

SAFER AT GRADE INTERSECTIONS ON BRAZILIAN RURAL ROADS FOR HEAVY TRUCK TRAFFIC

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ABSTRACT

The paper presents a method to compare alternative design concepts of at grade rural road intersection layouts, considering the increasing traffic of long and heavy combination vehicles on Brazilian two lane highways. The basic concept used on Brazilian two lane rural road intersections is a roundabout of 20m internal radius, diametrically crossed by the main roadway, without speed reduction devices. As legal speed limits on these roads vary from 80 to 110 km/h and the number of accidents with fatalities is high, alternative concepts are investigated, including: a standard roundabout with a 40m internal radius; a roundabout with diametric crossing, an enlarged 40m radius and controlled speed limit of 60 km/h; an elongated roundabout, 40m wide and 240m long, with controlled speed limit of 60 km/h; and an elongated crossing with traffic flow split and traffic canalization, similar in concept to layouts used in the USA and Canada. The evaluation of potential traffic conflicts of each conception is based on an innovative equivalent conflict concept, described in the paper. Total processing capacity is evaluated using the Integration simulation software. A construction cost table is also presented to compare the relative investment costs of the alternatives. The performance comparison of the various intersection configurations, considering a traffic composition with a high percentage of trucks - 45%, being, 20% of unit trucks, 15% of semitrailers and 10% of long combination vehicles, leads to the conclusion that, for the evaluated operational conditions, the widely used configuration of a roundabout diametrically crossed by the main roadway has an inferior performance than the standard roundabout and the elongated roundabout. As the method permits parametrization, it can be used to evaluate different operational conditions or geometries used in other countries.

INTRODUCTION

In the year 2000, 6.543 deaths in 110.387 accidents were reported on controlled federal roads (DNER, 2000). The numbers show, not only a large number of accidents, but a large number of high severity accidents, as the number of fatalities indicates.

The Brazilian intercity road network has a total length of 1.720.000 km of which only 164.000 are paved roads (DNER, 2002a). The majority of these paved rural roads, more than 95%, are two lane roads with at grade intersections. On two lane rural roads, intersections, bridges and horizontal curves, account for a large number of accidents (Brinkman And Smith 1984 apud TRB 1987), a statement that, together with subjective reasoning based on observations as a road user, served as the major motivation for the investigation.

The main hypothesis underlying the investigation is that, the layout of the roundabout diametrically crossed by the main roadway has an important contribution to severe accidents and deaths due to the large speed difference between the main and secondary road traffic flow, and the fact that, at left turns and at crossings, the crossing driver is forced to pay attention to both traffic flow streams at the crossing maneuver. As the crossing of trucks demands larger crossing times (Demarchi et al, 1994), the systematic traffic increase of heavy trucks, semitrailers and truck+trailer units, and of extra-heavy trucks, road trains and B-trains of up to 30m length and 74t GVW, leads to the natural concern that the safety problem will be aggravated.

The choice among alternative configurations is complex because many factors intervene in the decision process, like: physical, vehicle, traffic, economic and human factors (Alberta Infrastructure, 1999).

The method proposed in this paper to compare at grade rural road intersection layouts is based on three measures of performance: total processing capacity, number of equivalent traffic conflicts and construction costs, for an intersection where the percentage of truck traffic is rather large-45%, being, 20% of unit trucks of 23t GVW, 15% of semitrailers/ truck+trailer of 45t GVW and 10% of long combination vehicles of 74t GVW.

Three variations of the roundabout with diametric crossing – “trevo vazado”, and three alternative configurations described in detail in the next section, chosen with the purpose to create layouts which, in theory, could improve driver response, reduce the differential in traffic speed and, consequently, reduce the severity of accidents, were studied.

INVESTIGATED INTERSECTIONS

The investigated intersections are presented on Table 1.

Table 1. Investigated intersections.

