = 0,278 V x G;<br>V = design speed of the major street [km/h];<br>G = gap of acceptance [sec]. |

**Table 3: Comparison among the critical gaps for right turn**

| Right turn | |
|---|---|
| *Methodology* | *G [sec]* |
| HCM | 6,2 |
| Report 383 | 7,5 |
| Green Book 2001 | 6,5 |

**Table 4: Comparison among the critical gaps for left turn**

| Left turn | |
|---|---|
| *Methodology* | *G [sec]* |
| HCM | 7,1 |
| Report 383 | 7,5 |
| Green Book 2001 | 7,5 |

**Table 5: Comparison among the critical gaps for crossing**

| Crossing | |
|---|---|
| *Methodology* | *G [sec]* |
| HCM | 6,5 |
| Report 383 | 6,5 |
| Green Book 2001 | 6,5 |
| Roma-Trieste 10/09/2001 | 6,0 |

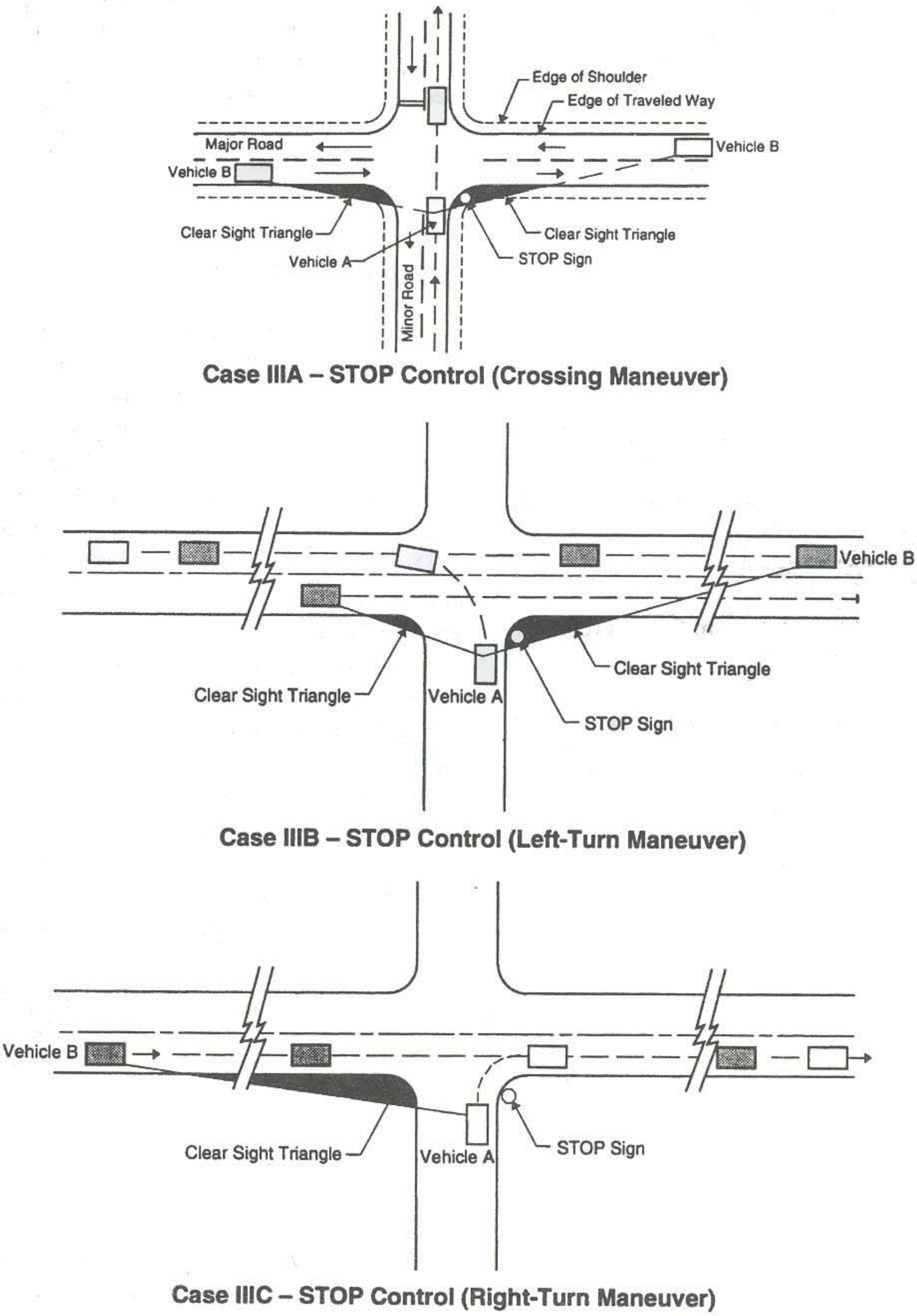


**Figure 1: Visibility Triangles on the basis of the indications given by AASHTO**

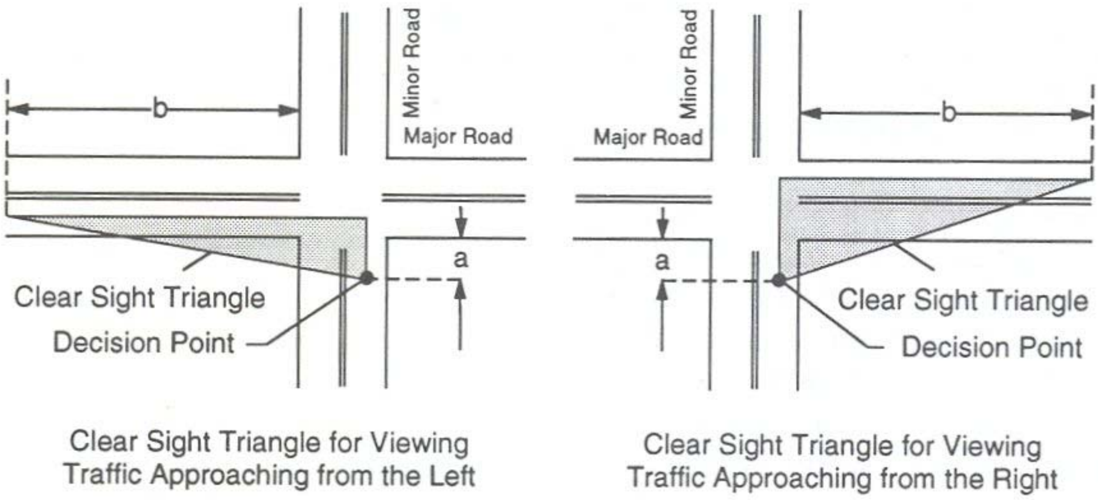


**Figure 2: Visibility Triangles on the basis of the criteria connected to the critical acceptance gap**

## RESULTS OF EXPERIMENTAL SURVEYS

We started on September/October 2003, a campaign of experimental surveys at several intersections at grade, in order to verify on the field the behaviour of the drivers who entry a major street, coming from a stop regulated intersection. We can anticipate, since now, that the attitude of most drivers, staying at stop line, is to wait for the best moment (space-time) to safely merge into the major vehicular stream.
We carried out the surveys at four intersections regulated by a stop sign: two of them are situated in the Municipality of Riposto and the other two intersections are located in the Municipality of Giarre (both cities belong to the province of Catania, Sicily). Three of these intersections have three legs, and the remaining one, located in Riposto, is a four legs junction.
The exact location of examined intersection is reported here below:

