The variability of Level Of Service and Surrogate Safety Assessment of urban turbo-roundabout with BRT system

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***Abstract*—A surrogate safety analysis is showed on this paper linked to urban traffic flow of an unconventional turbo roundabout through the use of the SSAM tool. Six scenarios are implemented evaluating flow and capacity ratio and the possibility of congested and uncongested conditions. Mix of traffic vehicles is implemented by integration of a percentage of bus rapid transit line (BRT), considered nowadays an efficient local public transport system that can minimise the use of the private vehicle compared to the greater environmental protection.**

The results of the various scenarios show that such implementation can provide benefits both from the point of view of safety in terms of LOS and surrogate values such as TTC and PET.

Keywords—road safety; micro-simulation; turbo roundabout, bus rapid transit, TTC and PET

I. INTRODUCTION

Congestion is a growing problem that produces unpredictable time delay, air pollution, safety, etc. upon residents as well as business owners. For businesses, market areas might shrink due to the unpredictable and/or increased travel time resulting in added costs and inefficiency. In general, the time lost in travel delays can prove to be costly to the economic growth of the country. The impacts of growing congestion and the limitations of the conventional approach to reduce congestion created a pressing need for innovative congestion management approaches.

Historically, the quantitative assessment of road safety has required the occurrence of crashes to formulate engineering countermeasures and for the development of predictive statistical models. In the same sense, qualitative methods have been developed based on perception of road safety, whose subjectivity can be seen reflected in the evaluation itself. In this situation, the Swedish Traffic Conflict Technique [1] and its surrogate measures has overcome to some extent the above limitations, under a preventive approach. This research focuses on the multivariate analysis of surrogate measures for road safety comparison of six scenarios of mix of traffic on urban turbo-roundabout. The traffic flow of turbo-roundabout generally run separately even before the entry into the roundabout, they occupy separate lanes all the way throughout the roundabout, whereas traffic flows go forward separately also at the exit from the roundabout [2]. Physical separation of traffic lanes is interrupted only at the entry into the inner circulatory carriageway. Physical separation is achieved by specially shaped elements – delineators, which hinder (but not prevent) the change of traffic lanes in the roundabout – weaving conflicts. The central island of turbo roundabout is designed by means arcs of circumferences with different centers and radius. The design of turbo-roundabout is linked to a reduction of conflicting points related to different type of manoeuvres [3.]

The presence of collective transport systems allows one side to transcend a large number of users with a private car and on the other side drastically reduces the value of collisions, especially if there are preferential lanes. The assessment of road safety can be achieved by means of multivariate analysis of traffic conflicts and surrogate measures; It is possible also to recognize the best alternative solution considering the impacts of congested and uncongested operations..

The introduction of collective transport systems, such as Bus Rapid Transit (BRT) within the mix of traffic often allows to decrease the congestion and pollution phenomena as the number of circulating private cars.

At this moment BRT systems around the world are considered very efficient in all cost, engineering and environmental prospective. In particular BRT systems are bringing out more equitable allocation of road space among the road users rather the vehicles on the road. With the rapid increase in the automobiles leading to traffic congestion, urban sprawl, air pollution and other such ill effects there is an immediate need for improving the transportation systems around the urban cities in the world [4] .

The aim of the development of these transport systems is to bring the quality of service to rail-based approach (rail or light rail transport), but maintaining the lower costs of bus-based systems. These systems can have a wide variety of solutions, such as a separation from the roadside (ensuring optimal service such as a tram or subway), or use preferential lanes, dedicated corridors or high-occupancy lanes (HOV lanes, High Occupancy lanes) with their own road markings, or like itineraries shared with other vehicles. A marginal benefit of this feature is the lower construction costs for the lanes, which may be smaller than the standards while remaining safe. As is well known, travel times are closely related to the average commercial speed of the system. The analysis of applied systems showed that these operate at an average speed of about 30 km / h, and only, in special cases, can be reached higher speeds that can make a quick connection, as implicitly the name implies. Often too high transport demand leads to overcrowding of stations both in terms of people and vehicles, mainly due to the inappropriate frequency of the service because if the frequency is too high, it can lead to problems due to physical interaction between the vehicles which are stationary; in fact, platforms not very wide in length would allow one or two vehicles to stop and, therefore, in order to reach the goal to ensure high frequency service that could meet a high demand for transport, it is possible to make the mistake of do not consider the physical space needed for all vehicles near all the stations. This would inevitably lead to a propagation of queues in close proximity to particular bus stops, hence an increase in stop time and, consequently, lower real capacity. Even too much lower demand levels than the maximum available capacity can create system problems. In addition to capacity, the BRTs also emerge for their costs because construction and operation costs are much lower than light rail systems. The roundabout intersections with a turbo scheme (turbo roundabouts) are characterized by the physical separation between lanes, both at entries and on the ring. Given the positive effect on the moderate running speeds and the potential improvement of safety conditions, they are appropriate to be implemented above all in urban contexts. In these areas, the simultaneous presence of vehicles and pedestrians requires an accurate evaluation of the operational conditions of intersections, considering that pedestrian flows (often with quite a significant intensity) are generally given priority over vehicle flows [5,6].

