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Cycling traffic at turbo roundabouts: some considerations related to cyclist mobility and safety

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Abstract

The growing need for sustainable mobility has led the transport policy-makers as well as population to use more of soft mobility solutions such as pedestrian and cycling traffic. Several European countries are implementing policies for total mobility with less motorization in order to reduce the negative environmental effects generated by industries and transport. In the same time new unconventional types of intersections are developed in order to ensure safer conditions not only for motorized traffic but also for pedestrians and cyclist. One of those is turbo roundabout, at-grade two-lane roundabout, introduced also in urban areas where heterogeneous traffic users are expected and on which traffic safety should be considered carefully. This article aims to analyze the safety of cyclists in different traffic conditions at turbo roundabout with and without separated traffic lanes for cyclists. Through the evaluation of level of service and surrogate safety parameters, the advantages and critical aspects linked to turbo roundabout are highlighted. The research will be conducted on theoretical turbo roundabout with substantial variation in traffic flow. Comparison of the results will allow a better understanding of functionality (level of service, traffic safety) of turbo roundabout in the presence of pedestrians and cyclists of different age. The aim of this article is to present possible solutions to enable safer introduction of cycling traffic at turbo-roundabouts and help defining conditions (number of vehicles, number of cyclist, and number of pedestrians) in which safety of cyclist is questionable and there is need for different solution.

Keywords: cycling traffic, sustainable mobility, traffic safety, microsimulation, turbo-roundabout

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1. Introduction

Current transport policies relating to urban mobility are attempting to take specific measures to facilitate cycling, given the benefits in terms of sustainability and human health.

But, despite its positive impact on public health, cycling is still not present and popular in many countries and the fear of accidents in mixed traffic conditions is often cited as an important deterrent. Globally, the total number of cycling fatalities is likely to be higher than 50 000 per year, or 6% of the world's total number of road deaths (WHO, 2015). Among 29 countries providing cycling fatality data to the IRTAD database since 2000 and earlier, the median share of cycling fatalities was 5% in 2000 up to 8% in 2016. This reflects a stronger progress in reducing fatalities for vehicle occupants than vulnerable road users. Nevertheless, between 2000 and 2016, the number of cycling fatalities decreased by 34% across the 29 countries (OECD/ITF, 2013).

Injuries are another cause for concern, and an area where global statistics are lacking. This is partly due to low rates of cycling injuries being reported to the police, as a significant proportion of cycling crashes involve no other road user and/or no motor vehicle. However, analyses proved that health benefits of cycling outweigh the cost of fatal and serious injuries (Mueller et al., 2018). In accordance with Woodcock et al. (2014) the net health benefits are largest at older ages mostly due to the higher prevalence of chronic diseases among older people, which physical activity contributes to preventing.

Urban areas with greater safety conditions for cyclists tend to be those in which people travel more by bicycle and where cycling infrastructure is more developed. Intersections are particularly risky part of road network for cyclists because of the interference with motorized road users. Different are the impacts on safety of cyclist, several studies have been conducted in the literature to evaluate how a geometric pattern of urban intersection affects cycling safety (Møller & Hels, 2008). Some studies take into consideration the cycling component considering current geometries and comparing possible alternatives (Macioszek et al., 2010).

The extensive study done by Sakshaug et al. (2010) regarding traffic safety of cyclist in roundabouts, confirmed that cyclists are safer at separated then on integrated roundabouts as the number of interactions and conflicts is higher on integrated roundabouts. Entrance and exit of roundabouts were confirmed as most problematic points of integrated roundabouts where drivers face a higher degree of complexity and thus safety level decreases.

Recently some new, unconventional, types of roundabouts are introduced among which so called turbo-roundabout or roundabout with spiral traffic movement. Turbo roundabout proved to be very efficient in terms of safety (Tesoriere et al., 2018; Campisi et al.2017), as well as capacity (Gallellia et al. 2016) and environmental impact (Tollazzi et al., 2015; Vasconcelos et al. 2014) so there is tendency to apply this type of roundabouts around Europe.

