

**PARAMETERS FOR EVALUATING PEDESTRIAN SAFETY PROBLEMS IN  
SIGNALIZED INTERSECTIONS USING THE TRAFFIC CONFLICT ANALYSIS  
TECHNIQUE – A STUDY IN SÃO PAULO, BRAZIL.**

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## PARAMETERS FOR EVALUATING PEDESTRIAN SAFETY PROBLEMS IN SIGNALIZED INTERSECTIONS USING THE TRAFFIC CONFLICT ANALYSIS TECHNIQUE – A STUDY IN SÃO PAULO, BRAZIL.

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### ABSTRACT

*This paper reports diagnostic parameters for pedestrian traffic safety problems using the Traffic Conflict Analysis Technique (TCT), particularly for pedestrian crossings at urban signalized intersections. The applied method of study, based on the U.S. FHWA-Federal Highway Administration guides for vehicular conflicts, uses data collected from 26 pedestrian crossings of several types observed in 4 critical signalized intersections with high vehicular and pedestrians volumes at the Sao Paulo's expanded CBD. The adaptation of the technique for the observation and analysis of pedestrian-vehicle conflicts is discussed and related to previous works. The results from field data include the pedestrian conflict count limits  $C$  (abnormally high level of counts for problem detection) and the ratio  $R$  of accidents per million of conflicts (risk index and accident forecasting rate) for the types of urban crossings observed in the signalized intersections of the study. Despite limitations on the quality of accident data, to our knowledge this is the first study offering these results for pedestrian-vehicle traffic conflicts, and its parameters are consistent with the evidence presented in previous works.*

### 1. INTRODUCTION

This paper presents the results of a research aiming at establishing parameters for the diagnosis of pedestrian traffic safety problems in urban signalized intersections, distinguishing types of conflicts and types of crossings for signalized intersections, using the Traffic Conflict Analysis Technique (abbreviated here as TCT). Despite of failing to achieve large application up to now, the need of the TCT as an alternative method for the study of traffic safety problems based on direct observation appears recurrently along the time.

The concept of traffic conflict was stated as an event in which two road users (or a road user and another traffic element) became in a course of collision and an evasive action is observed (braking, swerving or accelerating) to avoid the potential accident (see 1 for a historic background and the results of several studies of the international “calibration” effort). Following this collective effort, several countries published guides for applying TCTs, including recommendations and criteria for its use in the diagnosis of road safety problems (e.g. 2, 3, 4, 5, 6), referred here as official guides, where one can distinguishes two ways in which the diagnosis using traffic conflict data can be carried-out.

The basic diagnosis, reported in all TCT guides, is based on the interpretation of traffic count data, relating them to traffic and site features and to the qualitative observations made during field work. The classification of traffic conflicts by type and severity aids the analysis but the task of identifying a set of relevant safety problems (and of selecting proposals for improvement of safety) remains an expert challenge, as in the process of diagnosis based on accident analysis (more abundant and confident data is an advantage of TCT but this feature should be weighted against the risk of missing important factors in accident causation).

There is another type of diagnosis, recommended in the U.S.FHWA guide only (see 5), that tries to identify types of traffic conflicts displaying abnormally high frequency compared to normal levels of traffic conflict counts (on a standard 11 hour period of a week day) and also tries to weight their accident proneness measured by the ratio of accidents to conflicts, or

million of conflicts, counts (a measure of the risk level of each conflict type that can also be used to forecast expected accident frequency based on conflict counts). These refined diagnostic tasks are carried-out by the type of conflict considering the type of physical and traffic environment of the site and using objective diagnostic parameters.

One should note that the viability of the refined diagnosis is constrained by the availability of previously calibrated parameters on the abnormal level of counts and on the accident risk ratio of traffic conflicts, by conflict type and type of site, developed in a careful and representative study of a set of similar sites. The U.S.FHWA guide was based on data from such kind of previous studies (7, 8) for some usual classes from unsignalized and signalized intersections, but there was little progress in developing new data since then.

Despite this practical constraint, it is very important to stress the content of the refined diagnosis, underlining its meaning and relevance for the traffic safety analysis.

For example, a validation study (9, 10) counted the same-direction and transversal conflicts between vehicles in an unsignalized intersection with medium traffic level. The expanded count for the standard period was 239,0 same-direction and 133,5 transversal traffic conflicts. Nevertheless, based on the U.S.FHWA data, the limits for abnormal frequency of conflicts are 410 and 24 (for a 90% confidence level), saying that the less frequent conflict type is the safety problem at the site. Also, again based on U.S.FHWA data, the accident/conflict ratio indicates that only transversal conflicts have a significant risk of generating accidents at this kind of site and, using the accident to conflicts ratio, it is possible to forecast a frequency of 13,6 collisions per year on weekdays with dry weather. The record in the previous year was 16 (all accidents), every of them being transversal collisions, as predicted. This real case study clearly shows the importance of the diagnostic parameters in the analysis.

In this setting, we built on our previous research and on the guidelines for TCT applied to vehicular conflicts (mainly in 5) and searched for the development of diagnostic parameters for pedestrian-vehicle conflicts.