Since its inception in 1965, the Level-of-Service (LOS) has proved to be an important and practical “quality of service” indicator for transportation facilities around the world, widely used in the transportation and planning fields. The LOS rates these facilities’ traffic operating conditions through the following delay-based indicators (ordered from best to worst conditions): A, B, C, D, E and F. This LOS rating has its foundation on quantifiable measures of effectiveness and on road users’ perceptions; altogether, these measures define a LOS based on acceptable traffic operating conditions for the road user, implying that traffic safety is inherent to this definition. However, since 1994 safety has been excluded from the LOS definition since it cannot be quantified nor explicitly defined. According to [7],Level of Service of Safety (LOSS), is defined like an indicator that qualitatively assigns a degree (i.e. magnitude) of safe or unsafe roadway facilities. The LOSS concept is built within the framework of Safety Performance Functions (SPFs) (i.e. crash prediction models relating safety with traffic exposure) and problem diagnostics (i.e. the issue of diagnosing the cause of any safety problem). The focus of this research is establish the LOS for different traffic scenarios and at the same time investigate the surrogate safety measures that has been of great interest to the transportation engineering community in recent times. Transportation Agencies generally consider the use surrogate safety measures derived from microscopic simulation models for several reasons. In fact Surrogate safety measures can be used to predict the level of safety of a facility which is under design or where the actual crash activity is low or crash data is unavailable. According to[8] the relative rarity of crashes on a roadway segment makes surrogate safety measures desirable as a predictor of roadway safety. In order to obtain a more realistic model of driver behaviour, developed a method for introducing driver error and inattentiveness to a model to produce a “less than perfect driver”. Their point of view is that microscopic simulation models are capable of modelling and evaluating surrogate safety measures, but only if the model can be calibrated to accurately portray realistic driver behaviour

II. Road geometrical comparison with micro-simulation tools

A micro-simulation VISSIM model of a urban turbo-roundabout is calibrated successfully using the average values of different indicators compared with traffic details.

Once known the demand of the intersection, six scenarios is designed, simulated and calibrated under the micro-environment, for the same place and safety aspects. Vehicular trajectory files are obtained from calibrated simulation models, which are analysed by SSAM tool are linked to different type of traffic conflicts and their surrogate measures; this evaluation required a calibration process according to [9].

BRT system integrated in urban traffic flow of a traditional turbo roundabouts are implemented to reduce accident phenomenon, minimize the number of vehicles and increase simultaneously vehicle outflow capacity in accordance with [10].

In order to define the performance of the lane, the analysis should appropriately consider different parameters (i.e. roadway conditions, traffic conditions, driver behaviour especially lane change and lane operations).These conditions involve too many complex situations. Analysis with traditional / analytical tools would be difficult and moreover the accuracy of estimations also matters. On the other hand, the complex traffic behaviours can be easily considered in microscopic simulation models more precisely and realistically than the other methods. Micro-simulation models analyse individual vehicle/driver behaviour, although its accuracy and validity depend mainly on the quality of underlying driver behaviour models. The input data implemented on VISSIM software includes vehicular characteristics, traffic flow composition, desire speed distributions, vehicle flows and composition, and driving behaviour parameters namely car-following and lane change behaviour. The micro-simulation software tool VISSIM (Version 5.30) is used to simulate operations at analyzed at grade intersection . This software can be used to generate all types of outputs simultaneously (safety, traffic performance, and capacity, allowing a more complete and comprehensive picture of the combined effects in making comparisons of various roundabout design scenarios. The VISSIM output included vehicle trajectory files that were then imported into the Surrogate Safety Assessment Model—SSAM, a specific tool designed to perform analyses of vehicle trajectory data output from microscopic traffic simulation models to derive proximal measures such as conflicts, based on thresholds for either time to collision (TTC) or post encroachment time (PET). The estimated conflicts were then applied in crash-conflict models for roundabouts developed in other research to compare the roundabout designs on the basis of expected crashes. Traffic flow composition and in particular vehicle volume are given as an input from the classified traffic volume count data collected on the ground at different time intervals. The vehicle composition is also given as an input from the classified traffic volume count data to the model. In VISSIM, vehicles would be randomly generated as per the given volume and composition. Other output data is Desired Speed Distribution that include minimum speed, maximum speed and their distribution of each vehicle type. These values are given in the simulation as an input based on the observed speed data from the field.