This research analyses the aforementioned unconventional roundabout scheme, turbo roundabout, by evaluating the intersection capacity (LOS) and safety of cyclist and other users on separated (turbo-roundabout with separated lanes for cyclist) and integrated turbo-roundabout (turbo-roundabout without separated lanes for cyclist). In the analyses of different traffic scenarios meaning shares of personal vehicles, heavy vehicles, buses and bicycles were introduced. The traffic shares were hypothesized with percentages of increasing cyclists, considering a progressive reduction in the use of cars in the coming years.

Through the micro-simulation analyses done with VISSIM approach the traffic flow conditions for different scenarios were estimated and the evaluation of safety surrogate parameters (TTC, PET) analyses was done with SSAM tool. The results provide an important basis for future geometric-functional improvements of urban road intersections, where heterogeneous traffic is expected, and can help local authorities to select safer solutions for different expected traffic conditions.

2. Analysis and methods

Research on roundabout capacity and cycling safety was done on typical turbo-roundabout with standard geometry. Different traffic scenarios were compared, through the level of service (LOS) obtained by micro-simulation traffic model (VISSIM). Safety analyses included comparison of parameters: time-to-collision (TTC) and post-encroachment-time (PET) and was done by Surrogate Safety Assessment Model (SSAM).

2.1. Turbo-roundabout geometry

The turbo roundabout is relatively innovative design of the two-lane roundabout that has revolutionized roundabout design in the Netherlands and in several European countries such as Slovenia (Tollazzi et al. 2011). In this geometry the traffic flows run separately even before the entry into the roundabout, they occupy separate lanes all the way throughout the roundabout, also at the exit from the roundabout (Ticali & Corriere, 2018). Physical separation of traffic lanes is interrupted only in places of entry into the inner circulatory carriageway. They are achieved by specially shaped elements – delineators, which hinder (but not prevent) the change of traffic lanes in the roundabout – weaving conflict. The central island is designed by means arcs of circumferences with different centers and radius. The Archimedean spiral is often used with the aim to limit the variation of the centrifugal acceleration around the central carriageway in accordance with Tollazzi et al. 2016.

2.2. Vissim approach

Micro-simulation models can analyze public and private transport operations by considering different geometries and traffic composition. This means that it can be a useful tool for the evaluation of various alternatives based on transport engineering and effectiveness of planning measures. Micro-simulation modeling is able to simulate movement of individual vehicles traveling within a road network through the accurate replication of driver behavior. In this sense the micro-simulation modeling is distinct from strategic, belt area and local models in which all vehicles exhibit a common, uniform behavior. It is possible to model the impact of variability on the behavior of the network, and present complex traffic problems. In this way the use of traffic microsimulation tools allows to be able to compare different traffic or geometric scenarios in order to understand and mitigate the possible critical issues even before their realization. The microsimulation of traffic through the Vissim 9 software allows the modeling of vehicular and cycling flows by considering the car-following models (Wiedemann, 1974).

2.3. Surrogate Safety Measures Assessment

Surrogate Safety Assessment Model (SSAM) is a software application designed to consider vehicle trajectory data output (Pu et al. 2008) from microscopic traffic simulation models (like VISSIM output files) to derive proximal measures such as conflicts, based on thresholds for either time to collision (TTC) or post encroachment time (PET). The concept of surrogate security measures is based on the collision observations (Tarko, 2018). Proximity interactions or surrogate events are generally observed during monitoring of intersection. These surrogate events, or interactions, may reflect safety or lack of safety in the form of value close to the realization of a conflict but are not themselves collisions. The estimated conflicts from SSAM are used in crash-conflict models for roundabouts to compare the roundabout designs on the basis of expected crashes. SSAM has many parameters to configure which allow user to visualize the analysis and customize the analysis results. Generally the data required to adequately analyze the traffic situation includes the following:

- Network geometry (i.e., number of lanes in each direction, turning pockets, and driveways)
- Traffic-stream data (volume of traffic in each direction, change in the volumes over the simulation period)
- Definition of signalized or not signalized intersection with specific priority of each arms or circulatory carriageway
- Driver behavior data (i.e., aggressiveness distribution and gap-acceptance criteria).