In the following, we discuss the observation of pedestrian-vehicle conflicts, clarifying our methodological options, and review previous work on the typologies of conflicts and crossings to be used in studying pedestrian-vehicle conflicts in section 2. Our study and the results we gathered are then presented and analyzed in section 3, with emphasis on the recommendations for practical application. The final section summarizes the conclusions and underlines some suggestions for further research.

## **2. THE IDENTIFICATION, CLASSIFICATION AND ANALYSIS OF PEDESTRIAN-VEHICLE TRAFFIC CONFLICTS**

We identified five points that should be clarified for developing operational concepts of pedestrian-vehicle conflicts. Three general points are discussed, explicitly or not, in official guides (i.e. 2, 3, 4, 5, 6) and cover: the delimitation of real conflicts (as opposed to “virtual” conflicts, seen as conflict of slight severity or very small risk of generating accidents), the identification of their severity (of the conflict itself) and of their level of risk (proneness of generating accidents). Two other points are recommendations driven to application, related to

the typology of conflicts and the typology of sites that should be used for vehicle-pedestrian conflict studies, and were found only in some of the guides.

Despite providing detailed instructions for field work and preparation of results in TCT studies of vehicular conflicts on intersections, the U.S.FHWA guide roughly sketch the procedure for the observation of pedestrian-vehicle conflicts. A similar problem can be observed in TCT guides of other countries (e.g. 2, 3, 4). For vehicular conflicts, the U.S.FHWA guide provides the required diagnostic parameters for the usual conditions considered as well as parameters for sample design. The corresponding diagnostic parameters for pedestrian-vehicle conflicts are completely missing from the U.S.FHWA guide (or other).

The recommendations for observation of pedestrian-vehicle conflict in several sources are too general and their details are largely inconclusive. We classified them in two phases, considering their date relative to the intense work that resulted in the official guides (i.e. 2, 3, 4, 5, 6). The antecessor studies are mainly exploratory works (e.g. 11, 12, 13, 14, 15) and used previous tentative concepts or classifications of traffic conflicts and other related events. The successor studies are predominantly applied works (e.g. 16, 17, 18, 19, 20) and contain little advice on theoretical or operational concepts (but there are interesting hints in 16, 18, 20).

In the following comments, we discuss the specific tips involved in observing and recording pedestrian-vehicle conflicts and describe our methodological options.

### **2.1. Delimitation of Relevant Traffic Conflicts (or, more generally, traffic events)**

Despite the clarity of the general concept, there are several practical questions that appear on field observation of conflicts and have to be judged. This point is related to the severity of the traffic conflict (remember the Hydén prism of traffic events; see 2, p.27) but also to the identification of the traffic conflict and, perhaps, some other relevant events. The grading of severity will be discussed in the next topic. The other observational hints are covered here.

All guides disregard *virtual* or *potential* conflicts (without significant risk of generating accidents, that can be ignored) and also preventive maneuvers (as the lowering of vehicle speed or the running of pedestrians without the presence of a conflicting user or element).

All guides devote special attention to quasi-accidents (conflicts with emergency evasive actions) and include near misses (events with high risk of accident, given speeds and proximity, even without a course of collision, perhaps by chance, but in which reaction time is very small and no evasive action could be taken if mandated).

All guides distinguish conflicts from other traffic events, as traffic violations or user distraction (limiting its annotation to events that happen to generate traffic conflicts due to their occurrence). These events could be of interest also but should be registered separately.

A point worth noting is that the U.S. guide is the only one that has a special concern with distinguishing normal maneuvers that just give the right of way to users having priority on the road (discarding them, unless there is a clear sign of the accident potential) from conflicts (in which the evasive actions reacts to the danger of accident). The major simplification in the U.S. guide is to avoid the classification of conflicts by severity level. The U.S. guide is also

the only one that clearly identifies events with multiple conflicts and distinguishes primary from secondary conflicts (despite discarding secondary conflicts in the analysis of results).

Most of these points are not carefully discussed in all official guides and we felt it to be a relevant missing point, especially for the observation of pedestrian-vehicle conflicts.

The analogy to vehicular conflicts can be supposed the hidden assumption in all official guides. The French guide (see 3, pp.49-53) includes a detailed description of pedestrian-vehicle (and motorcycle) conflicts, based on both vehicle and pedestrian evasive actions and accepts a clear analogy to vehicle conflicts. The Swedish technique even recommends the use of the same criteria (and values) for classifying the severity of pedestrian-vehicle and vehicular conflicts. These points will be discussed in the next topic also.

The acceptance of the simple analogy can be disputed as, on the field, the observation of who makes the evasive action is a clear distinguishing point related to pedestrian-vehicle conflicts, particularly when comparing the stopping (of pedestrians) and braking (of vehicles).

The same point was discussed in other studies. For example, Cynecki distinguished events with each type of actor doing the evasive action and decided to use only the observation on the driver maneuver for the determination of conflict severity, based on the same feeling (12, p.15). The U.S. guide seems to extend this view to the identification of conflicts, counting only the events in which the vehicle is taking the evasive action (see 5, p.17). One would count events in which pedestrians are taking the evasive action only if they are near misses.

Another relevant point is that events involving multiple users are much more common when dealing with pedestrians (that usually walk in groups). The U.S.FHWA criterion for vehicle conflicts distinguishes the vehicle that generates the event and the one that takes the evasive action and recommends counting multiple conflicts based on the number of vehicles taking evasive action (and as a single conflict if several vehicles are generating the conflict).