- intersection n° 1: Viale Amendola – Lungomare Pantano (Riposto) (Figure 3);
- intersection n° 2: Via Mattarella – Via Carbonaro, (Riposto) (Figure 4);
- intersection n° 3: S.S. 114 – Via Fucini (Giarre) (Figure 5);
- intersection n° 4: S.S. 114 – Via Ungaretti (Giarre) (Figure 6).

**Figure 3: Intersection n° 1. Viale Amendola - Lungomare Pantano (Riposto)**

**Figure 4: Intersection n° 2. Via Mattarella - Via Carbonaro (Riposto)**

**Figure 5: Intersection n° 3. S.S. 114 - Via Fucini (Giarre)**

**Figure 6: Intersection n° 4. S.S. 114 - Via Ungaretti (Giarre)**

We have used for survey operations the following equipment: 1 video camera, 1 tripod, 1 chronometer and 1 video tape.
We registered traffic operations at each intersection using the video camera, kept in a fixed position by the tripod, avoiding the hours of major and minor traffic. We surveyed flows in a time-interval of three hours for each intersection, realizing a total of 12 hours of survey.
The following step of the survey was to determine the time-intervals among the vehicles running on the major street, accepted by the drivers while executing left or right turns and crossings from the stop line present at each one of the minor leg.
We used a normal video tape VHS connected to a television set to measure such intervals, analyse the films relevant to the survey hours and subsequently, by means of chronometer, compute the time-intervals accepted by the vehicles moving from the stop line.
In this phase of the study we carried out a careful selection, so to free the observed gap from the too large acceptance intervals. At this purpose, we have deleted all the values bigger than 9 seconds for what concerns the right turn, and the values bigger than 10 seconds for what concerns crossing and the left turn.
In the figure n. 7 we reported the criterion of measuring the intervals accepted by the drivers of minor street vehicles, in the case of left turn. We can notice that the time $t_1$ of reference was chosen in the precise moment when the major street vehicle (vehicle B) is exactly in front of the vehicle standing at the stop line (vehicle A). The moment $t_2$ is on the contrary when the vehicle A entered the free space between two next vehicles present on the major street (vehicles B and C). In conclusion, the acceptance time is the interval so defined: $G = t_2 - t_1$.
We used a similar procedure for what concerns right turn and crossing.
In total we surveyed and timed (with chronometer) 993 time intervals of acceptance, as follows:

- 375 for right turn;
- 515 for left turn;
- 103 for crossing.

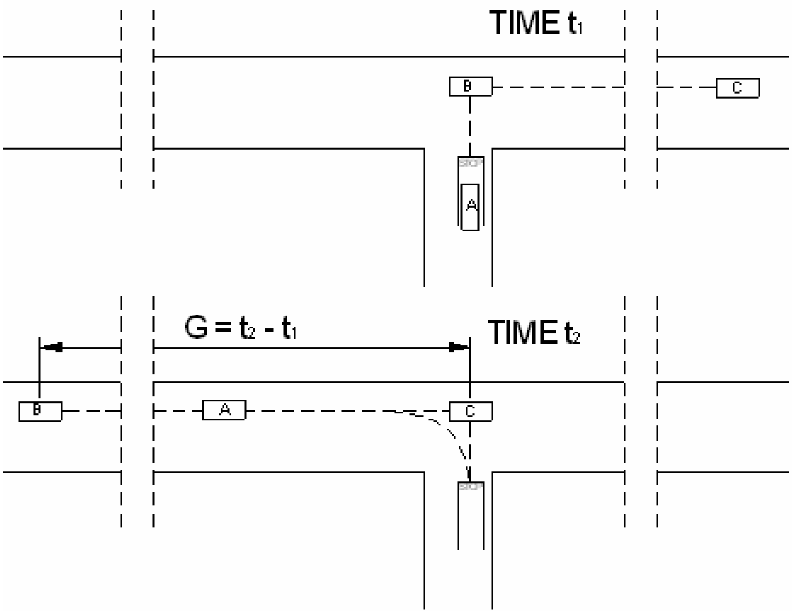


**Figure 7: Measurement Criteria of acceptance time-intervals (left turn)**

We reported in table n. 6 the subdivisions of the intervals measurement for each intersection and maneuver. Crossing is present only in one of the analysed manoeuvres (intersection n. 2)

**Table 6: Number of analysed intervals for each intersection and manoeuvre**

| | Accepted intervals Right turn | Accepted intervals Left turn | Accepted intervals crossing |
|---|---|---|---|
| **Intersection n° 1** | 131 | 155 | / |
| **Intersection n° 2** | 95 | 78 | 103 |
| **Intersection n° 3** | 77 | 154 | / |
| **Intersection n° 4** | 72 | 128 | / |
| **Total** | *375* | *515* | *103* |

## ANALYSIS AND INTERPRETATION OF THE DATA

Data collection phase was followed by data elaboration and interpretation.
In particular, we carried out a probabilistic analysis which requested the evaluation of the frequencies relative to the obtained times and subsequently also the frequencies cumulated, for each one of the examined intersections and maneuvers.
In particular, we indicate with $n_i$ the number of repetitions of the same gap-i and with n the total number of the executed measurements, the **frequency relative** to the gap-i is given by the ratio $f_i = n_i / n$.
Besides, the cumulated frequency by the same gap-i measurement is as follows:

$$F_i = \sum_{j=1}^{i} f_j = \sum_{j=1}^{i} \frac{n_j}{n} \qquad [1]$$

Whether n is the total number of observations, we obviously get: $F_n = 1$.
Once we had determined the values of the cumulated frequencies, we graphically described these ones through a series of diagrams.
The following step was the determination of the probability distribution curve in order to better approximate the cumulated frequencies curve (N.C.H.R.P. Report 383: Intersection sight distance). We made reference to the method of logistics regression, according to similar studies present in literature. It's a representative statistic model of the probability that one event may occur (as gap acceptance) which analytical expression is as follows:

$$\ln\left(\frac{p}{1-p}\right) = a + b \cdot G \qquad [2]$$

- p = probability that a G length gap is accepted [%];
- G = time gap of acceptance [sec];
- a, b = regression coefficients.