3. Inputs for Analyses and Results

The evaluated intersection is a turbo-roundabout with medium diameter (external radius - 22 m) theoretically located in urban area with both motorized and non-motorized traffic, with distinguished main and secondary direction of traffic flow, respectively A-C and B-D, considered both without and with separated lanes for cyclists. The capacity of respectively 50 and 80% of the theoretical value of the traffic capacity of a turbo-roundabout were considered for the roundabouts with the following geometric scheme (Fig. 1.):

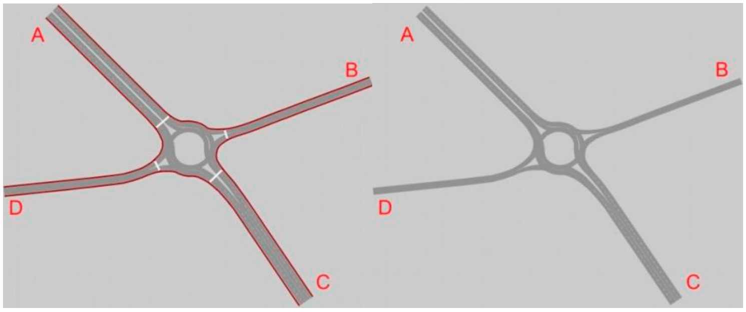

Fig. 1. Turbo-roundabout scheme with (left) and without (right) separated cyclist dedicated cycling lanes

At the considered turbo roundabout, there are two directions, the main with 60% of the traffic load and a secondary with 40% of the traffic load. The scheme in both cases consists of 4 arms with lanes of equal width. Each arm in the main A-C direction has 4 lanes (two for each oncoming or outgoing flow). The secondary direction B-D has 3 lanes of which two entry and one exit lane. In the scheme with lanes dedicated to cyclists, a lane has been added to each direction. This lane allows the cyclists to make a right turn easily and, by using the pedestrian crossing, to change direction.

The evaluated traffic scenarios consider different vehicular components with a gradually increasing percentage of the cycle component compared to the vehicular component. (Table 1)

The scenarios were selected according to expected transport policy that should favor the use of public transport and cycle mobility instead of high use of personal vehicles. It is possible to observe how the scenarios gradually evaluate the presence of an ever-increasing cycle component with a diversification of users in age groups and therefore critical issues related to speed variation and possible conflicts with other users.

The table below shows the comparative scenarios:

Table 1. Simulated scenarios considering a traffic flow of 2480 veh/h and 1550 veh/h.

Scenario		LV	BUS	HV	Cyclist
Traffic flow =2480 veh/h (80%max capacity) with 60% on main and 40% on secondary direction	1st	70%	10%	10%	10%
	2nd	40%	20%	10%	30%
Traffic flow= 1550 veh/h (50% max capacity) with 60% on main and 40% on secondary direction	3rd	70%	10%	10%	10%
	4th	40%	20%	10%	30%
Traffic flow =2480 veh/h (80%max capacity) with 60% on main and 40% on secondary direction with cyclist dedicated lane	5th	70%	10%	10%	10%
	6th	40%	20%	10%	30%

The comparisons of the results obtained by the different scenarios allowed to highlight the variations in average speed, number of STOPs, length of the queues and finally the calculation of Level of Service (LOS). In terms of average speed the maximum values are obtained in 2nd scenario characterized by a value of vehicular flow close to capacity and without lanes for cyclists and with 40% of light vehicles (LV).

In Fig. 2 the trend of the average queue length is shown. It can be seen that in the B-D direction in the 1st and 3rd scenarios the AVG queue length values are more than 140 m causing decelerations and relative delays in maneuvers.