The turbo roundabout geometry on Fig. 1 is relatively innovative arrangement of the two-lane roundabout that has revolutionised roundabout design in the Netherlands and in several European countries.The road intersection showed on Fig. 1is characterized by the main direction is titled A_C while the secondary direction is titled B-D. The research work has focused on the comparison of geometric diagrams with dedicated turning lane right along the directions A-D and C-D as best described below.

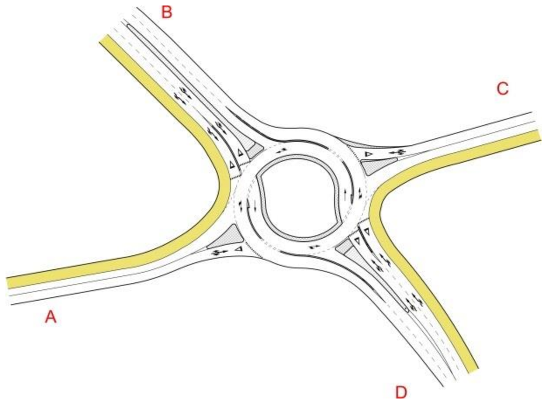


Fig. 1.*Geometrical scheme of turbo roundabout with or without dedicated lane (on yellow)*

The presence or absence of lanes for the right turn movement is investigated considering only direction corresponding to the A and C arms. These lanes are able to accommodate only specific types of vehicles as described below on Table 1.

TABLE I. ANALYZED SCENARIOS WITH OR WITHOUT DEDICATED LANE FOR BRT

SCENARIO	LANES	TRAFFIC MIX
1	presence of a preferential / dedicated turning lane on the right	BRT, taxi and police along the A arm
2	presence of a preferential / dedicated turning lane on the right	BUS, taxi and police along the direction of the Arm A and BRT flow with other traffic components on B-C-D arms
3	absence of preferential / dedicated lane	absence of preferential / dedicated lane and circulation of total traffic mix along the 4 arms and circulatory ring
6	absence of preferential / dedicated lane	absence of preferential / dedicated lane and circulation of total mix of traffic along the 4 arms and circulatory ring
4	presence of two symmetrical preferential turning lanes to the right	BUS, taxi and police along the direction of the A and C arm BRT flow with other traffic components
5	presence of two symmetrical preferential turning lanes to the right	BRT, taxi and police along the A and C arm

III. RESULTS

Different traffic scenarios are implemented through micro-simulation tools VISSIM. The first hypothesis has considered that the distances of the BRT stop is so far to not influence general flow on intersection. This analysis is addressed to understand what the best alternative could be of the use of TPL mobility type BRT integrated in road infrastructures with unconventional intersections of the turbo type. The array of investigated flows is characterised by a symmetric distribution of the flows linked to matrix Q1 with 15% of vehicles turn right, 70% cross, 15% turn left like described on table below.

TABLE II. TRAFFIC FLOW DISTRIBUTION IN TERMS OF O/D MATRIX

MATRIX Q1				
O/D	**A**	**B**	**C**	**D**
A	0	0,15	0,7	0,15
B	0,15	0	0,15	0,7
C	0,7	0,15	0	0,15
D	0,15	0,7	0,15	0

The mix of traffic considered will be chosen considering the percentages of vehicle categories described on table 3.