Currently, when observing pedestrian-vehicle conflicts the hidden assumption of analogy should be tempered using subjective criteria with more stringent requisites for discarding virtual conflicts (especially if the evasive action is taken by the pedestrian). The guiding idea is the same (to disregard events with ample reaction time) but the time scale is different. Thus, the idea of counting events in which the pedestrian does the evasive action only if the reaction time is very small can be recommended (it will be a near miss if there is no evasive action).

More stringent criteria are also used for counting conflicts involving several users when multiple pedestrians are involved. They are counted as a single conflict, even when the group of pedestrians are taking the evasive action, if they are acting as one group (a mother and her children, a group walking “together”, ...). When multiple vehicles or multiple groups take the evasive action, the number of vehicles or groups defines the conflict multiplicity. The criterion of viewing single events with several users as one single conflict is a sensible option.

The concepts of primary and secondary conflicts are kept as usual. Following the U.S.FHWA recommendation, conflicts generated by other conflicts are counted as secondary conflicts and used only for the qualitative analysis (diagnostic parameters use primary conflicts only).

## 2.2. Criteria for Identifying the Severity of Traffic Conflicts (and their use)

Most of the discussion of severity in official guides is also limited to vehicular conflicts. The official guides, other than the U.S.FHWA one, give great attention to the identification of the conflict severity but its final importance to the objective analysis is small. In the established methods applied for vehicular conflicts, the severity is used to identify virtual conflicts (as the lower severity level usually discarded) and as qualitative information for the diagnosis.

The Swedish TCT is an exception in which some studies related severity of conflicts to the risk of accident for vehicles and pedestrians (see 2, and mainly 23). The severity criterion of the Swedish TCT is based on comparing the value of the TA variable against a critical value (TA is the estimate of Time to Accident and is defined as the time until the occurrence of the potential accident if the road users keep the same trajectories and speeds as practiced at the beginning of the evasive maneuver). Note that, in the application of the Swedish TCT, the TA is evaluated based on the subjective estimation of distance and speed carried-out by a trained observer. The calculation of TA and classification of conflicts are done at the office.

In the current Swedish TCT, the same critical values of TA are used for vehicular and for pedestrian-vehicle conflicts (23). The critical values are derived from a vehicle braking curve (2, pp.117-118) and replaced the original constant value of 1,5 seconds (2). This criterion would be inadequate to grade conflicts in which the evasive action is not the vehicle braking. For example, in the practical application of Swedish TCT, we observed that the “official” criterion is often complemented by a subjective judgment when evaluating pedestrian-vehicle conflicts (see 22, in which a more general criteria, based on the available reaction time for the evasive action, excluding the time of braking or maneuver, is suggested as a replacement).

The British TCT asks for the evaluation of four variables (time to accident, intensity and complexity of evasive maneuver, proximity of conflicting vehicles), gathered subjectively by the trained observer. The classification of the severity is, then, done at the office based on a summary table for converting combinations of the variable levels into a severity grade of a four level scale (4, p.33 e 34). It is initially used for discarding the slightest level of conflicts.

The French TCT provides a careful description of a three level scale (light, moderate and severe conflicts) and asks for the subjective classification of road events by the trained observer (3, item IV3.2). The classification has to be made by trained personnel during the field observation and, again, the slightest level of conflicts is discarded.

Compared to the evaluation of the severity of each conflict in other guides, the U.S.FHWA TCT is really simplistic and only asks for identifying and discarding virtual conflicts (also described as conflicts with ample time for the evasive action), in the field work. Nevertheless, the U.S.FHWA guide is the only one that proposes a measure of degree of risk involved in the overall level of conflict frequency at a site. This is the role attributed to the count limits C of normal traffic conflict level, differentiated by type of conflict and site, and related to the usual distribution of conflict counts for similar sites, both referred to a standard period. A statistical confidence level has to be defined for C (5, provides  $C_{90\%}$  and  $C_{95\%}$  values).

For pedestrian-vehicle traffic conflicts, the attention to the criteria for the grading of conflict severity decreased along the time. A subjective risk measure of safety in pedestrian crossings

is proposed by Zegeer *et al.* (11, p.28), derived from conflict severity based on constant values of *TA* (moderate severity between 1,0 and 1,5 seconds, severe under and slight over the moderate range). Cynecki (12) also evaluates the severity of pedestrian-vehicle conflicts but used a coarse scale (events with a distance greater than 7 meters between vehicles and pedestrians in the road, with or without evasive actions, were taken as slight conflicts; the events with a smaller distance and evasive action are classified as moderate conflicts and the quasi-accidents are classified as severe conflicts).

In the official guides, there is little advice other than the dubious suggestion of applying the same criteria for grading the severity of conflicts involving unprotected road users (as cyclists and pedestrians) as for vehicular conflicts. Only the French TCT proposed clear recommendations based on its subjective grading procedure of a three level scale: slight (an unforeseen stop in the walkway or a simple accelerated walking), moderate (a sudden stop, jump back or running ahead when the vehicle brakes or proceed) and severe (a very rapid jump or a sudden jump when facing the vehicle body). Of course, the specific criterion is applicable only when the pedestrian takes the evasive action (as the regular criterion should be applied when the vehicle does the evasive action).

