Comparison between Surrogate Safety Assessment Models (SSAM) and Accident Models on Unconventional Roundabouts

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Abstract— **This paper describes the comparison between the Surrogate Safety Assessment Model (SSAM) of the Federal Highway Administration (FHWA) and the predicted number of accidents calculated through analytical models, regarding Unconventional Roundabouts. The novelty of this comparison lies precisely in the fact that the 3 roundabouts analyzed fall into the category of so-called Unconventional Roundabouts, i.e., arrangements with "roundabout circulation", which do not fall within the types listed in the Italian Legislation (Ministerial Decree 19-04-2006). In roundabout intersections, among the various types of accidents that may occur, those of the rear-end collision type occur more frequently, for which it was decided to use the formulas of the accident models relating to this type of conflict. In particular, the conflicts type "Approach" for the Maycock & Hall model and the conflict type "Rear end" for the Arndt & Troutbeck model were taken into consideration. As mentioned, in addition to the application of analytical models, possible points of conflict (of the same category, i.e., "Rear end") were evaluated using dynamic simulation models. In particular, the dynamic simulation software Aimsun™ was used as a means to obtain the necessary inputs for the evaluation of the surrogate safety carried out through SSAM, a software application that reads the trajectory files generated by the simulation programs. In the final part of this paper, the conclusions on the comparison and some possible future ideas for further research developments have been included.**

Keywords- Unconventional Roundabouts; Microsimulations; Aimsun; SSAM; Accidents Models.

I. INTRODUCTION

This paper starts from the idea of the authors to develop the work carried out by Vasconcelos et al. in the article "Validation of the Surrogate Safety Assessment Model for Assessment of Intersection Safety" [1]. In particular, the authors have decided to resume the research work carried out and extend it with their contribution, starting from their conclusion that the Surrogate Safety Assessment Model is a quite promising approach to assessing the safety of new facilities, innovative layouts and traffic regulation schemes. Then, the present work started from the fact that it is difficult to calculate the possible number of accidents in roundabouts with innovative layouts, because, unlike the conventional ones which are "geometrically identifiable", they have highly variable geometric parameters and therefore it is difficult to able to describe their road safety with a single model. So, this research tried to describe the comparison between the Surrogate Safety Assessment Model (SSAM) of the Federal Highway Administration (FHWA) and the predicted number of accidents calculated through analytical models, regarding Unconventional Roundabouts. The extension of the work of Vasconcelos et al. and therefore the novelties lie precisely in the fact that the 3 roundabouts analyzed fall precisely into the category of so-called Unconventional Roundabouts, i.e., arrangements with "roundabout circulation", which do not fall within the types listed in the Italian legislation (Ministerial Decree 19-04-2006: "Functional and geometric rules for the construction of road intersections" [2]). These roundabouts have shapes and dimensions that are out of the ordinary concept of roundabout intersection. As regards the accident models, it was decided to consider the formulas of the conflict type "Approach" for the Maycock & Hall [3] model and those of the conflict type "Rear end" for the Arndt & Troutbeck [4] model. This choice is based on the fact that among the various types of accidents that can occur in roundabout intersections, rear-end collisions occur more frequently (literature the values vary from 20% to 25%). As far as the surrogate safety evaluation is concerned, it was carried out using SSAM (a software application that reads the trajectory files generated by the simulation programs) [5]. It was decided to use Aimsun™ as a dynamic microsimulation software, with which it was possible to obtain the ".trj files", i.e., the trajectory files, essential for calculating the possible points of conflict, which, by definition, are the points where two vehicles can potentially collide with each other at road intersections.

Also, in this case, the points of conflict of the "Rear end" category have been taken into consideration. Finally, to improve the visualization style of the points of conflict extrapolated from SSAM, it was decided to use the software Quantum Geographic Information System (QGIS); in this application, the files extrapolated from SSAM were inserted and geolocated. The following sections will follow: a first more theoretical section which will deal with the Italian Unconventional Roundabouts with some examples that are taken into consideration; two sections concerning the SSAM approach from FHWA and the existing roundabouts accident models; the final section, followed by the conclusions and the future research work, which will explain the comparison of the two approaches.

II. ITALIAN UNCONVENTIONAL ROUNDABOUTS

The subsections that follow will primarily deal with the theory of the so-called Unconventional Roundabouts, with reference to the Italian Legislation; and then move on to some practical instances.