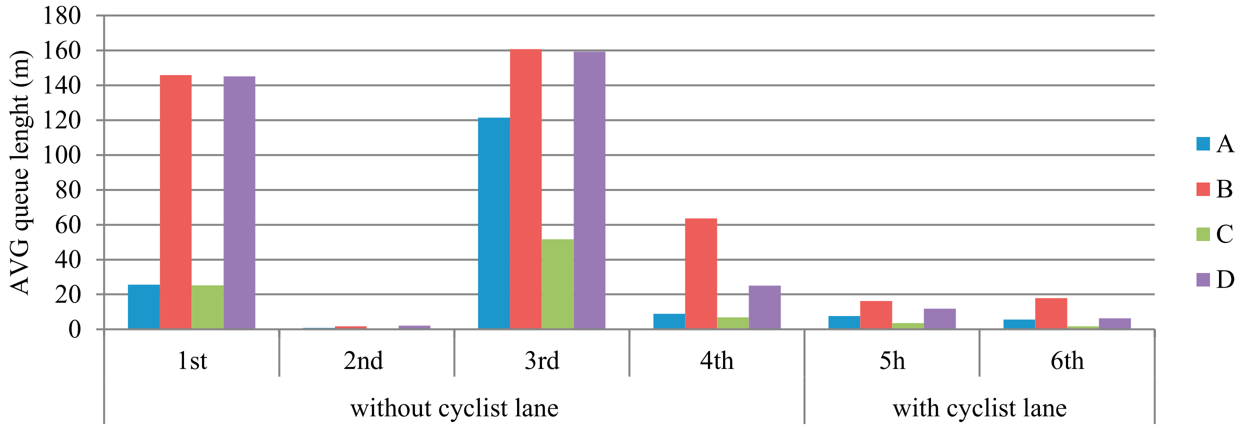

Fig. 2. Comparison of average queue length

In terms of the LOS, like showed on Fig. 3, it is possible to notice optimal values (LOS B and C) in the 2nd scenario, without lanes for cyclists and 5th and 6th scenario, with dedicated lanes. In the other cases, an unacceptable LOS values were obtained (equal to E or F).

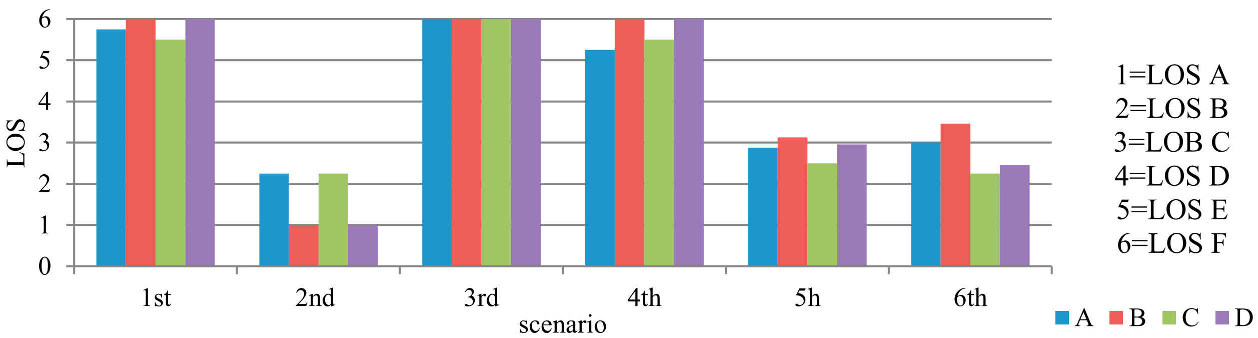

Fig. 3. Comparison of LOS

From these comparisons it is possible to see how the turbo-roundabout scheme, although it reduces the number of conflict points to 16 (with respect to other intersections at level), does not bring advantages from the point of view of the level of service (LOS) if the analysed scenarios are applied, except for 3rd scenario. The LOS of the two directions is overall comparable but the presence of cycle lanes does not lead to an overall improvement in the secondary direction.

The evaluation of the possible criticality of each scenario was investigated by evaluating the safety parameters through the use of the SSAM tool (Pu et al. 2008).

The results can provide safety level on investigated scenarios considering level of service (LOS) and also the possibility of obtaining time to collision (TTC) and post-encroachment time (PET) through the use of surrogate parameters obtained by SSAM tool (Horst, 1991; Kieć et al., 2018). This assessment is useful in order to assure functionality, in terms of traffic safety, of this type of roundabout. TTC and PET are both indicators of potential vehicle collision. All the evaluated scenarios show an equal value of TTC (1.5) with a value of mTTC and mPET> 90. For the parameter PET there is a fluctuation of the value within the range 2.3-2.45 as shown in Fig.4.