Based on our discussion, the subjective identification of virtual conflicts based on a subjective grading is recommended, as the one proposed in the French guide, but taking a more stringent criteria when the pedestrian takes the evasive action. Our practice was to use the grade of conflict severity for discarding virtual conflicts only. It seems to be enough and similar to other criteria for practical purposes as the evasive action is usually taken by the vehicle (we collected data for applying the Swedish severity grading, but the results were similar; see 22).

### **2.3. Criteria for Identifying the Measure of Risk in Traffic Conflicts**

The concept of level of risk (hazard or danger) is not explicitly stated in any of the official TCT guides or even in other related papers. Nevertheless, the differences in the probability of generating an accident (accident proneness) of each type of conflict and type of site (perhaps weighting the level of conflict severity and/or traffic conditions) are widely recognized in the official guides and other works. This is the content we attribute to the concept of level of risk for traffic conflicts (that we distinguish from the level of danger, a measure that also should weight the severity of the accident eventually generated in the events).

For vehicular conflicts, the ratio *R* of accident to conflict, or million of conflicts, displayed by the U.S.FHWA guide is a clear example that was previously discussed as a parameter for refined diagnosis (weighting accident proneness) and for forecasting the expected frequency of accidents, by type of conflict in each type of intersection and level of traffic (signalized with medium and high traffic flow, and unsignalized, with low and medium traffic flow).

The Swedish TCT also determined accident to conflicts ratios (2, item 5.4 to 5.6), taking more general classes of conflicts and sites (signalized or unsignalized intersections, straight or turning movements, high or low speed sites, vehicles or unprotected road users).

The French TCT proposed a risk matrix based on the subjective evaluation of experts to evaluate the accident proneness in three levels (null/small, medium and high), with weights

differentiated by type of conflicts in signalized or unsignalized intersections and also considering conflicts with pedestrians and motorcycles (3, p.28-30).

Some studies evaluated the relationship between accidents and conflicts using other tools (e.g. 17, 19, and also 24). Nevertheless, the clear meaning of the ratio variables favors their use as a measure of risk, leaving only the questions on the variability of these parameters for analysis, given a classification of conflicts and sites, that sets the level of detail needed to reach useful ratios. There is no opposition, also, between the risk levels defined in the French guide and the ratio of accidents to conflicts as the former is used as a clear proxy for the later.

The same judgments can be extended to the study of the risk involved in pedestrian-vehicle conflicts but the calibration is more difficult as data available is scarce. The generic accident to conflict ratios developed by the Swedish guide (2, p.71; see also 23 in which ratios vary by severity level) are the available information. Table 1 has a sample of ratios that will be used for comparison with our empiric estimates, reported ahead. The risk levels attached to pedestrian-vehicle conflicts in the French guide are the other relevant but coarse data.

<Insert Table 1>

The scarcity is noticeable as the classification (or segmentation) problem has the drawback of requiring the availability of large samples for significant statistical results, with good conflict and accident data (what is even worse when dealing with pedestrian-vehicle conflicts and accidents). So, it seems unavoidable that knowledge in this subject should progress through a series of individual studies, devoted to specific samples.

#### **2.4. Typology of Pedestrian-Vehicle Conflicts**

There is no general agreement on the more convenient typology of pedestrian-vehicle conflicts, but there is a clear trend to simplified categories based on the type of movements for each user (as in the typology of vehicle conflicts). A fundamental reason behind this option is the desire of adopting a typology similar to that conventionally used for accidents.

Both official guides that treat this question (3, 5) recommend 4 types of pedestrian-vehicle conflicts similar to vehicle conflict types. These can be combined in 5 types (the U.S.FHWA separates the conflicts with straight vehicles based on their position before or after the intersection, while the French guide aggregate them but includes a category of conflicts with pedestrians and vehicles in parallel movements). The British guide does not deal with pedestrian-vehicle conflicts and the Swedish guide does not recommend a standard typology.

Former studies (e.g. 11, 12, 15) distinguished several types of events based on the way the pedestrian approaches the road, on the vehicle movements involved and on the type of traffic violation observed (13, 12 and 12 types in 11, 12 and 15). More recent studies have kept a smaller level of detail. For example, Clark *et al.* (18, p.41) used 5 types, classified based on type of evasive action (that would be difficult to use in a disaggregate analysis, despite being elucidative in the study). Some studies even treated conflicts aggregately. However, the difficulties faced in the studies using aggregate data (particularly for relating conflicts and accidents as in 24 and 25) is an evidence on the importance of using an adequate typology.



Our previous research (22) used 8 types of pedestrian-vehicle conflict based on the U.S.FHWA typology but distinguishing the pedestrian direction of flow relative to the vehicle, as shown in Figure 1, and recording conflicts by pedestrian crossing instead of vehicle approach (2 other types would be added based on the French guide). Nevertheless, our studies were unable to demonstrate the relevance of the added detail (direction of pedestrian flow). Our study also shows the difficulty involved in using the same typology as for accidents, giving the lack of clear information in police accident records for recovering the exact crossing location and pedestrian/vehicle movements.