A. Unconventional Roundabouts Theory and Italian Legislation

First of all, it is appropriate to specify what is meant by Unconventional Roundabouts [6] and why the authors decided to develop their research on them. In the Italian legislation (Ministerial Decree 19-04-2006 [2]), there can be three basic types of roundabouts based on the diameter of the outer circumference: Conventional Roundabouts with an outer diameter between 40 and 50 m; Compact Roundabouts with outside diameters between 25 and 40 m; Mini Roundabouts with external diameter between 14 and 25 m. For arrangements with "roundabout circulation", which do not fall within the above typologies, we, therefore, speak of Unconventional Roundabouts and for them, the geometric dimensioning and verification must be adapted. When we talk about Unconventional Roundabouts must be considered both the so-called "new generation roundabouts" (Raindrop Roundabouts; Turbo Roundabouts [7] [8]; Two-Geometry Roundabouts [9] [10]), which are currently being built for the purpose of fulfilling safety and performance objectives in cases where classic roundabouts are unable to work well; both the so-called "old roundabouts" which had dimensions and geometries suitable for when precedence was on the branches instead of on the ring (first generation roundabouts) [11]. In Italy, there are many Unconventional Roundabouts of both "typologies", both because in terms of space there is the need to adopt solutions that are not conventional, and because for the moment there are always obsolete roundabouts on the national territory which have not been adapted and which in fact are often poor in terms of security. Precisely for this last consideration, in this discussion the authors have decided to take into consideration 3 Unconventional Roundabouts of the latter type and have decided to analyse them in terms of safety, also because from this point of view there are no in-depth studies for them. A final introductory consideration concerns the type of accidents that the authors decided to analyse, i.e., rear-end collisions.

They are the conflicts/accidents that occur on the entrance branches more frequently at "roundabout" intersections and for this reason they were chosen as a study parameter.

B. Territorial framework and O/D Matrices of the 3 identified Roundabouts

This short paragraph lists the 3 Unconventional Roundabouts analyzed by the authors. All 3 roundabouts are situated in Italy, in the Tuscany region and are located in urban areas, therefore the speed referred to during the calculations is equal to 50 km/h [12]. In particular, in Fig. 1, Fig. 2 and Fig. 3, the 3 aerial images extracted from Google Earth are reported, where the progressive numbers of the branches of the roundabouts are also reported. Reference is made to them for the reconstruction of the Origin/Destination (O/D) matrices, reported in turn in Table I, Table II and Table III.

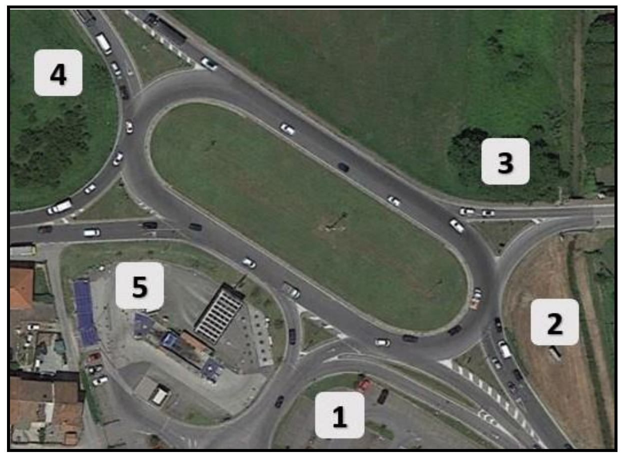

Figure 1. Territorial framework of the 1st Unconventional Roundabout located on SP61-Lucchese-Romana in Lucca, Tuscany, Italy (*source*: Google Earth Pro)

Figure 2. Territorial framework of the 2nd Unconventional Roundabout located on Viale Nazario Sauro in Livorno, Tuscany, Italy (*source*: Google Earth Pro)

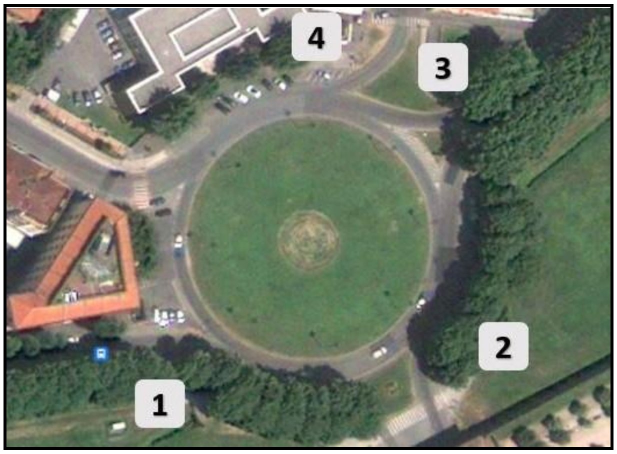

Figure 3. Territorial framework of the 3rd Unconventional Roundabout located on Porta Santa Maria in Lucca, Tuscany, Italy (*source*: Google Earth Pro)