TABLE III. TRAFFIC COMPOSITION RELATED TO INVESTIGATED ROAD INTERSECTION

Type of vehicles	Percentage of mix traffic
2-wheel vehicles	20%
4-wheel light vehicles	40%
Heavy vehicles	10%
BUS	20%
BRT	1%
Special Vehicles	respectively 4% taxi and 5%police

Two different scenarios are implemented such as:

- not congested scenario with 2480veh / h, where the value is 80% of the maximum flow (3040 veh / h);
- congested scenario with 3040 veh / h.

Congested scenario could make the use of this unconventional intersection critical and thus generate congestion phenomenon and problems linked to road safety and acoustic-environmental impact.

Generally, bus-based transport networks are benefiting from the high flexibility of such systems in terms of infrastructure and management.

The flexibility of the bus as a means of transport allows the development of management programs with a fluid passage of lines from BRT infrastructures to normal road traffic.

In addition to reducing local emissions through BRT systems, global emissions must be taken into account when assessing the eco-compatibility of a means of transport. Preferential lanes and precedence over other road users provide a fluid driving style with fewer stops and lower fuel consumption. The evaluation of results considered an average population of 100,000 inhabitants with 20% of service users with a modulation of races from 07:00 to 20:00. The peak of traffic flow is evaluated to different scenarios. The data analysis used high frequency BRT of racing, equipped with hybrid eco-friendly motors and with a maximum capacity of 140 walking passes.

In terms of BRT transportation survey, 1 BRT every 10 minutes 6BRT / h is considered with stops at 1000m from the intersection investigated and a daily traffic demand for the BRT system of 10% compared to the total population. In terms of the average delay of the queues, the simulation results show an average maximum delay value for arm A in all scenarios. In terms of average speeds, the presence of preferential lanes for BRT does not indicate a reduction of values, especially on un saturated scenario while displaying a constant trend considering the case of congested flow. The passenger stops of the BRT system have been evaluated as not appropriately distant from the intersection examined in order not to compromise the acceleration and deceleration values of the vehicles. The graph below on Fig. 2 shows the increasing trend of total average speed comparing all scenarios related to uncongested traffic flow .Instead, a steady trend appears during the congested traffic scenario with or without referential lane.

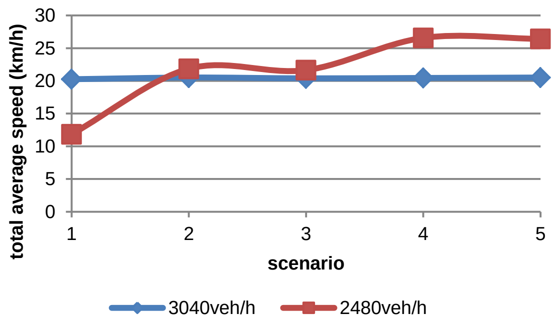


Fig. 2.*Total average speed trend for congested and uncongested traffic flow*

Total average delay is maximized with saturation flows, especially in scenario 3 / 6 without preferential lane. Constantly consistent returns are noted from the graph on the Fig. 3for both traffic scenarios with a proportionality factor of about 4 times greater.

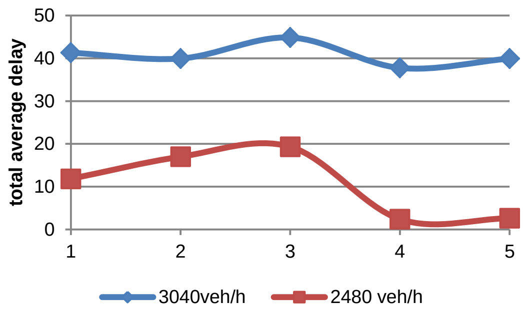


Fig. 3. *Total average delay trend for congested and uncongested traffic flow*

The lack of dedicated lanes and the mixing of traffic flow components maximize the negative effects of flow fluctuations and therefore more easily generate congestion of the intersection: in fact average speed and average delay contribute to the definition of the LOS service level infrastructure. On graph below is clear that the value of LOS is strongly related to LOS E and LOS F when turbo-roundabout is subjected to about 80% of the flow leading to saturation (3040veh / h) above all during all scenarios in the Be D arms (main direction). Considering, however, scenarios with 2480veh/h few congestion problems appears with LOS values corresponding to 1 value (corresponding to LOS A and B) during scenarios 4-5, and this is due to the separation of the flows of traffic and road geometry that guarantees this flow as in congestion-free flow.