<Insert Figure 1>

As the pool of evidences is again scarce, we feel that additional study should be devoted to this question. The use of similar typologies for conflicts and accidents is a practical advantage and the need of more detailed classes is a research theme. We keep on using the 4 classes typology based on the U.S.FHWA guide (as the parallel movements conflict is rarely observed and identified in intersections). However, from our experience, the annotation of details on the events is recommended, also as a way for studying and developing alternative typologies. The use of the Swedish record sheet (see 21, 23) or the annotation procedure of recording one conflict in each line of sheet suggested by Hummer (26) for the U.S.TCT (and appending relevant comments on the events), both would favor this task.

## **2.5. Typology of Pedestrian Crossings in Signalized Intersections**

The U.S.FHWA guide suggests the use of the overall intersection, instead of each approach as the unit of analysis in the study of vehicle conflicts, at least for the refined diagnosis. One can question this option for the study of vehicular conflicts and, even more, for the study of pedestrian-vehicle conflicts. Of course, using more detailed data could bring a higher coefficient of variance and then would request more hours of observation to reach similar statistical quality. Nevertheless, the aggregate unit can lose significant detail and would multiply the number of possible types of sites, perhaps reaching a prohibitive level when considering pedestrians. So, we will treat crossings individually.

With its unit of analysis for the refined diagnosis, the U.S.FHWA had suggestions of parameters for four types of intersections: high and medium flow signalized intersections and medium and low flow unsignalized intersections, all cases considered for four leg junctions of two way approaches (some other studies analyzed three leg junctions). At the technician risk, one can apply the provided parameters for intersections with peculiar features (some one-way approaches or other distinctive feature) with added care in the analysis of results (as in the successful real case that was commented on the introduction of this paper). The other guides had no suggestion for typology of sites (noting that the French guide differentiated signalized and unsignalized intersections in the risk matrix and the Swedish guide further segmented low and high speed unsignalized intersection when studying accident to conflicts ratios).

Official guides have no specific recommendation for the analysis of pedestrian-vehicle conflicts, at the intersection or crossing level. Among former studies, Cinecky (12, p.12-13) made an exploratory discussion of relevant features, taking a large number of variables. Among more recent studies, Garder (16, p.440) selected a typology similar to the one used by Hydén (2), with three classes: signalized intersections, low speed or high speed unsignalized

intersections (the effect of several other variables were also studied). Studies about accidents (e.g. 27, 28) also showed a similar pattern of classes and variables.

Because the typology of sites will be used for establishing diagnostic parameters (and determine the level of effort needed for collecting field data), the segmentation should be revealing and parsimonious, at the same time. Nevertheless, we were not able to find any conceptual discussion of the criteria for classifying sites and adopted the distinction between essential features (that change the way road users interact) and residual features (that vary the level of safety in the interaction), on the hypothesis that the first group of features always must be distinguished in the classification analysis.

Admitting also that the crossing is a better unit of diagnosis, our previous research on signalized intersections with medians (22) segmented pedestrian crossing in two main groups: near or stop line crossings and far or free crossings. Of course, crossings of two-way approaches without median and crossings of unsignalized intersections are other similar types.

Criteria for further segmenting pedestrian crossings, even for signalized intersections with medians, are not evident. Ranges of flow or speed are natural criteria (as suggested by other studies or other settings). The existence of vehicle turning movements and red-running pedestrian crossings (that can be related to the availability of gaps on the vehicle stream) also should be studied. Other factors, as the existence of pedestrian signal heads, of a painted or signed pedestrian crossing, the use of pedestrian refuges or displaced crossing lay-outs are less probable as essential candidates. The type of treatment for pedestrians in signal phases (as exclusive/protected or concurrent/permitted pedestrian phases) seems to be next candidate as essential feature but a larger sample will be required to develop finer crossing categories.

### **3. DIAGNOSTIC PARAMETERS FOR PEDESTRIAN-VEHICLE CONFLICTS IN THE SÃO PAULO STUDY**

The diagnostic parameters for pedestrian-vehicle conflicts were obtained based on the 1998 study carried-out in 26 pedestrian crossings of four critical signalized intersections of the City of São Paulo (22). Conflict counts were carried-out during two days of march, 1998, from 07:00 to 18:30 (actually, 16 and 17 of march, a Monday and a Tuesday). Data was gathered using 6 one hour counts in each day (and half hour rest periods, separated by one and a half hour for lunch just before or after mid-day), amounting to 312 hours of observation on all crossings. Both days had good weather (and dry pavement). Recorded counts were expanded to the standard period of each day, following U.S.FHWA recommendations (5).

Common features of all signalized intersections and their crossings are:

- high vehicle and pedestrian flows, with averages around 1.500 vehicles and 1.000 pedestrians per hour in each crossing; road markings (mainly painted crossings and stop lines) were in good conditions, where provided, but significant pedestrian movements were observed also in some unmarked crossings; the flows related to commercial activities and transit services is very important in the areas;
- carriageways have at least two lanes and are all one-way or divided (two-way roads have carriageways separated with raised medians); there are signal groups for vehicle

and pedestrians at all intersections but one (where pedestrian signal heads are missing); especial lanes and especial phases for turning vehicles are absent and left turn are locally forbidden and rerouted through loops using adjacent streets.

Additional information about the crossings and the gathered data can also be found in 29, where statistical methods for parameters determinations were discussed and reported.