NAME	DESCRIPTIONS
ROTATORIA	Roundabout
TREVOSIM60	Simple “trevo vazado” intersection with speed of 60 km/h
TREVOSIM80	Simple “trevo vazado” intersection with speed of 80 km/h
TREVOACEL	“Trevo vazado” intersection with acceleration and disacceleration lanes
INTDIVENTRE	Elongated roundabout or intersection with traffic flow split and weaving
INTDIVCANAL	Intersection with traffic flow split and traffic canalization

The configurations are shown on Figures 1 to 5.

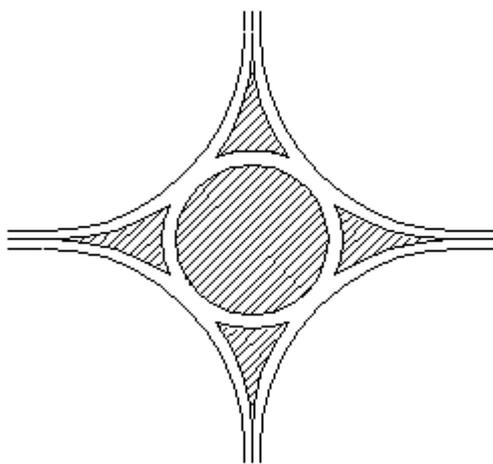


Figure 1. Roundabout.

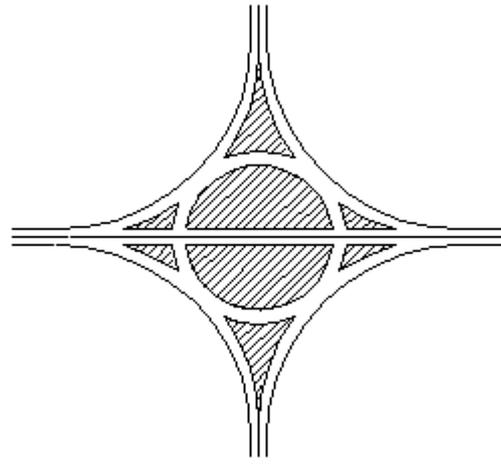


Figure 2. Simple “trevo vazado” intersection.

The variations of the “trevo vazado” concept in this study aim to evaluate their performances when acceleration and disacceleration lanes exist and speed reductions from 80 to 60 km/h on the main road are enforced.

The ROTATORIA, INTDIVENTRE and INTDIVCANAL intersection configurations were based on intersection layouts found in the international literature like Robinson et al (2000), TAC (1986), AASHTO (1994) and Alberta Infrastructure (1999). The INTDIVENTRE works like an elongated roundabout and all secondary road accesses are protected by traffic islands. The INTDIVCANAL is a design that includes three principles: flow split by traffic island, exclusive left turn lane on the main road and crossing in two stages.

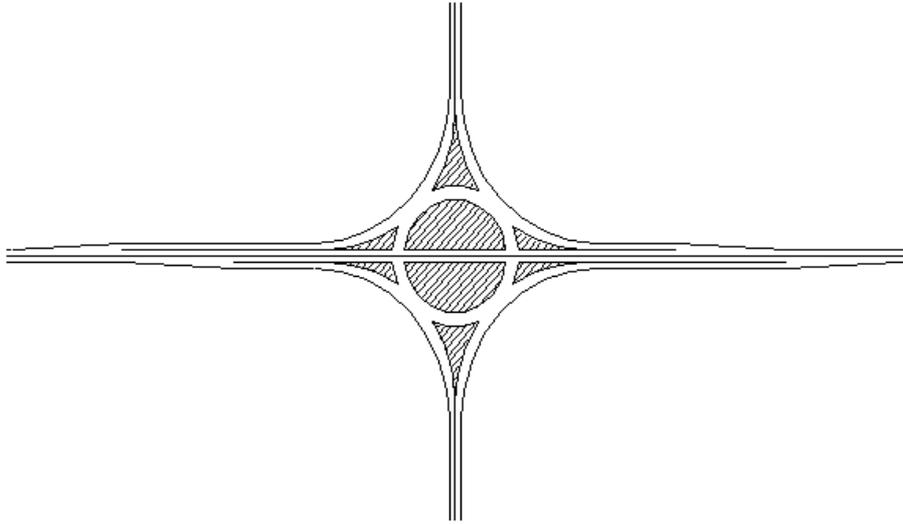


Figure 3. “Trevo vazado” intersection with acceleration and deceleration lanes.