TABLE I. O/D MATRIX OF THE 1ST UNCONVENTIONAL ROUNDABOUT

Roundabout 1 - SP61 Lucchese-Romana (Lucca, Tuscany, Italy)						
Matrice O/D	1	2	3	4	5	TOT
1	0	142	60	36	72	310
2	36	0	140	346	812	1334
3	44	204	0	114	76	438
4	58	320	56	0	280	714
5	58	794	184	372	0	1408
TOT	196	1460	440	868	1240	4204

TABLE II. O/D MATRIX OF THE 2ND UNCONVENTIONAL ROUNDABOUT

Roundabout 2 - Viale Nazario Sauro (Livorno, Tuscany, Italy)				
Matrice O/D	1	2	3	TOT
1	0	390	517	907
2	443	0	691	1134
3	476	541	0	1017
TOT	919	931	1208	3058

TABLE III. O/D MATRIX OF THE 3RD UNCONVENTIONAL ROUNDABOUT

Roundabout 3 - Porta Santa Maria (Lucca, Tuscany, Italy)					
Matrice O/D	1	2	3	4	TOT
1	181	299	1749	0	2229
2	253	0	195	0	448
3	951	52	12	0	1015
4	263	51	12	0	326
TOT	1648	402	1968	0	4018

These matrices were elaborated starting from the data surveys carried out on the 3 roundabouts through the use of Sony DCR-SX34 digital cameras, positioned at specific points of the intersections, during the peak periods of the week [13].

III. SSAM APPROACH FROM FHWA

This concise section has been included to define what is meant by surrogate security assessment and how it is possible to carry out such an assessment. Safety analysis is a decisive aspect in the evaluation of design choices both for the new road system and for the adaptation of the existing road network. The Federal Highway Administration (FHWA) has developed and made available the Surrogate Safety Assessment Model (SSAM) program, through which it aims to offer designers, researchers and companies specializing in road design and construction a tool for assessing the safety of an intersection by estimating the frequency of conflicts [14] [15].

The concept of surrogate safety derives from the desire to develop alternative tools to the existing ones to evaluate the accident frequency of road infrastructure: in particular, while the ordinary methods derive from statistical evaluations based on accidents that have occurred, the surrogate safety methods are instead based on factors that do not require years of accident statistics. The SSAM program elaborates the trajectory files (.trj files) obtained in output from a dynamic simulation program (in the case of the present research it is decided to use the Aimsun™ program, but in general VISSIM™, TEXAS™, etc.). In detail, SSAM evaluates every single vehicle-vehicle interaction according to criteria with which it can establish whether there is a point of conflict and to which category it belongs. At the end of the elaborations, SSAM presents the results in tables, allowing the user to filter them according to parameters of his choice. As regards the classification of conflicts, the program contemplates four types: Rear end, Lane changing, Crossing and Unclassified. To classify them, the program evaluates the crossing angle of the trajectories, if this angle is less than 20° the conflict is of the Rear end type. In the present research, the latter have been taken into consideration, since, as already explained, they are the ones that occur most frequently in roundabout intersections. Their unit of measurement is expressed in conflicts/day.

IV. EXISTING ROUNDABOUTS ACCIDENT MODELS

Roundabouts, in general, are considered to be the safest road junctions as they have several advantages including reduction of points of conflict and lower movement and departure speeds. However, accidents can also occur on them and in particular, several studies state that the most common accident that can occur is a rear-end collision. To study the safety characteristics of the elements of the road system, there are several models for predicting accidents [16]. The authors have decided to use in this research two of the most used models, namely those of the Maycock & Hall model and the Arndt & Troutbeck model. They were chosen because they allow the number of accidents to be calculated taking into consideration both the traffic demand, the geometric characteristics of the intersection, and the dynamic ones (such as speed, for example). With these models, it is possible to calculate various types of accidents, but clearly, as explained above, it was decided to use the formulas of the Conflicts Type "Approach" for the Maycock & Hall [3] model (1) and those of the Conflict Types "Rear end" for the Arndt & Troutbeck [4] model (2), which indicate precisely rear-end collisions. Both models make it possible to estimate the number of accidents over a period of time and therefore their unit of measurement is expressed in accidents/years [17]. The two formulas (1) and (2) used are therefore reported below, specifying that the coefficients of these formulas are the standard ones calibrated for conventional roundabouts. In fact, another of the interesting aspects of this research was precisely that of verifying whether these coefficients could also work for Unconventional Roundabouts. To answer this question, see the next section.