### 3.1. Determination of Count Limits for Daily Conflicts

Count limits  $C$  were determined for several segmentations. In all cases, limits are for expanded counts in the standard period of eleven hours. The values were derived from the statistical distributions fitted to observed data for selected confidence levels that are used to set limits of normal (expanded) counts. In professional applications, crossings are elected for treatment if at least one of the conflict types has an expanded count from field data over the limit. The decisions depend on the segmentation because a count for a more aggregate type of conflict will evaluate only the “average” safety of the site and a count limit for a more aggregate type of crossing will display the abnormal level of the “mixed” crossing. Then, a more detailed segmentation is desirable as long as based on valid data and statistical criteria.

The main segmentation criterion for the type of crossing distinguishes TP (i.e. near or stop line crossings) and TA (far or free crossings) sites. Remembering that all the carriageways are one-way or divided, this is a fundamental classification based on pedestrian vehicle interaction. On TP crossings of signalized intersections, conflicts can only occur on traffic violations by pedestrians or vehicles and this possibility increases sharply when there are available gaps on vehicular flow. Then further segmentation was considered based on the level of saturation of the vehicle approach (TP-Sat or TP-NSat). On TA crossings, there are concurrent movements of pedestrian and vehicles even without violation and the conflicts can occur also in this situation. Then, segmentation based on the pedestrian flow was used because some crossings have very high pedestrian movements (TP-Ped or TP-Ped+, taking 900 ped/h as the threshold of high flow pedestrian crossings).

In the following, the basic terminology is: aggregate/disaggregate for pooled or distinct conflict types and complete/segmented for pooled or distinct crossing types.

We present results for the complete sample with aggregate and disaggregate analyses (by conflict type with 2, 4 and 8 types) and also for the TA/TP segmentation with aggregate and disaggregate analyses (by conflict type with 2 and 4 types). Both analyses are carried-out for three levels of confidence (75%, 90% and 95%). More refined segmentations, with TP-Sat/TP-NSat and TP-Ped/TP-Ped+ are also presented for illustrative purposes because, despite the small samples available in each cell, this data suggests the potential gain from further segmentation (and its effect on the need of a disaggregate analysis of conflict types).

Table 2 summarizes count limits based on the sample of crossings, taking several alternatives for segmentation of crossings and disaggregation of conflict types. Part 2a contains the basic data for the complete sample and the segmentation of crossings in two groups TA/TP, with 4 types (P/TP, P/TA, P/TD and P/TE), with 2 types (P/VA, with P/TP and T/TA, and P/VT, with P/TD and P/TE) or pooling all conflicts in an aggregate type. Part 2b contains preliminary

data on more detailed analysis with further segmentation (TA-Ped/TA-Ped+, TP-NSat/TP-Sat) or disaggregation (all the 8 conflict types of Figure 1).

<Insert Table 2>

The lower confidence level was introduced based on the observation that there is a significant gain on using them when higher accident savings are conjectured (i.e. requiring a higher statistical confidence runs against safety). Based on our data, the use of the 75% confidence level with the TA-TP segmentation and the classification with 4 conflict types is preferred and the use of the more detailed segmentation is promising, based on our results (29). The same pattern seems to be suggested by results from the more detailed disaggregation of conflict types but, in this case, the performance is not clearly always superior.

Our simulations have shown that the use of more stringent statistical criteria (as the 95% confidence level included in the U.S.FHWA guide) seems to be overly conservative on economic grounds, on behalf of safety benefits.

### **3.2. Determination of Ratios of Accidents per Million Conflicts.**

The problems in identifying movements of vehicles and pedestrians involved in traffic accidents commanded an aggregate analysis of the risk measure (the ratio of accidents per million conflicts). The following analysis is, then, limited to the comparison of the ratio on each crossing type (all, TA/TP, TA-Ped/TA-Ped+ and TP-NSat/TP-Sat). Only 13 accident records from the 29 registered pedestrian-vehicle accidents at the sites were recovered and used in the determination of the ratios (a general adjustment factor is used for the final ratios).

Table 3 summarizes the results on the ratio of accidents per million conflicts for each of the pedestrian crossing segments used in this study. One can clearly see that differences in the values of the ratio are relevant based on an engineering criteria but the statistical significance is reduced by the high variance of the estimates. Table 3 reports also the Average Absolute Error in Accident Prediction, against recovered accidents in each crossing. The prediction is based on the ratios for recovered accidents and the equivalent yearly conflict counts in the crossing from the field data (expanded for the standard periods of week days of a year).

<Insert Table 3>

The difference of the ratio of the risk measure of conflicts in TA and TP crossings is suggested to be highly relevant (one order of magnitude) and also statistically significant (at least based on the quasi-t statistic). At a smaller degree, the same meaning can be attributed to the difference between the risk measures of conflicts on TP-NSat and TP-Sat crossing and clearly point to the importance of diagnostic parameters for a proper analysis. Despite the high variance, only the segmentation of TA crossings based on pedestrian flows is discarded as non-relevant and non-significant. This conclusion can be attributed to the high level of pedestrian flow (900 ped/h) used as a threshold between classes. As our sample have a very small number of crossings with small pedestrian flows, our choice was constrained.