Saturation values closer to the Be D (main direction) arms are best achieved during the scenarios 1-2 3/6.

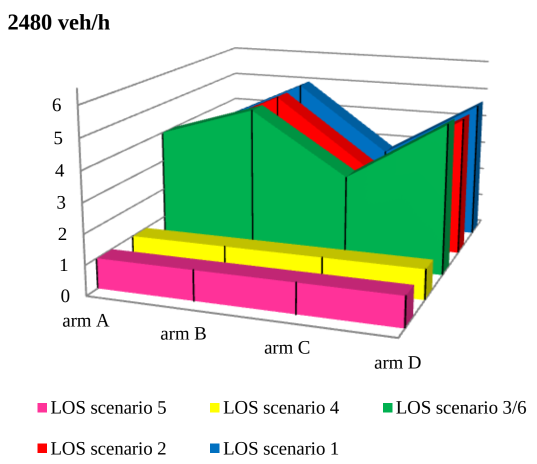


Fig. 4. *Level Of Service trend on uncongested scenarios related to traffic flow of 2480veh/h*

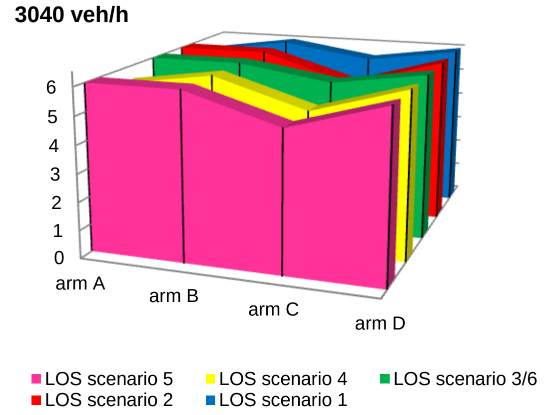


Fig. 5. *Level Of Service trend on congested scenarios related to traffic flow of 3040 veh / h*

In terms of surrogate safety, SSAM tool is calibrated on vehicle-to-vehicle interactions to identify conflict events and catalogues all events found.

For each such event, SSAM also calculates several surrogate safety measures, including the following:

- Minimum Time-To-Collision (TTC);
- Minimum Post-Encroachment Time (PET).

The simulation-based intersection conflicts data provided by SSAM are significantly correlated with the crash data collected in the field, with the exception of conflicts during path-crossing manoeuvres (e.g., left turns colliding with opposing through-traffic), which are under-represented in the simulation. Most of the SSAM output parameters are related to rear-end collisions. In particular considering rear-end collisions, TTC and PET are two efficient indicators in discriminating between critical and normal occasions [11,12,13]

According to[14] ,TTC and PET can convert distance between vehicles into time. However, the results obtained from these measures are sometimes inconsistent, hence making a decision would be difficult like described on TTC and PET. The relationship between TTC and PET has been defined on Table 4.

TABLE IV. CORRELATION BETWEEN TTC AND PET PARAMETERS

Relationship between parameters TTC and PET in car following scenarios according to Vogel 2003		
TTC	PET	
	small	large
small	danger imminent	impossible
large	potential danger	safe

In terms of car-following scenario, TTC value is proneness to describe an imminent danger, and PET increase a potential danger. In fact when TTC value is small, there is a high probability of rear-end collision unless a change in the vehicle course and speed occurs. On the other hand, when TTC value is large but PET is small, there is no risk of rear-end collision, but even a slight change in the motion characteristics may lead to a rear-end collision.

Therefore Traffic Conflicts Techniques, Time-To-Collision (TTC) has tested to be an effective measure for rating the severity of traffic conflicts and for discriminating critical from normal behaviour. The results of several studies point to the direct use of TTC like decision tool for traffic management .Traffic Conflicts Techniques, Time-To-Collision (TTC) has proven to be an effective measure for rating the severity of conflicts.

Hayward [15] defined TTC as: "The time required for two vehicles to collide if they continue at their present speed and on the same path”. The minimum TTC as reached during the approach of two vehicles on a collision course (TTCmin) is taken as an indicator for the severity of an encounter. In principle, the lower the TTCmin, the higher the risk of a collision has been. TTCmin indicates how imminent an actual collision has been.