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$$A_2 = 0.0057 \times Q_e^{1.7} \times \exp(20C_e - 0.1e) \quad (1)$$

where:

- Q_e = entering flow, respectively (1000s of vehicles/day);
- C_e = entry curvature [Ce = 1/Re and Re = entry path radius for the shortest vehicle path (m)];
- e = entry width [m].

$$A_r = C_1 \times Q_a^x \times Q_c^y \times S_a^z + C_2 \quad (2)$$

where:

- Q_a = average annual daily traffic (AADT) on the approach;
- Q_c = various AADT flows on the circulating carriageway adjacent to the approach;
- S_a = 85th percentile speed on the approach curve (the potential relative speed between approaching vehicles) [km/h];
- $C_1 = 9.62 \times 10^{-11}$; $C_2 = 0$; x = 1; y = 0.5; z = 2. [4]

V. Comparison of the Two Approaches

The following section presents the results of the research. First of all, a summary table (Table IV) of the calculations carried out is shown which served to reconstruct the graphs on which most of the considerations will be made.

TABLE IV. SUMMARY TABLE OF THE CALCULATIONS MADE

Roundabout	Approach	Qe [veh/d]	Arndt & Troutbeck Rear-end [acc/y]	Maycock & Hall Approach [acc/y]	SSAM (TTC = 1.5 s) [conflicts/d]
1	1	3100	0,10	0,07	24
	2	13340	0,28	0,33	383
	3	4380	0,14	0,13	63
	4	7140	0,19	0,23	165
	5	14080	0,29	0,34	207
2	1	9070	0,16	0,15	120
	2	11340	0,20	0,37	203
	3	10170	0,16	0,27	119
3	1	22290	0,18	0,55	160
	2	4480	0,15	0,13	82
	3	10150	0,16	0,32	104
	4	3260	0,09	0,07	36

Furthermore, the authors considered it necessary to also report an explanatory image of the surrogate safety assessment. In detail, the following image (Fig. 4) shows an extract of the QGIS software of one of the roundabouts chosen as an example (Roundabout 2), where the points of conflict have been inserted, georeferenced (with TTC = 1.5 s) extracted from the SSAM software after processing the ".trj file", which in turn was obtained from the Aimsun™ simulation software. The Time to Collision (TTC) is one of the SSAM software parameters and expresses the minimum collision time [18]. It can range from an infinite maximum value, when two vehicles never meet, to a minimum value of 0 seconds when an accident occurs. Various studies have been conducted to identify a threshold value of the TTC, such as to separate major accidents from minor and negligible or without consequences accidents [19]. This value, depending on the study, was identified as a fixed value or as the result of a function dependent on the speed or deceleration of the vehicles. The authors have decided to keep the default value of the SSAM program which assumes the value TTC = 1.5 s.

Figure 4. Example of Number of Conflicts obtained by SSAM software and reported on QGIS of 2nd Roundabout

Below are the graphs (Fig. 5, Fig. 6 and Fig. 7) which summarize most of the research results. In particular, each graph refers to one of the 3 roundabouts and is structured as follows: the Q_e (entrance vehicular flow) expressed in vehicles per day is shown on the abscissa axis; while there are two different y axes. The left y-axis is incident models (Arndt & Troutbeck / Maycock & Hall) and is expressed in accidents per year, while the right is the SSAM results and is expressed in conflicts per day.