The low quality of our accident data has to be remembered. Missing data and unrecovered records should be added to the usual flaw of unreported accidents. The remaining Average

Absolute Error in Accident Prediction also is shown to be relevant, despite being reduced almost generally with each additional level of segmentation. Anyway, one should note the comparable magnitude of our results to the ratios previously reported (see Table 1).

It is very important to stress that traffic conflicts at TP crossings, especially at TP-NSat crossings, are very rare events and could easily be outside the scope of safety problems that can be firmly evaluated with TCT studies. Despite being more usable than accident data for the evaluation of countermeasures in a safety studies to be conducted shortly after their implementation, warranting the maintenance of the relevant site features, the limitations of TCT data have also to be clearly understood (as with rare conflicts). Complementary methods and data should be searched for analyzing less frequent events that appear between vehicles and pedestrians (as between vehicles). Road Safety Audits or Conflict Opportunity Measures could be more practical in the diagnostic of safety problems with this kind of events.

## 5. CONCLUSIONS

This research aimed at determining the diagnostic parameters for the analysis of pedestrian safety problems at signalized intersections based on the traffic conflict analysis technique (TCT), using the U.S.FHWA concepts for refined diagnosis. Before undertaking our work, we discussed specific criteria for observing and analyzing pedestrian-vehicle conflicts, trying to avoid the hidden supposition of a simple and direct analogy to vehicle conflicts, and discussing specific problems related to the typology of conflicts and crossings.

The main result obtained was the support to the segmentation of near or stop-line crossings (TP) and far or free crossings (TA). Given our sample of divided carriageway or one-way approaches, this is clearly sound and would suggest that other classes could be relevant in a larger sample (crossings on two-way approaches and unsignalized crossings at least). More detailed segmentations were preliminarily analyzed, and were able to reach useful results based on an internal validation, recommending further study based on the a larger dataset.

The results on the criteria for identifying abnormal conflict counts recommended the use of a 75% confidence level on the segmentation of TA/TP crossings and 4 conflict types (the same types used in the U.S.FHWA guide) and suggest that further benefits can be expected from more detailed parameters. Nevertheless, the study showed that the decision on the best criteria is highly sensitive to benefit and cost parameters and could limit the scope for detailing.

The results on the measure of risk (accident proneness) of different conflict types or of crossing types were constrained by the impossibility of identifying the precise vehicle and pedestrian movements involved in accidents. Only the aggregate analysis of accidents and conflicts at each crossing type was possible and, even so, suggested a relevant and significant difference between the ratio of accidents per million conflicts in TA and TP crossings. This result can be traced back to the fact that this segmentation also segregates pedestrian movements at stop lines (the more rare and risky movement) from other conflict types. The results from further segmentation also were promising.

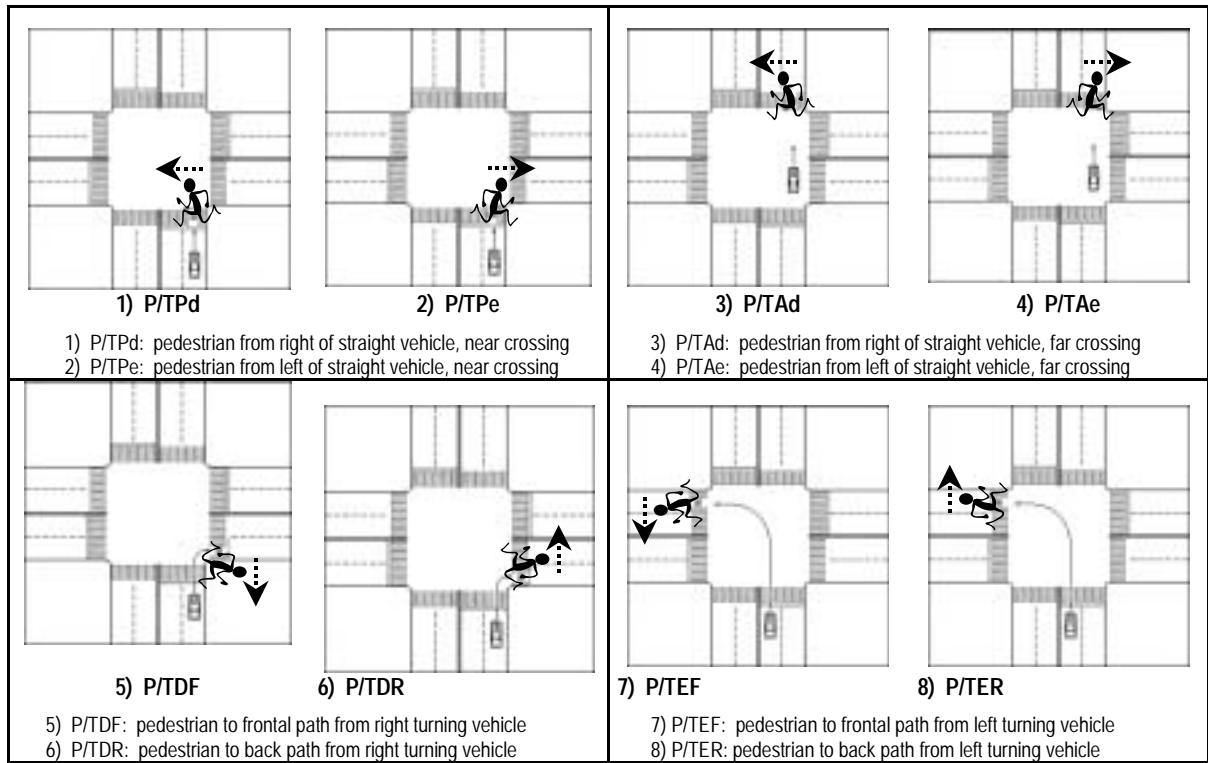
Despite the need of further improvements, at least the basic results seem to be preliminarily applicable to the diagnosis of vehicle-pedestrian conflicts on the type of crossings studied.