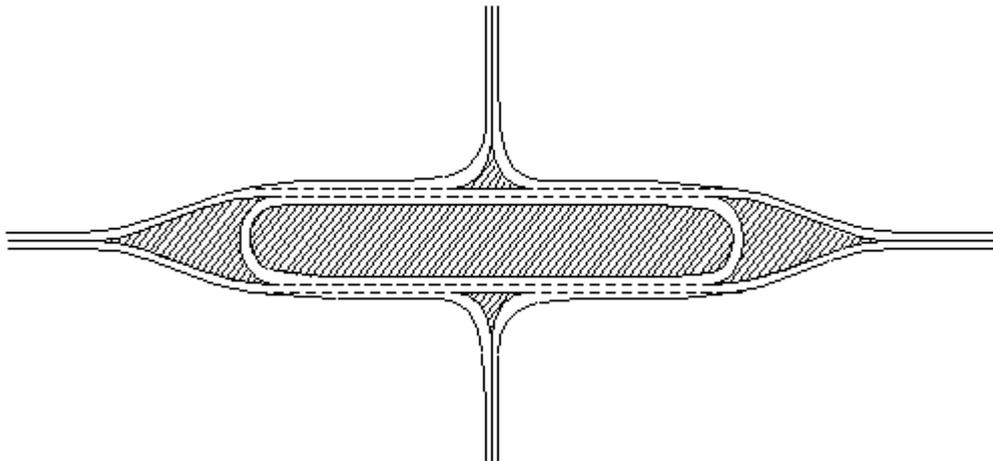


Figure 4. Elongated roundabout.

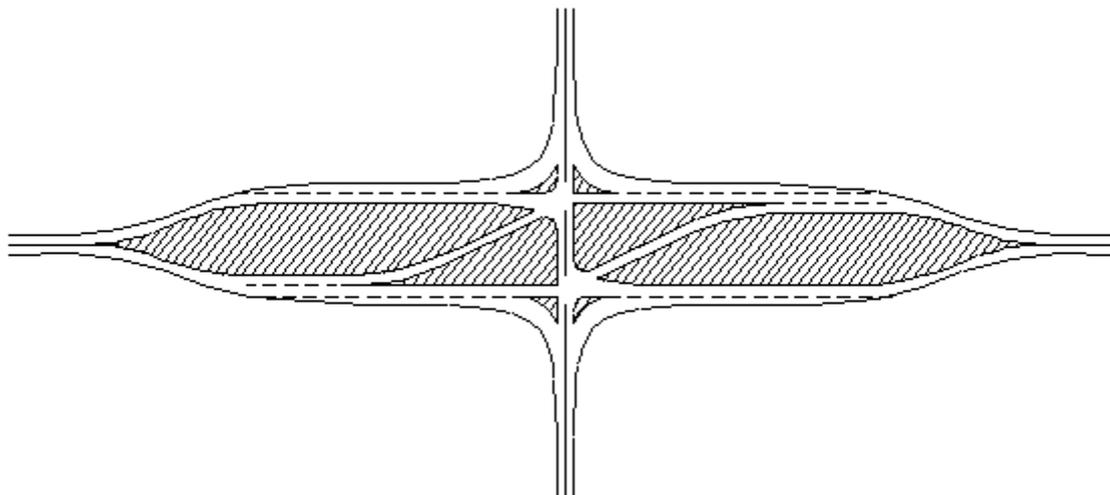


Figure 5. Intersection with traffic flow split and traffic canalisation.