Practically, we have determined for each intersection the probability distribution curve, and evaluated, time by time, the regression coefficients a and b for each maneuver.Then, we determined the critical gap, defined as the time gap accepted by the 50% of the drivers (N.C.H.R.P. Report 383: Intersection sight distance). We calculated such interval, indicated with $G_{50}$, through the equation [2], inserting p = 0,50 and resolving in G.
The diagrams of the following figures report, for each node and for each maneuver taken into consideration, the cumulated frequencies curves and the relevant logistic expression, deduced through the above mentioned procedure.

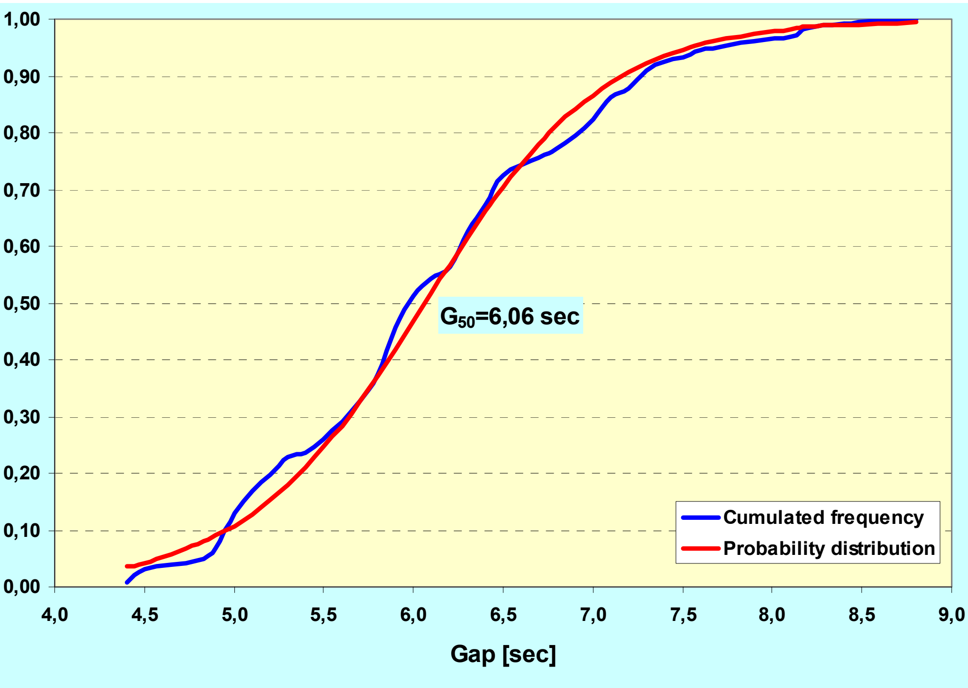


**Figure 8: Intersection n° 1 – Value of $G_{50}$ for right turn**

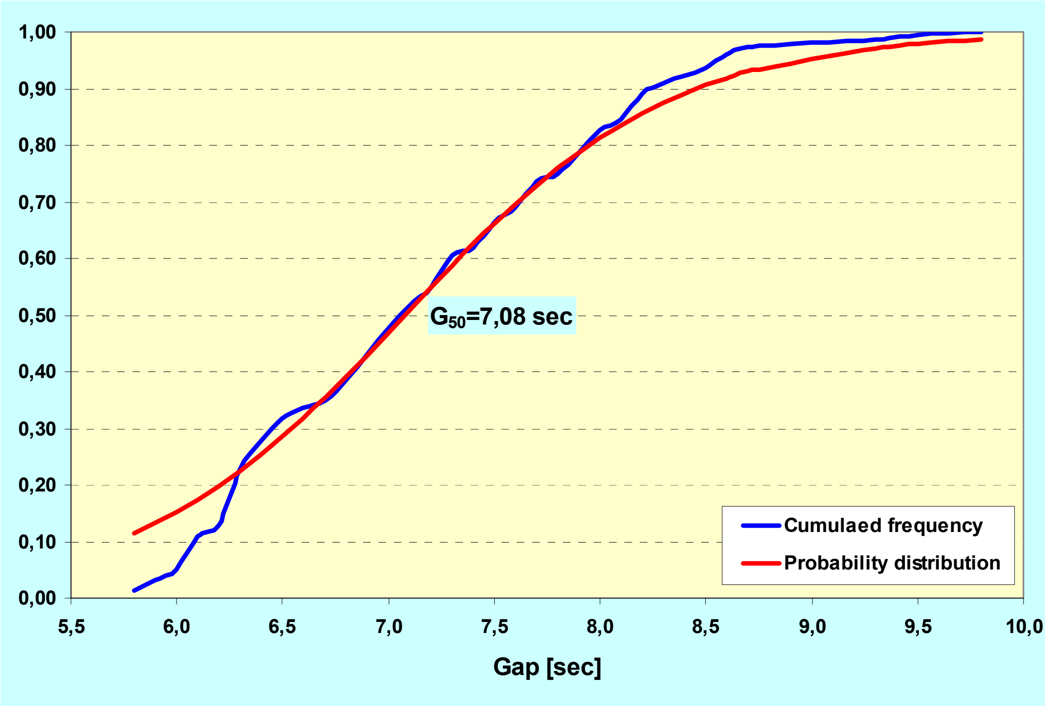