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**Figure 1 – Pedestrian-Vehicle Conflict Types in Intersection Crossings**



**Table 1 – Ratio of Accidents per Million Conflicts from Swedish Studies.**

	Sweden/98 – All Severe	Bolívia/94 – Low Severity	Bolívia/94 – High Severity
Car-Car “parallel”	28	10	60
Car-Car “right-angle”	119	40	200
Car-Unprotected Road User	339	200	700

Source: 21, 22, 23 (transformed to Accidents per Million Conflicts)

**Table 2 – Results on Normal Count Limits for Pedestrian-Vehicle Conflicts, São Paulo Study.**

**a. Basic Results on Normal Conflict Count Limits for 75%, 90% and 95% Confidence Levels**

Segmentation	All-Aggregate	All-2Types		TA/TP-Aggregate	TA/TP-2 Types		TA/TP-4Types			
Confl.Type	Aggregate	P/A	P/V	Aggregate	P/A	P/V	P/TP	P/TA	P/TD	P/TE
Cros.Type	All	All		TA	TA		All-TA			
75%	31.6	13.1	28.3	56.2	16.3	28.3	16.3	39.9	72.3	
90%	65.0	24.2	46.9	95.2	31.1	46.9	31.1	61.5	116.1	
95%	92.4	33.0	61.0	125.0	43.0	61.0	43.0	77.3	148.8	
Cros.Type				TP	TP		All-TP			
75%				10.1	10.1		10.1			
90%				15.9	15.9		15.9			
95%				20.2	20.2		20.2			

**b. Further Results on Normal Conflict Count Limits for 75%, 90% and 95% Confidence Levels**

Segmentation	Ped+/N/Sat-Aggregate	Ped+/N/Sat-2 Types		TA/TP-8Types							
Confl.Type	Aggregate	P/A	P/V	P/TPD	P/TPE	P/TAD	P/TAE	P/TDF	P/TDR	P/TEF	P/TER
Cros.Type	TA-Ped	TA-Ped		All-TA							
75%	34.8	15.6	29.8			7.7	7.9	20.8	19.1	37.3	34.9
90%	76.1	37.3	50.6			18.0	12.8	35.0	28.1	58.5	58.0
95%	110.9	56.3	66.5			27.0	16.4	45.8	34.6	74.1	75.5
Cros.Type	TA-Ped+	TA-Ped+									
75%	71.1	14.5	27.4								
90%	107.9	19.6	46.8								
95%	134.8	23.1	61.6								
Cros.Type	TP-NSat	TP-NSat		All-TP							
75%	12.1	13.2		4.8	5.4						
90%	17.8	18.4		8.4	9.6						
95%	21.9	22.1		11.1	12.9						
Cros.Type	TP-Sat	TP-Sat									
75%	5.0	5.0									
90%	9.9	9.9									
95%	13.9	13.9									

**Table 3 – Results on the Ratio of Pedestrians Accidents to Million Conflicts, São Paulo Study.**

**a. Basic Results on the Ratio of Accident to Million Conflicts and Yearly Accidents to Hourly Conflicts.**

	Number of Sites	Total Number of Accidents in Sites	Ratio of Accidents per Million of Conflicts	Standard Deviation of Ratio Estimate	Coefficient Variation of Ratio Estimate	Adjusted Ratio, for all accidents at the sites *	Average Absolute Error in Prediction
Aggregate-All	26	13	35.04	12.75	36.38%	78.16	0.67
Aggregate-TA	13	5.5	17.51	8.00	45.70%	39.05	0.47
Aggregate-TP	13	7.5	131.92	51.03	38.68%	294.29	0.61

\* The adjusted ratio is the final parameter for practical purposes as it includes a general correction factor (actually  $29/13=2.23$ ), for the partial set of accident reports recovered and used in the analysis.

**b. Further Results on the Ratio of Accident to Million Conflicts and Yearly Accidents to Hourly Conflicts.**

	Number of Sites	Total Number of Accidents in Sites	Ratio of Accidents per Million of Conflicts	Standard Deviation of Ratio Estimate	Coefficient Variation of Ratio Estimate	Adjusted Ratio, for all accidents at the sites*	Average Absolute Error in Prediction
Aggregate-TA-Ped	6	2.5	25.69	26.97	104.98%	57.31	0.67
Aggregate-TA-Ped+	7	3	13.83	6.99	50.54%	30.86	0.32
Aggregate-TP-NSat	9	4.5	93.81	43.88	46.77%	209.26	0.52
Aggregate-TP-Sat	4	3	337.87	142.41	42.15%	753.71	0.43

\* The adjusted ratio is the final parameter for practical purposes as it includes a general correction factor (actually  $29/13=2.23$ ), for the partial set of accident reports recovered and used in the analysis.