METHOD

The basic idea is to indicate, for a particular modeling condition, the intersection that has a large safety factor at comparable capacity levels and compatible construction costs when compared to the other alternatives.

Total processing capacity method

The total processing capacity of a road intersection, as proposed in this paper, is a performance measure that, opposed to conventional capacity methods TRB (2000), is able to compare different types of layouts, operations and traffic controls.

This measure is defined as the traffic volume sum of the main and secondary road approaches and corresponds to the total flow of processed vehicles through the intersection, that is to say, the volume of vehicles which left their origin nodes and completed the whole journey to their destination nodes in one hour of traffic flow simulation using the Integration (Van Aerde, 2000 a/b) simulation program for a particular modeling situation.

The calculation method is an empirical method, that uses basically: an observation on the computer screen of queues building up upstream of the system entrance nodes, an informative screen window of the simulator presenting information on deferred events and a sequence of result notes to feed the calculation algorithm.

The principle of the algorithm is to increase gradually the simulated traffic volume with a constant amount of traffic flow in each one hour simulation process until some stopping condition of the algorithm is attained.

An increase in the flow of the main approach of the primary road (VR) generates increases in all the other flows that compose the simulated volume in a demand table of every O/D pair on the intersection. The value of VR is also used as the pivot of the algorithm.

The stopping conditions are:

- the queues on the feeder links of the secondary roads have to be zero, indicating that vehicles coming from the secondary roads have had an opportunity to go into the intersection area without delay.
- the number of deferred vehicles at the end of the simulation period has to be zero, indicating that the main road traffic flow offers gaps that are large enough to permit secondary road vehicles to cross the main road;
- the difference between the standard flow (VR) at a stopping condition and the last iteration standard flow which had no restrictions must be smaller or equal than 10 vehicles per hour. This value was chosen empirically, assuming that it is small enough for the intended simulation precision.

Equivalent conflict method

This method was developed based on Alquist and Ekman (2001), Domingues Jr. (2001) and IPR (1976). Its aim is to quantify the total of low severity equivalent conflicts (TLSEC) for a certain traffic volume. This volume was selected as the smallest total processing capacity of each investigated configuration for a given traffic volume composition. The steps of the method are presented in the sequence.

Characterization of an intersections conflict points

An intersection is characterized through its layout, allowed turns and maximum allowed speeds in each traffic link. A conflict point is defined as any node on the network where crossing, merging or diverging occurs.

Characterization of conflicts at each conflict point

Conflicts are characterized by one of the following conditions:

- For a crossing maneuver, the secondary road vehicle can not get an expressive speed, so this speed is assumed equal to zero. The collision angle is assumed equal to 90° in most cases, with exception for one crossing in the INTDIVCANAL configuration, where an angle of 135° was assumed.
- For a merging maneuver, the closing angle between two conflicting vehicles is assumed equal to 45° ;
- For a diverging maneuver, there are two situations: first, in a back collision, closing angle is 0° degree; and second, in a side collision, closing angle is assumed equal to 10° .

Calculation of relative speeds and kinetic energies

Relative speed is the closing speed between two conflicting vehicles and is the vectorial sum of the speed vectors.

As the kinetic energy is transformed in friction and deformation in any crash between vehicles, it is assumed to be representative of the level of severity of a potential collision. The kinetic energies were calculated for each identifiable conflict, considering a simplification hypothesis that all vehicle have equal masses. The mass was assumed equal to 1.

Conflict classification and severity level factor

The severity of a conflict was classified into three categories: low, medium and high. The classification of a conflict is based on three limits of severity level, which are calculated through the difference between the smallest and the largest kinetic energy (D) divided into three classes of equal amplitude. Table 3 presents the structure of the calculating table.

Table 3. Limits of severity level.