Figure 9: Intersection n° 1 – Value of $G_{50}$ for left turn

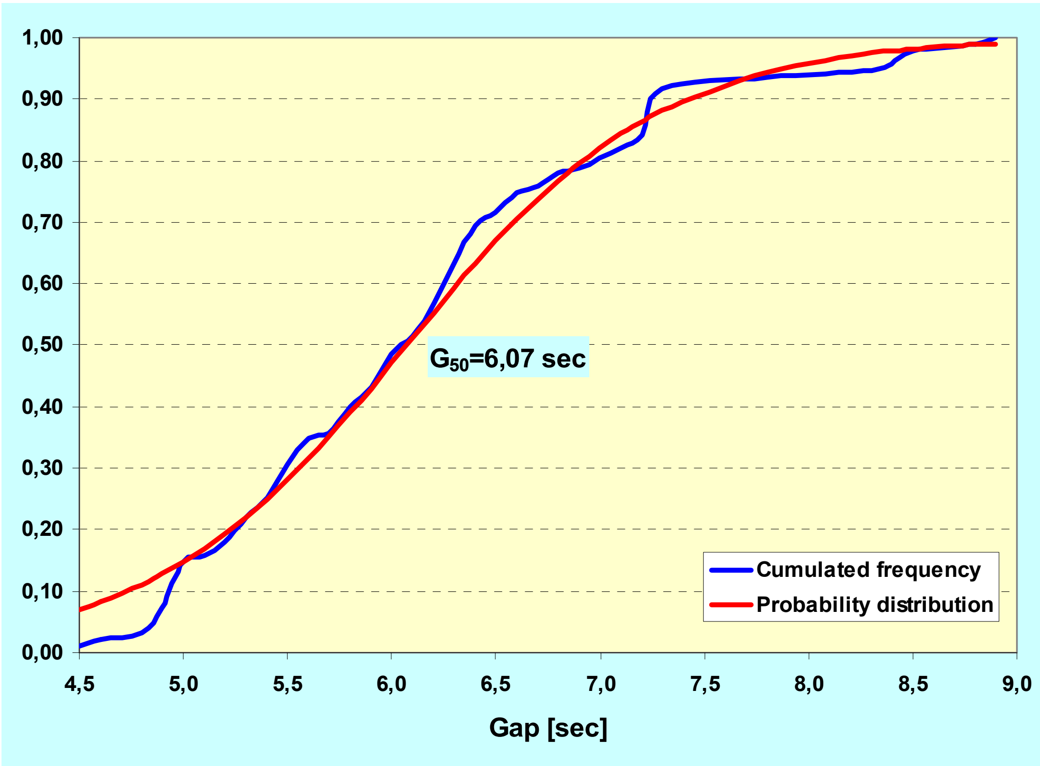


Figure 10: Intersection n° 2 – Value of $G_{50}$ for right turn

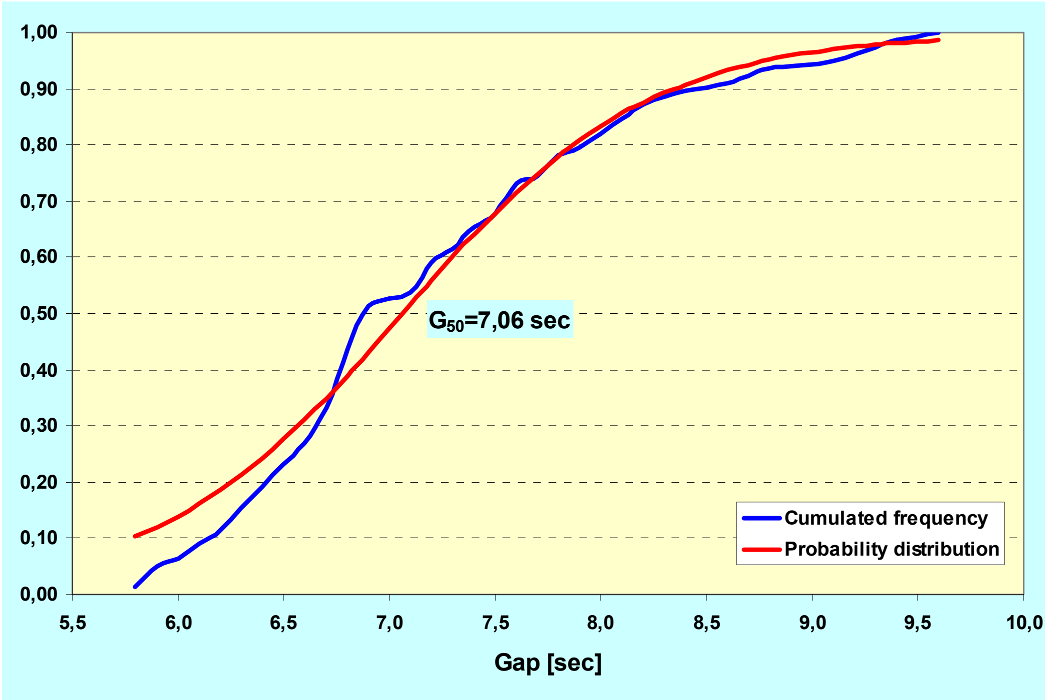


Figure 11: Intersection n° 2 – Value of $G_{50}$ for left turn

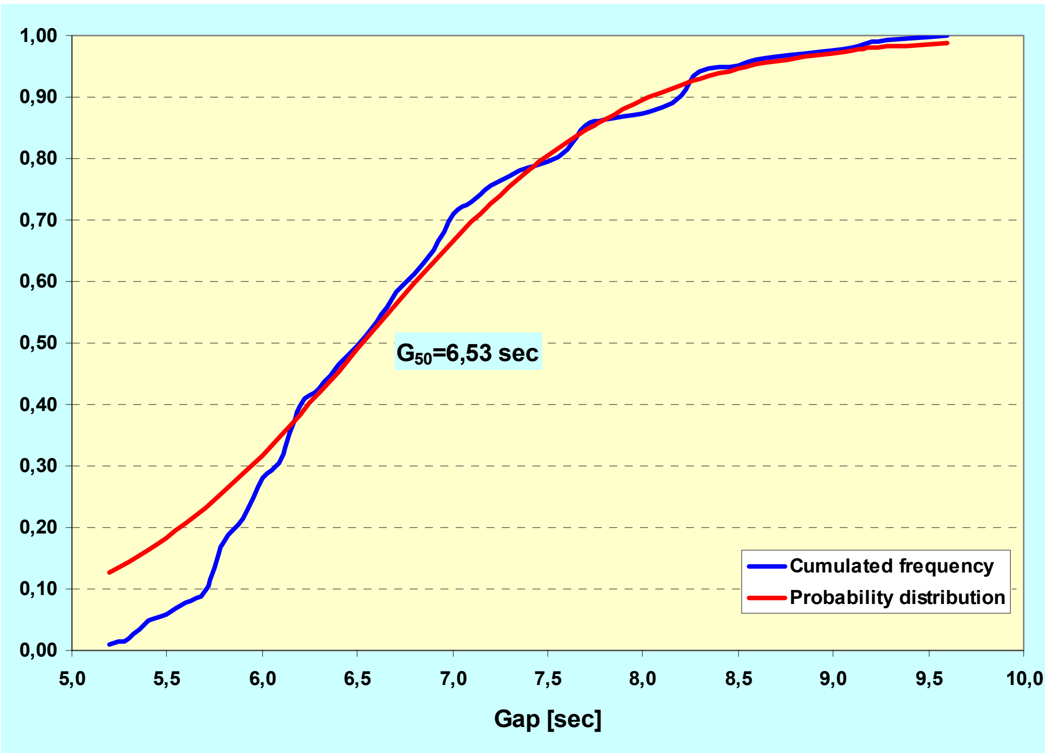


Figure 12: Intersection n° 2 – Value of $G_{50}$ for crossing

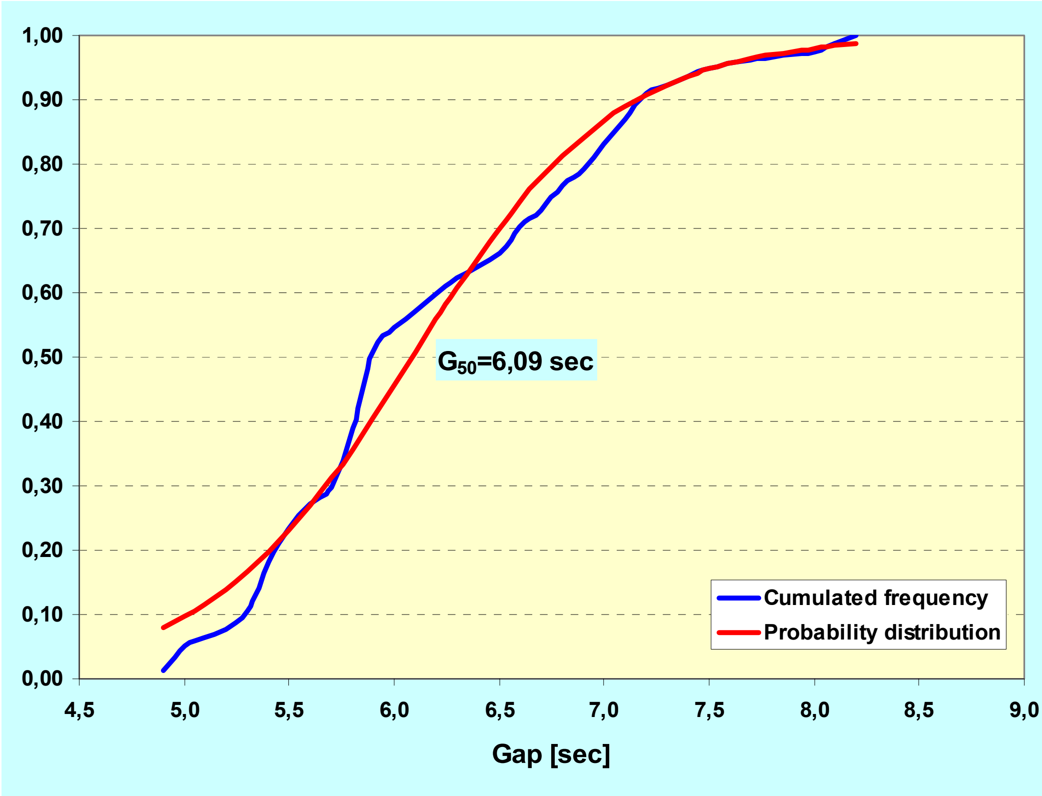


**Figure 13: Intersection n° 3 – Value of $G_{50}$ for right turn**

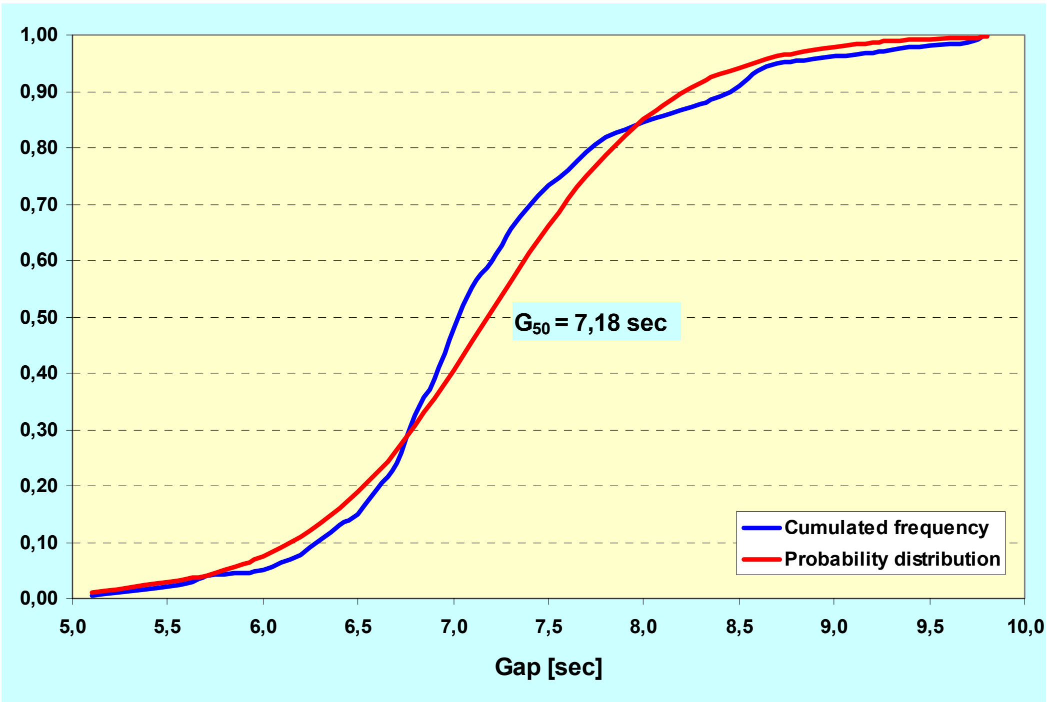


**Figure 14: Intersection n° 3 – Value of $G_{50}$ for left turn**

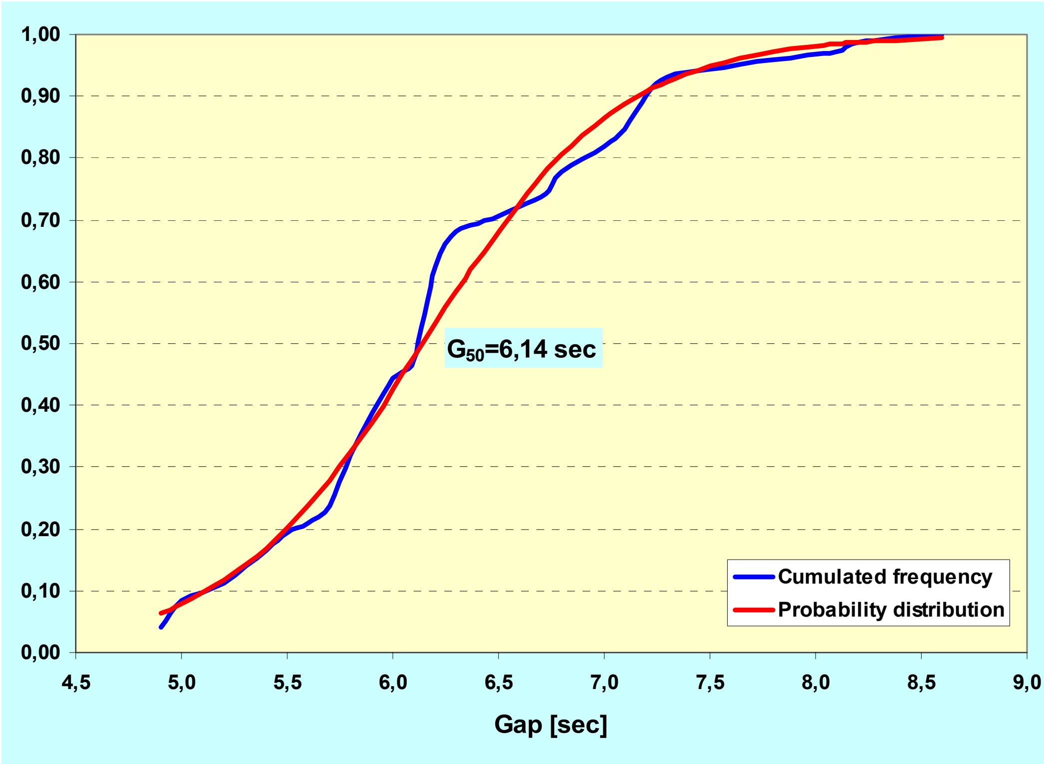


**Figure 15: Intersection n° 4 – Value of $G_{50}$ for right turn**

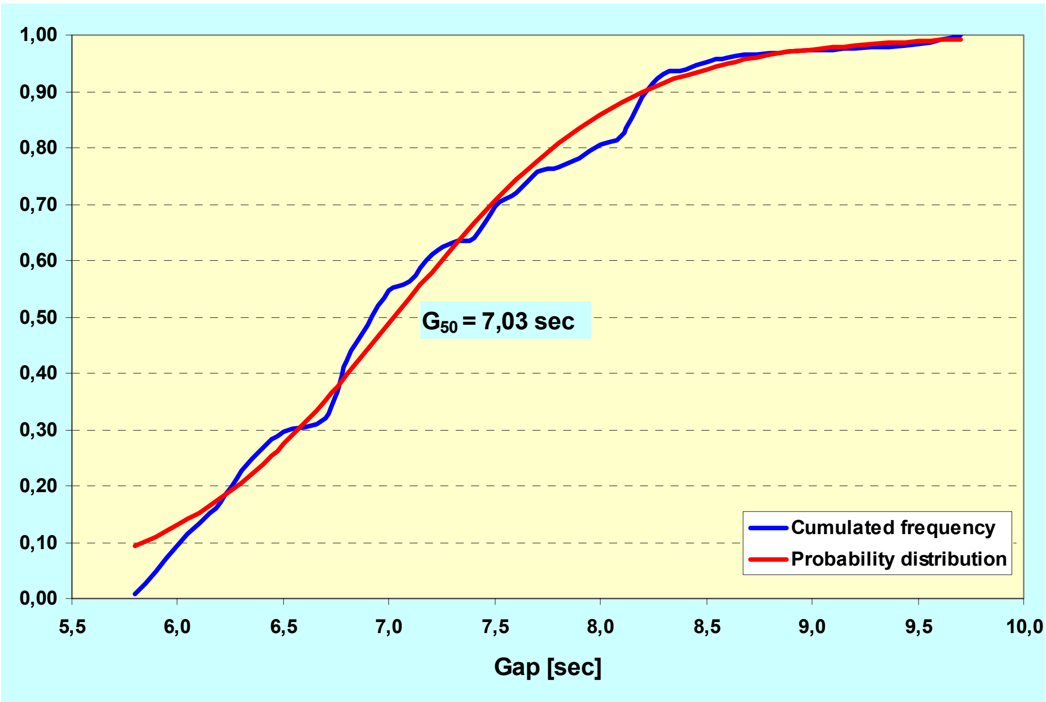