The probability of a conflict is greater when the value of these parameters is lower (Tollazzi et al., 2016). The research was founded on specific range for both safety parameters in order to establish the possibility of defining a potential conflict, considering 0.1 s < TTC <1.5 s and 2.3 s < PET < 2.45 s.

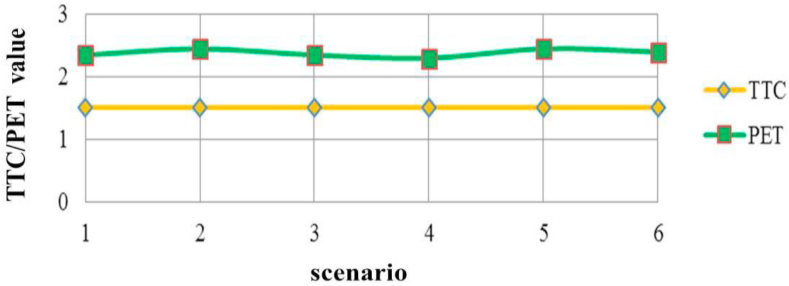

Fig. 4. Comparison of PET and TTC values

Interaction detection and severity rating is based on the value of PET between the cyclist and vehicle. PET< 3 seconds were considered to expose the cyclist to an elevated level of collision threat like described on Fig. 4. Among the data associated with each conflict is a MinTTC variable, which is the simulation time where the minimum TTC value for that conflict was observed (Tollazzi et al. 2015). That variable was used to filter out all conflicts that occurred during the simulation time.

It can be seen from Fig. 5 that in overall terms the greatest number of conflicts is identified in 2nd scenario, the 3rd scenario has the least number of conflicts. The gradual increase in the traffic flow and also the number of cyclists in the traffic mix with motorized vehicles gradually leads to an increase in number of conflicts. This can be justified by the different traction and relative speed between bikes and motorized vehicles.

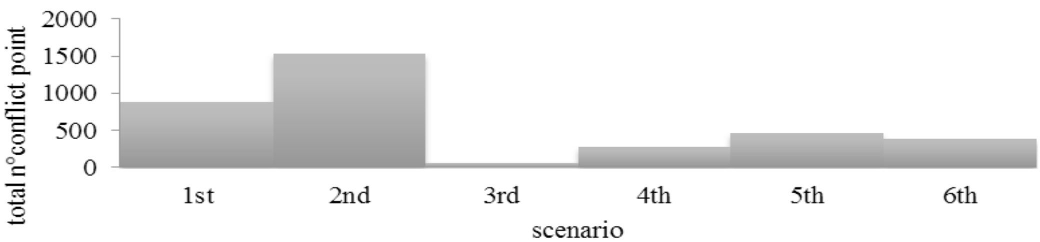

Fig. 5. Total conflicts trend for each scenario

In terms of different types of conflict, Fig. 6 shows a comparison between the various cases examined and highlights that the 2nd scenario has the highest number of conflict points in terms of rear end and lane change. Instead, the conflicts due to crossing are higher in the scenarios with dedicated lanes (5th and 6th scenarios) precisely because the necessity of crossing cyclists increase from the lanes dedicated to them through the zebra/pedestrian crossing.