Severity Level	Kinetic energy (E) limits	
	Lower	Higher
Low	E_{smallest}	$E_{\text{smallest}} + D/3$
Medium	$E_{\text{smallest}} + D/3$	$E_{\text{smallest}} + (2/3)*D$
High	$E_{\text{smallest}} + (2/3)*D$	E_{biggest}

The severity level factor is a normalization factor calculated in the following form: the arithmetic average kinetic energies of conflicts classified in each severity level class are divided by the arithmetic average kinetic energy of the low severity level class.

Calculation of total low severity equivalent conflicts (TLSEC)

The TLSEC calculating algorithm has the following steps:

- Identify traffic volumes of each maneuver for each approach;
- Identify conflict points for each maneuver on the network of each intersection configuration;
- Classify the severity level of each conflict point;
- Identify number of conflict points of a given severity level for each maneuver in each approach;
- Calculate total number of conflicts in each severity level class for each approach, summing the products of the number of conflict points by the traffic volume of each maneuver;
- Convert all conflicts into low severity equivalent conflicts, multiplying the total of conflicts of each severity level by its respective severity factor;
- Sum up the total of low severity equivalent conflicts for each approach;
- Sum up the total low severity equivalent conflicts (TLSEC) for all approaches.

Construction cost method

The construction cost is based on current rural road construction service tables used by national and state road administrations, like DNER (2002b) and DER-SP (2002).

The construction cost is calculated by a standard budget method including paving, earth-moving and drainage costs (Xerez, 2002). The method was developed based on Pedrozo et al. (2001) and the national road construction manual DNER (1999).

Traffic volume split and simulation parameters

The following traffic volume splits on the secondary approaches (VS) are used: 10%, 20%, 30%, 40% and 50% of the main approach (VP).

The basic parameters are:

- Flat topography;
- Respect for speed limits;
- Traffic composition: 50% of passenger cars; 5% of buses; and 45% of trucks, being, 20% of unit trucks, 15% of semitrailers and 10% of long combination vehicles;
- Percentage of right and left turn, 10% and 15% respectively;
- Free-flow speed is maximum allowed speed;
- Congestion density is 140 vehicles per kilometer on any link (DEMARCHI, 2000);
- Vehicle parameters used in the Integration simulator as proposed by PIERIN and DEMARCHI (2001) and DEMARCHI (2000) for brazilian operating conditions;

RESULTS

Total processing capacity

As shown on Figure 7, almost all intersection layouts have the same total capacity level for traffic flow percentages on the secondary road of 10%, 20% and 30% of the traffic flow on the primary road, except the ROTATORIA, whose capacity is a little bit smaller.

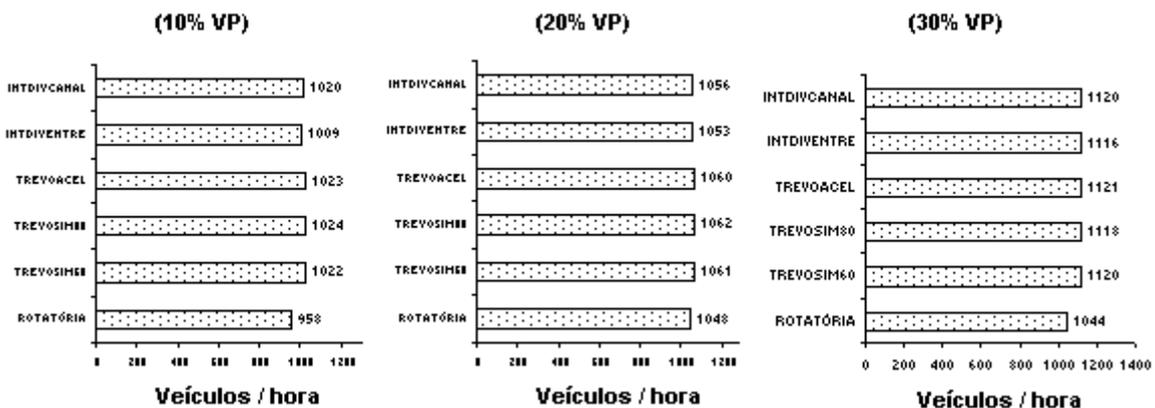


Figure 7. Total processing capacities for VS = 10%, 20% e 30% of VP.