Details of the calculation of TTC can be found in Van der Horst [16].TTC parameter can be defined as expected time for two vehicles to reach a common position on the road assuming their speed and trajectory remain the same and can be calculated using the following expression:

$$TTC_{i,t}=(x_{LV,t}-x_{FV,t})-L_{lv,t}/(V_{FV,t}-V_{LV,t}) \qquad (1)$$

where,

t = time interval (s)

X = position of the vehicles (m)

L = vehicle length (m)

V = speed (m/s)

Time to collision is defined by Hayward [17] to reflect the time separating a given FV (Following Vehicles) from its corresponding LV (Lead Vehicles), where their differential speeds are such that both vehicles are closing in on each other.

The basic assumption is that the FV maintains its speed despite it’s being on a collision path. When TTC is lower than a threshold value of 1.5 seconds (minimum perception/reaction time) suggested by Van der Horst , the two vehicles are assumed to be in conflict or in an “unavoidable” collision path.

Six surrogate safety measures are obtained from calibrated models in SSAM, for each one of the simulated conflicts [18]. In particular the graphs below show the variability linked to congested and uncongested scenarios with or without dedicated lane. In particular Fig. 6 is related respectively to 1st -3rd/6th -4th scenarios show a higher TTC value in the non-saturated traffic condition.

In general, only encounters with a minimum TTC less than 1.5 s are considered critical and trained observers appear to operate rather consistently in applying this threshold value. On each scenarios ,hardly display a TTCmin less than 1.5 s.

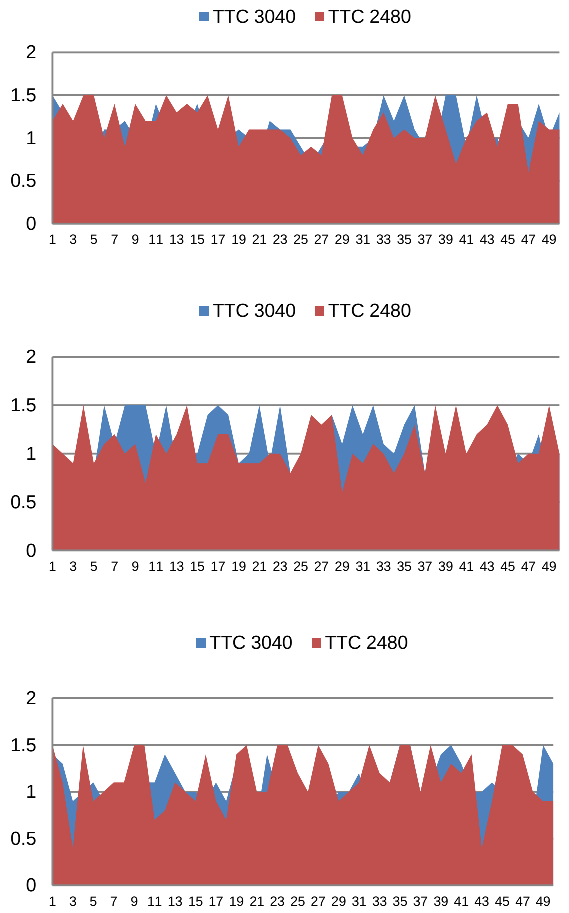


Fig. 6. *TTC distribution for congested and uncongested traffic flow for 1st -3rdand 6th -4th scenarios*

The TTC trend is reversed in 2nd scenario when traffic data predominates, leading to congestion of the intersection of the road like described on graph below.

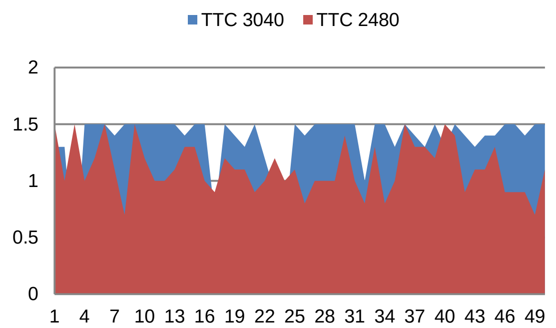


Fig. 7.*TTC distribution for congested and uncongested traffic flow for 2nd scenario*

A similar trend is linked to scenario 5 as shown on Fig.8.