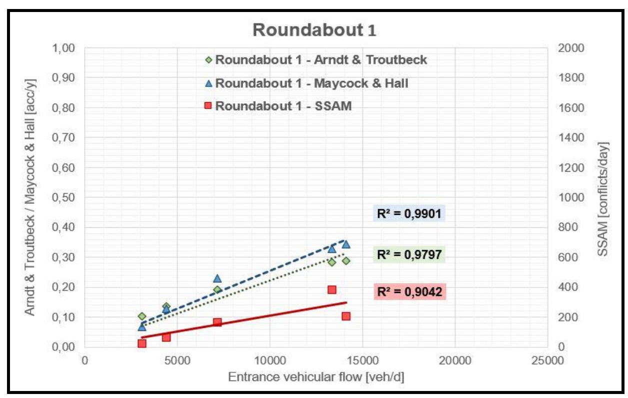

Figure 5. Graph of Results for the 1st Unconventional Roundabout

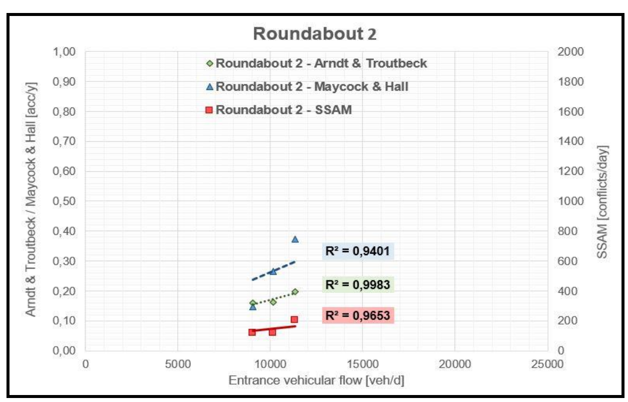

Figure 6. Graph of Results for the 2nd Unconventional Roundabout

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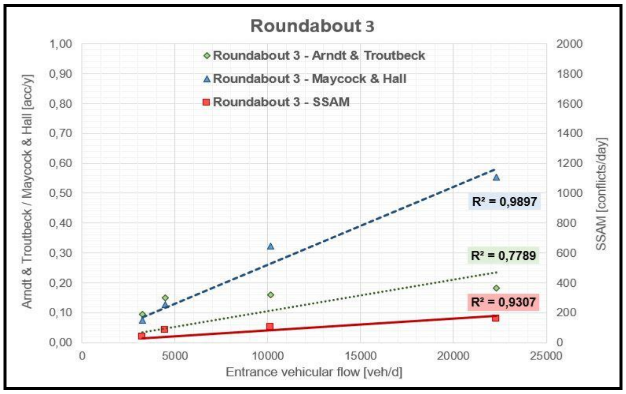

Figure 7. Graph of Results for the 3rd Unconventional Roundabout

On the graphs, as many points have been reported as there are entrance arms of the roundabout in question and a linear trend line passing through the origin (0; 0) has then been created for them. After that, the authors decided to calculate the coefficient of determination R^2 for each trend line. It is a statistical value that allows us to understand whether a linear regression model can be used to make predictions. Its value is always between 0 and 1, or between 0% and 100% if you want to express it in percentage terms. $R^2 = 0$ indicates a model whose predictor variables do not explain the variability of y around its mean at all. $R^2 = 1$ indicates a model whose independent variables fully explain the variability of y around its mean; that is, knowing the values of the independent variables one can predict exactly what the value of y will be. Clearly, the values 0 and 1 are limit values, what emerges is that the greater the value of R^2, the more the model has high predictive power, i.e., the better the ability of the explanatory variables to predict the values of the dependent variable. Usually, we talk about high R^2 values, when they are higher than 0.7. At this point, after having explained the type of graphs used and the reference values, it is possible to go into detail on the considerations relating to the actual results. For all the graphs, i.e., for all the roundabouts, the R^2 values are generally excellent (they are always higher than 0.9, except for one case), both as regards the accident models and as regards the values of the conflicts obtained with SSAM. This is an excellent result as the 3 roundabouts to which the models have been applied are Unconventional Roundabouts, i.e., "different" intersections from the ones on which the models have been calibrated. Therefore, as a first result, it is certainly possible to state that the accident models used (Arndt & Troutbeck / Maycock & Hall), which are already valid and validated for conventional roundabouts, can also be used for Unconventional Roundabouts, using the same formulations and the same coefficients. Also, with regard to the SSAM results, the R^2 values are always higher than 0.9 and despite the different scales it is possible to state that the trend of the trend lines of the points deriving from SSAM is very similar to that relating to the accident models. This is therefore another excellent result that the authors have arrived at, namely that even for Unconventional Roundabouts there is a correspondence between the accident models and the calculation of the conflicts carried out with SSAM.