For percentages of 40% and 50% on the secondary road, the INTDIVENTRE and ROTATORIA offer the best results in the group of intersections. The INTDIVCANAL layout has a similar performance as TREVO intersections up to 40%, a situation that changes for 50% as shown on Figure 8.

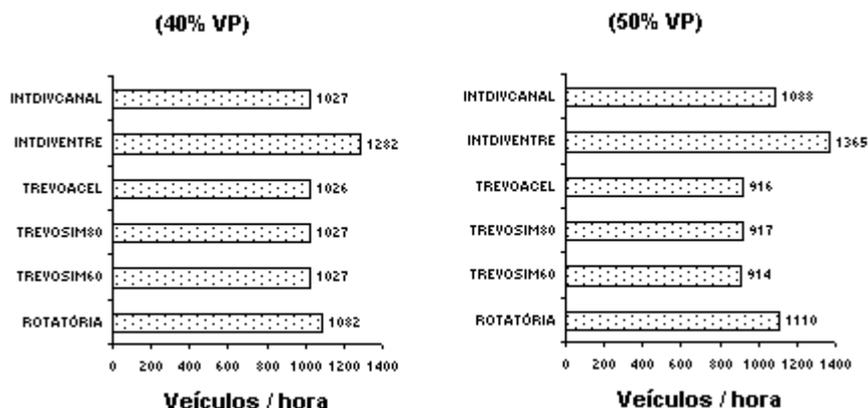


Figure 8. Total processing capacities for VS = 40% and 50% of VP.

Total low severity equivalent conflicts – TLSEC (TCEBS in portuguese)

Figure 9 shows that the ROTATORIA, INTDIVENTRE and TREVOSIM60 layouts are relatively safer than the INTDIVCANAL, TREVOACEL and TREVOSIM80 layouts in all cases. It also shows that the best options, from the safety point of view, are the ROTATORIA and INTDIVENTRE layouts.

Construction costs

According to Figure 10, construction costs of ROTATORIA, TREVOSIM60 and TREVOSIM80 are of the same order of magnitude. Another interesting result is that the higher construction cost of the TREVOACEL layout, with acceleration and disacceleration lanes, does not bring any gain in terms of total capacity or security for the simulated traffic conditions, where right and left turns are a relatively small percentage.