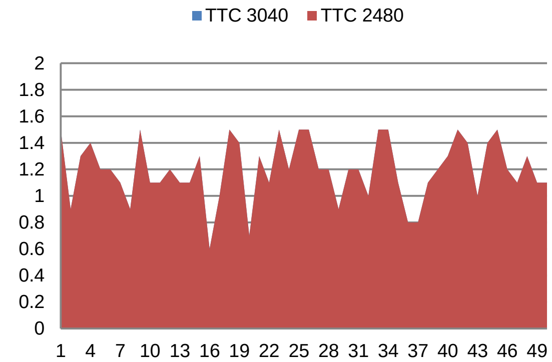


Fig. 8. *TTC distribution for congested and uncongested traffic flow for 5th scenario*

Considering PET average values is possible to consider the trend for all examined scenarios shoed on Fig.9. In particular is possible to appreciate the same trend for all scenarios ,changing congested or uncongested scenarios, except for 2nd scenarios where the increase of traffic flow is linked to an increase of value in terms of 15-20%.

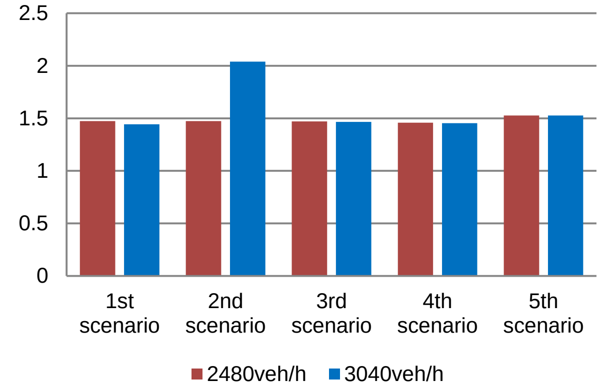


Fig. 9. *Comparison of average PET results for congested and uncongested traffic flow*

Thoroughly different type of collisions are considered to define the possible number of road users that can be involved during unsafe driving actions.

The estimated conflicts were then applied in crash-conflict models for roundabouts developed in other research to compare the roundabout designs on the basis of expected crashes.

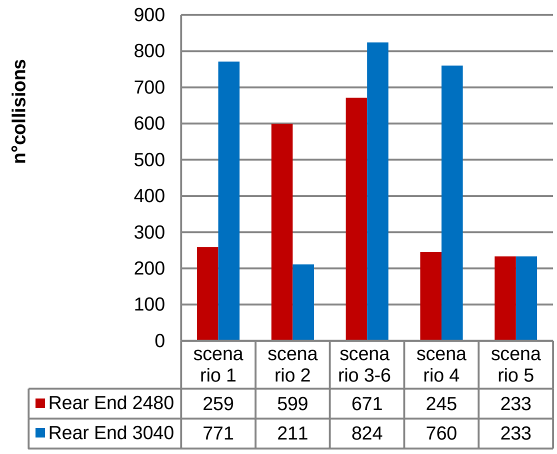
Specific attention is focused on:

- Rear End action;
- Lane Change action;
- Crossing action.

It is clear that the increase in these types of incident could increase in the absence of separation elements between the various lanes. Dedicate lanes, moreover, can reduce this type of collision for BRT or specific type of vehicle

In terms of Rear End (titled RE) the graph below shows an increase of this type of collision especially on scenarios 1 and 4 ,changing traffic flow, with an increase of about tree time.

The symmetrical displacement of dedicated lanes reduces the possibility of producing this type of collision as well denoted in scenarios 5 even in conditions of maximum vehicular flow.

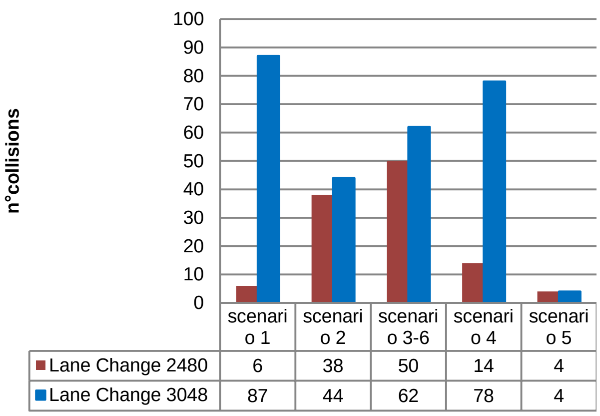


	scenario 1	scenario 2	scenario 3-6	scenario 4	scenario 5
Rear End 2480	259	599	671	245	233
Rear End 3040	771	211	824	760	233

Fig. 10. *Comparison of Rear End (RE) collisions for congested and uncongested traffic flow*

In terms of Lane Change (titled LC) the graph below shows an increase of this type of collision especially on scenarios 1 and 4,changing traffic flow, with an increase from about 10 collisions to more than 80 collisions, increasing traffic flow .