**Figure 16: Intersection n° 4 – Value of $G_{50}$ for left turn**

We summarized the obtained results by the parameters reported in table 7.

**Table 7: Critical gaps and regression coefficients for the studied intersections**

| | | $G_{50}$ [sec] | *Regression coefficients* | |
|---|---|---|---|---|
| **Intersection n° 1** | Right turn | 6,06 | a = -12,0625 | b = 1,9892 |
| | Left turn | 7,08 | a = -11,2574 | b = 1,5905 |
| **Intersection n° 2** | Right turn | 6,07 | a = -9,9642 | b = 1,6412 |
| | Left turn | 7,06 | a = -12,0988 | b = 1,7128 |
| | Crossing | 6,53 | a = -9,4617 | b = 1,4996 |
| **Intersection n° 3** | Right turn | 6,09 | a = -12,4950 | b = 2,0530 |
| | Left turn | 7,18 | a = -15,2603 | b = 2,1245 |
| **Intersection n° 4** | Right turn | 6,14 | a = -13,2283 | b = 2,1543 |
| | Left turn | 7,03 | a = -13,0354 | b = 1,8552 |

The analysis of the critical gap, showed in table 7, put in evidence an high homogeneity of the data relevant to every types of maneuvers. We therefore thought to group - for each possible maneuver – all the measures observed at each surveyed intersection.
In this way, we have created three aggregated curves of the cumulated frequencies (one for right turn, one for left turn and one for crossing); then we studied the probability distributions through the application of the logistics regression already explicated in the expression [2].
Figures 17, 18 and 19 show the probability distribution curves deduced through the logistics regression method, respectively for right turn, left turn and for crossing of the major street.