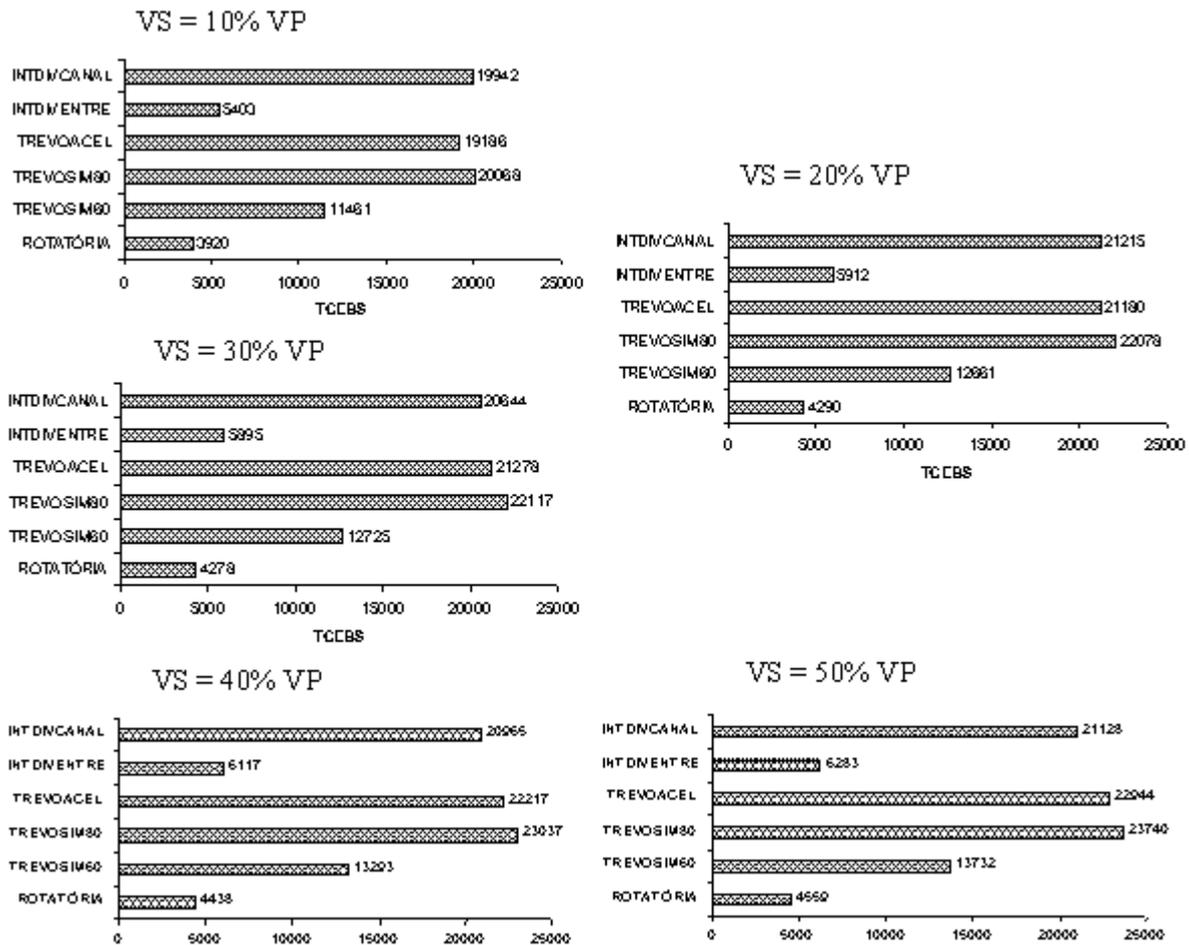


Figure 9. Total of low severity equivalent conflicts.

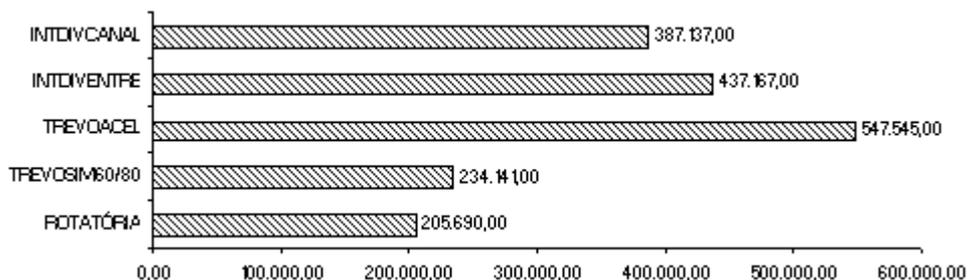


Figure 10. Construction costs.

CONCLUSIONS

For the simulated conditions the standard roundabout - ROTATORIA layout has the best overall performance, with the smallest TLSEC and smallest construction cost. The INTDIVENTRE can be considered the second best option as its TLSEC is close to the roundabout and its capacities are similar or higher than the other intersection layouts. Its good performance may justify its higher cost where capacity is a main factor. The results for the roundabout with diametric crossing and 60 km/h enforced speed limit -

TREVOSIM60 show that speed control on the main road would improve the safety factor significantly. However, its TLSEC is still relatively high when compared to the roundabout.

The proposed method offers a relatively simple and innovative way to establish a performance rank of intersection layouts for a particular modeling condition and to indicate alternative ways to design at grade intersections that have a better safety performance than the presently used on the Brazilian road network.

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