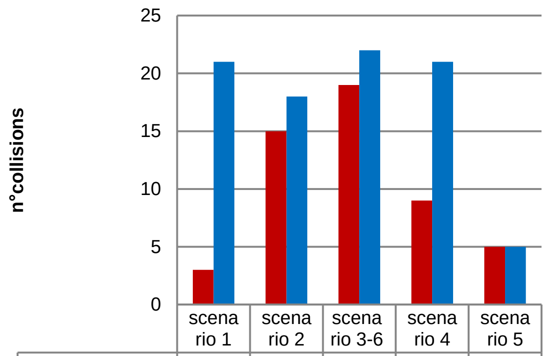
All scenarios show and highest values of Lane Change collisions, considering traffic flow of 3048veh/h .Even more than other case, a geometric distribution of symmetrical dedicated lanes results in a significant reduction in this kind of collision related to LC. It is clear, however, that scenarios 1 and 4 traffic congestion may raise more than 50% of this type of collision.



	scenario 1	scenario 2	scenario 3-6	scenario 4	scenario 5
Lane Change 2480	6	38	50	14	4
Lane Change 3048	87	44	62	78	4

Fig. 11.*Comparison of Lane Changes (LC) collisions for congested and uncongested traffic flow*

In terms of Crossing (titled CR) the graph below shows a similar growing ,considering the different evaluated traffic flow.



	scenario 1	scenario 2	scenario 3-6	scenario 4	scenario 5
CRossing 2480	3	15	19	9	5
CRossing 3048	21	18	22	21	5

Fig. 12. *Comparison of Crossing (CR) collisions for congested and uncongested traffic flow*

The trend of graph below shows a comparison of average values of different type of vehicle collisions. The peak value is about 20 collisions /h of micro-simulations of traffic linked to Rear End manoeuvres.

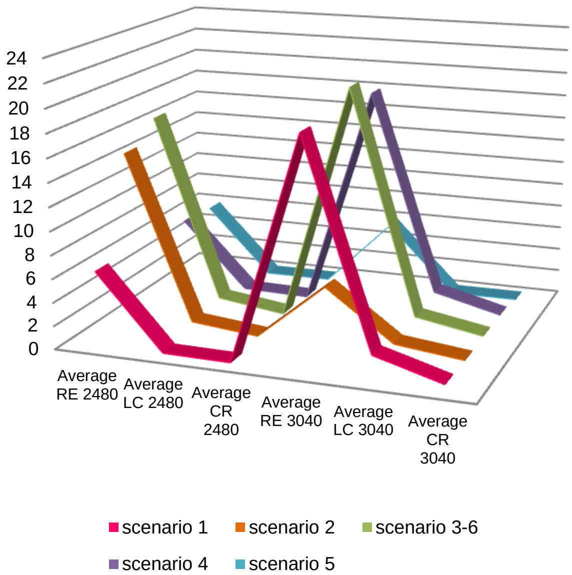


Fig. 13.*Comparison of average results for different type of collisions and scenarios*

IV. Conclusions

In order to plan and design a specific road intersection at grade ,the presence of unconventional intersections and, at the same time, a considerable presence of local public transport, whether traditional or Bus Rapid Transit, can lead to an optimal choice of Local Authority policy, increasing road safety and levels of service of infrastructures.

Particular attention must be paid to the dislocation of the separation elements of the lanes and to the symmetry of the road geometries, depending on the distribution of vehicular traffic.

The traffic simulation approach offers an assessment of security aspects and not only. It can be tapped by more in-depth assessments of traffic accidents.

The results lead to a decisive choice not only in terms of adopted road geometry, but also in terms of traffic management policy, considering the possibility to integrate Bus Rapid Transit system on vehicular traffic.

The proposed research will be implemented in the future by the evaluation of different traffic scenarios with the introduction of innovative vehicles and the aim will be to compare different types of road intersections at grade.

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