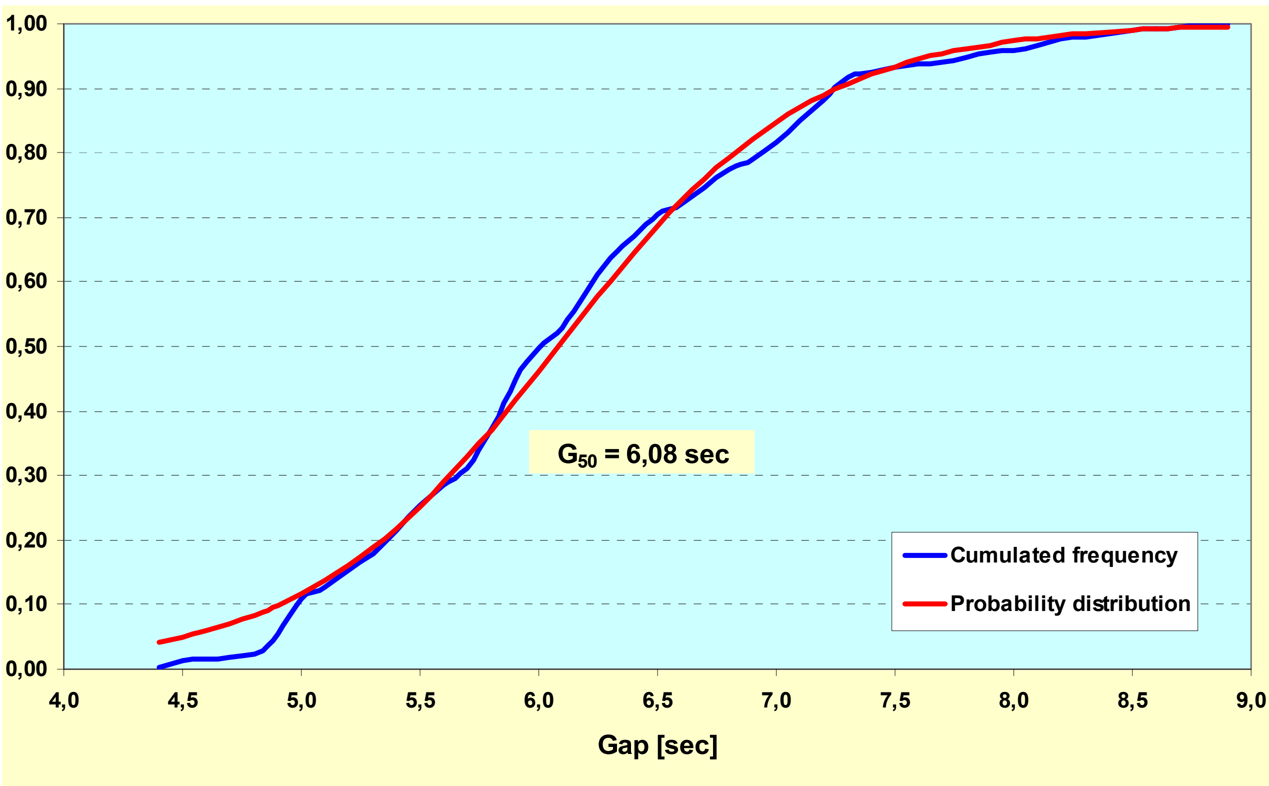


**Figure 17: Final value of $G_{50}$ for right turn**

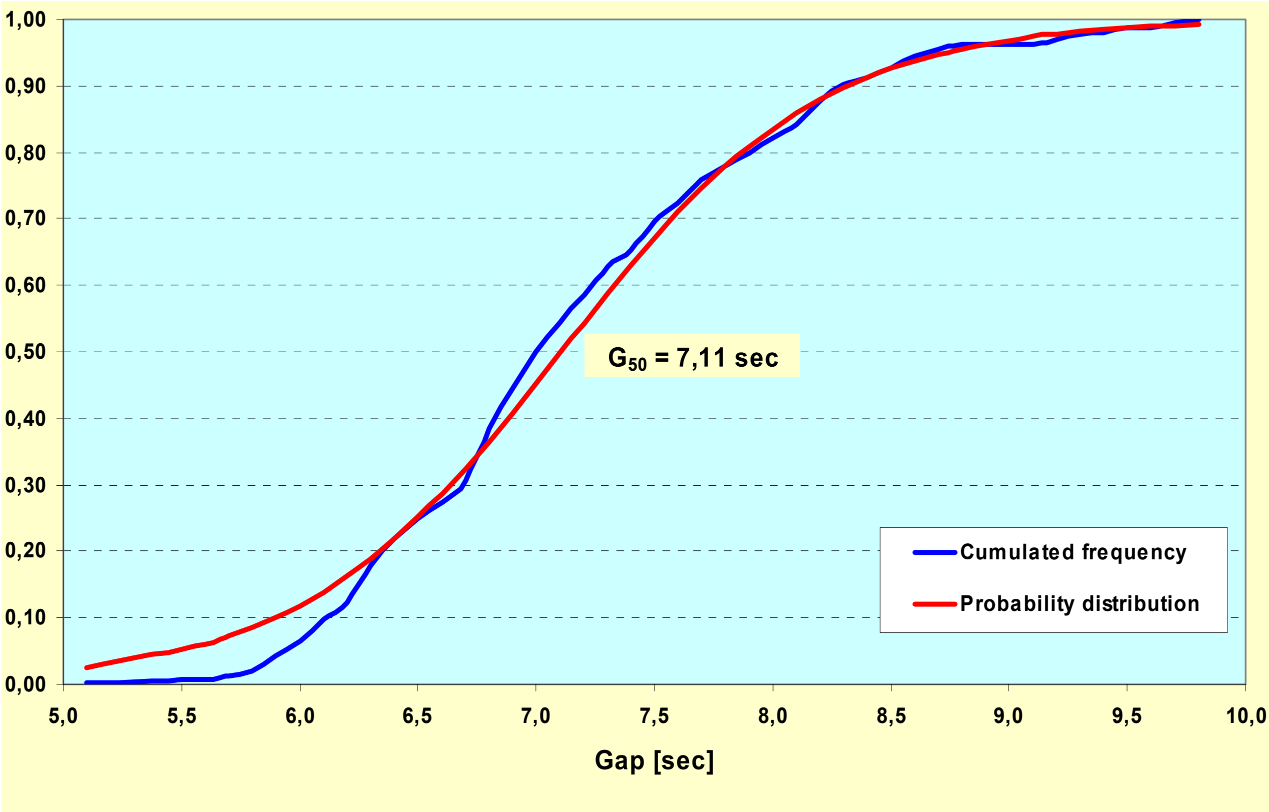


**Figure 18: Final value of $G_{50}$ for left turn**

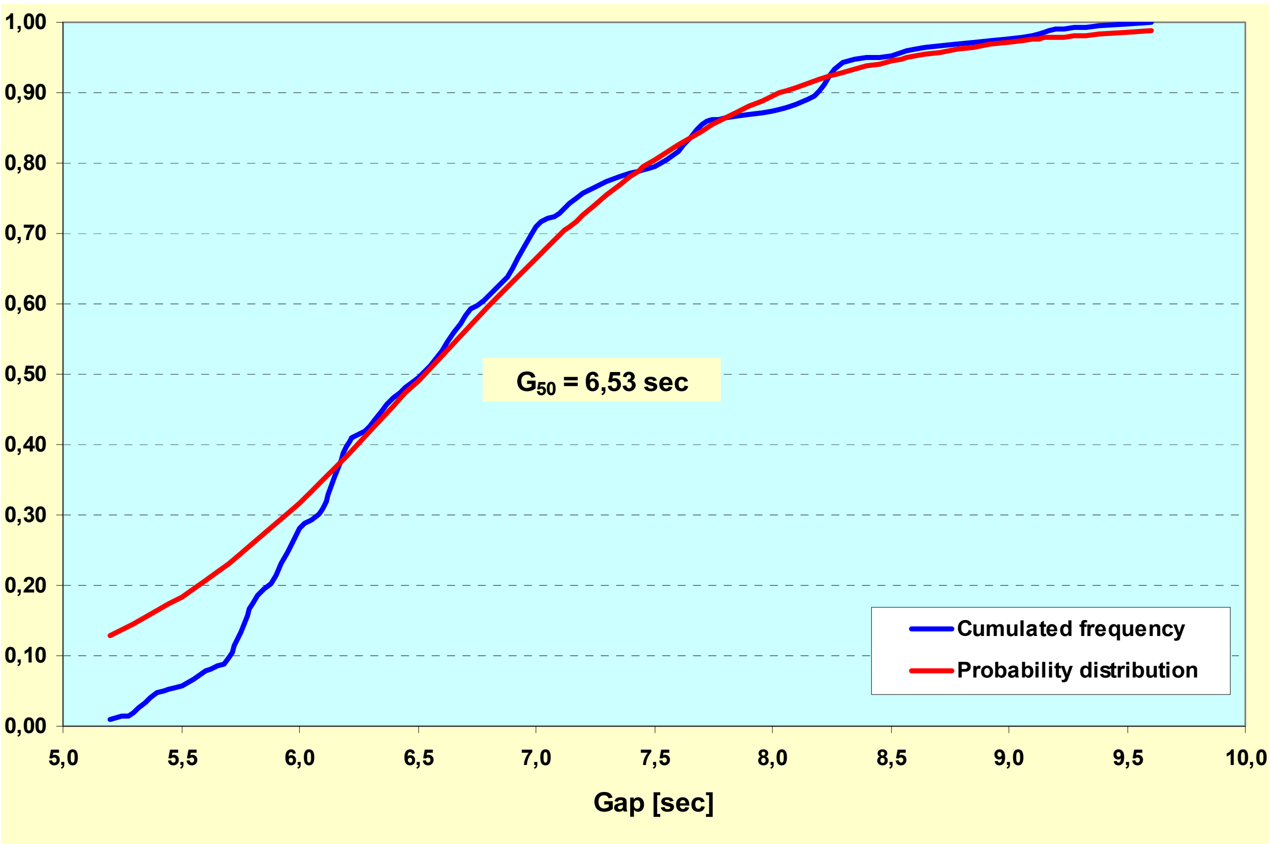


**Figure 19: Final value of $G_{50}$ for crossing**

We summarized the values of the critical acceptance gaps obtained by experimental data elaboration in table 8.

**Table 8: Values of the critical gaps obtained by experimental survey**

| Maneuver Type | $G_{50}$ [sec] |
|---|---|
| ***RIGHT TURN*** | ***6.08*** |
| ***LEFT TURN*** | ***7.11*** |
| ***CROSSING*** | ***6.53*** |

We can also notice that the $G_{50}$ values obtained by our experimental survey are very near to the values adopted by the Highway Capacity Manual (HCM) (tables 3, 4, 5).
It would be therefore appropriate to adopt a sight distance determination procedure, for stop-controlled intersections, utilizing just the values of the critical gap advises to you from the HCM, or, in alternative, from the other procedures highly consolidated (Green Book, Report 383) (tables 3, 4, 5).
So doing, we could have a real distinction of the triangles free from obstacles according to the different types of maneuver. This would permit to suitably characterize the major request of visibility on the left turn. We underline that the present research group already make action to implement this research, taking into account other factors as: behaviour of commercial vehicles' drivers and influence of plano-altimetric conditions (number of lanes of the major street, minor street gradient at stop sign).
In conclusion, it is better to determine (for what concerns stop-controlled intersections and the vehicle stopped on the minor street at a distance of 3.00 m. from the stop line) the length of the visibility triangle side along the major street like a distance run by a vehicle at design speed of the major street in a time equal to the deductible critical gap from the indications given from the HCM. (equal to respectively 6.2 sec. for right turn, 7.1 sec. for left turn and 6.5 for crossings).

## CONCLUSIONS

With the present study, we wanted to examine in details the problems tied to the request of visibility at the stop-controlled intersections.