Finally, the authors also noted a further fact regarding Fig. 7, i.e., the graph referring to roundabout number 3. The trend line of the Arndt & Troutbeck model has an R^2 that is always acceptable, but clearly lower than all the others (0.7789). The explanation that the authors came up with is the following: roundabout number 3, in addition to being of an unconventional type, is also atypical from the point of view of the approaches, since, as can be seen from the territorial framework (Fig. 3) and the corresponding O/D matrix (Table III), the approach 4 is formed only by the input branch and not the output branch. This, together with the particular geometry of the roundabout, has led to a high difference between the incoming flow rate Q_e and the circulating flow rate Q_c of the adjacent approach 1 (this difference is underlined in Table V). So, another result that the authors have reached is the consideration that the model of Arndt & Troutbeck does not adapt perfectly to Unconventional Roundabouts in which there is, for some branches, a high difference between the incoming flows and circulating flows.

TABLE V. EXTRACT FROM THE CALCULATION TABLE, WHERE THE DIFFERENCE BETWEEN QE AND QC CAN BE SEEN

Roundabout	Approccio	Qe [veh/d]	Qc [veh/d]	Delta (Qe-Qc/Qc)
3	1	22290	1150	18,38
	2	4480	19540	0,77
	3	10150	4340	1,34
	4	3260	14490	0,78

A final comparison was also made for the 3 Unconventional Roundabouts as a whole. In fact, a last graph (Fig. 8), of the same typology as the previous ones, was constructed however by taking into consideration the roundabouts as a whole and no longer approach by approach. In this way, it was possible to compare the 3 roundabouts on a single graph and this led to the following consideration.

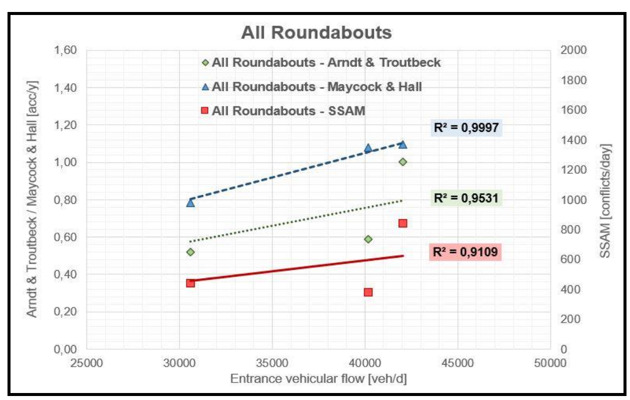

Figure 8. Graph of Results for the three Unconventional Roundabouts together

The values of R^2 are excellent and also the roundabout 3 which had a deficit on the Arndt & Troutbeck model due to the difference between the incoming flows and the circulating flows at one of the approaches, if it is considered as a whole, it is possible to homogenize with the other results.

VI. CONCLUSIONS AND FUTURE RESEARCH WORK

This article describes the comparison between the Federal Highway Administration (FHWA) Surrogate Safety Assessment Model (SSAM) and the predicted number of accidents calculated using the Arndt & Troutbeck and Maycock & Hall analytical models, as concern the Unconventional Roundabouts [20] [21]. 3 Unconventional Roundabouts located on the Italian territory that have different shapes and sizes from the regulatory standards were analysed. Other works and articles have been published regarding the comparison between the models mentioned, however, the novelty of this research proposed by the authors lies precisely in the different base data, i.e., the Unconventional Roundabouts. The type of accident and conflict chosen for the comparison made is that of rear-end collisions, as it is the most common present on roundabout intersections. In the sections of the article, various initial considerations follow one another which deepen the concepts of Unconventional Roundabouts, surrogate safety analysis models (SSAM) and accident models; up to section V where the results of the entire research were clearly explained. Summarizing these results, the authors found that: 1) the accident models used (Arndt & Troutbeck / Maycock & Hall) already valid and validated for conventional roundabouts, can also be used for Unconventional Roundabouts, using the same formulations and the same coefficients also because a certain correspondence was also found between them in terms of the number of accidents per year; 2) also for Unconventional Roundabouts there is a correspondence between the accident models and the calculation of the conflicts carried out with SSAM; 3) Arndt & Troutbeck model is not perfectly suited to Unconventional Roundabouts in which there is, for one or more branches, too high a difference between incoming flows and circulating flows. Before concluding the work, the authors decided to also propose some ideas of the possible future development of this research. First of all, this work can certainly be expanded by analysing further case studies and thus obtaining more points to use on the graphs obtained. Furthermore, the accident models utilised were used in the first analysis without the recalibration for the Unconventional Roundabouts; therefore another next steps could be proper to go and search for the actual accident data and thus verify whether the parameters used can be further improved and better recalibrated for Unconventional Roundabouts (it is emphasized that however, as explained in section V, the accident models used, can already be used also for Unconventional Roundabouts, given the statistical results obtained by the authors).

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