First, the evaluation of the triangle visibility free from obstacles, for this particular typology of intersections, may be referred to two types of approaches:
1) the analysis of the acceleration time of the minor street vehicle;
2) the determination of the critical gap of acceptance into the major street vehicular stream.
The behaviour of the drivers at intersections was observed in a campaign of experimental surveys and induced us to take into consideration the second type of approach.
In effect, we preferred to calculate the sight distance through a simple relation as follows:

$$ISD = 0.278\ V \cdot G \qquad [3]$$

- ISD = sight distance at stop-regulated intersections [m];
- V = design speed of major street [km/h];
- G = acceptance critical gap [sec];
- 0.278 = speed conversion factor (km/h into m/sec).

Practically, we thought it was right to estimate sight distance making reference to the progression time between two vehicles travelling on the major street.
The results of this experimental survey allowed us to differentiate the critical gap for crossing, right turn and left turn. This is in accordance with the more important International regulations in this sector. Also the numeric results are not very different from the values reported in the various analysed procedures (HCM, Report 383, Green Book - 2001).
This Research Group, in conclusions, recommends that the evaluation of sight distance at grade intersections controlled by a stop sign, has to be differentiate according to the maneuvers to be executed at junctions.

## REFERENCES

A.A.S.H.T.O. *A policy on geometric design of highway and street 1984 First Edition (Green Book)* – Ed. Copyright - 1984.

A.A.S.H.T.O. *A policy on geometric design of highway and street 1990 Second Edition (Green Book)* – Ed. Copyright - 1990.

A.A.S.H.T.O. *A policy on geometric design of highway and street 1994 Third Edition (Green Book)* – Ed. Copyright - 1994.

A.A.S.H.T.O. *A policy on geometric design of highway and street 2001 Fourth Edition (Green Book)* – Ed. Copyright - 2001.

AA.VV. *Highway Capacity Manual (HCM)* **–** Ed. Transportation Research Board – 2000.

AA.VV. *Norme sulle caratteristiche funzionali e geometriche delle intersezioni stradali* **–** Studio Prenormativo Roma-Trieste – 10/09/2001.

N.C.H.R.P. *Report 383: Intersection sight distance* - National Academy Press - Washington, D.C. – 1996.