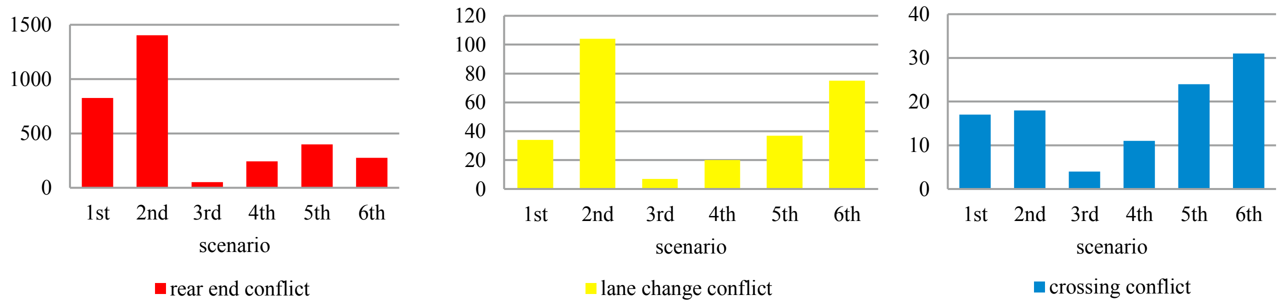

Fig. 6. Trend of different conflict considering evaluated scenarios

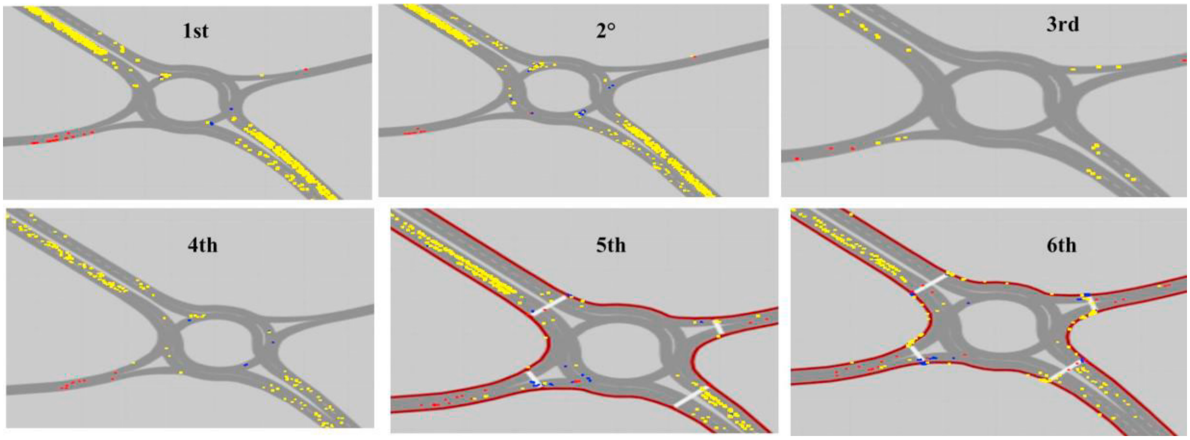

Fig. 7. Conflicts localization considering all scenarios.

The comparison in term of number of conflicts between the two represented geometries, with and without lanes for cyclists, show a clear reduction in the second case as shown in the Fig.7 where the concentration of the yellow points (lane change) along the axis A_C is considerably reduced.

The table below (Table 2) shows the results obtained by microsimulation and SSAM tool. It can be seen that for the same (higher) traffic volumes (1^{st} ,2^{nd} ,5^{th} and 6^{th} scenarios) separated cycling lines can help in improving traffic safety. In case of lower traffic volume (50% of theoretical capacity) traffic safety is, as expected, better also when cyclist are not separated.

Table 2. Simulated scenarios considering a traffic flow of 2480 veh/h and 1550 veh/h.

Scenario	LOS	N° conflict point
1^{st}	starting point	starting point
2^{nd}	increase (better LOS)	increase
3^{rd}	decrease (worse LOS)	decrease
4^{th}	decrease (worse LOS)	decrease
5^{th}	increase (better LOS)	increase crossing decrease others (rear end and lane changing)
6^{th}	increase (better LOS)	decrease rear increase others (crossing and lane changing)

4. Discussion/Conclusion

The growing development of cycling in urban centers is a current issue that must be studied globally to protect cyclists. The design choice of at grade intersection should consider safety of all users and in the same time optimize the LOS. Starting from a turbo-roundabout scheme that maximizes safety with respect to other types of roundabouts, this study focuses on the evaluation of different traffic scenarios in which traffic distribution among cyclist and motorized vehicles is varied. The evaluations were carried out by comparing the LOS for different scenarios and mitigating the safety through surrogated type of parameters such as the TTC and the PET.

Turbo-roundabouts with two or more lanes in each arm, like described before, can achieve better capacity for motorized vehicle traffic, but also increase potential conflicts and risks for cyclists.

The results in this paper show that adding dedicated lanes for cyclist increase safety for cyclist but also requires the presence of pedestrian crossings to enable changing maneuver direction.

These areas are those most affected by the crossing conflicts and therefore it is necessary to analyze in detail whether it is convenient to make underpasses or overpasses for vulnerable users. If this solution proves to be very expensive then it will be necessary to take into account the priorities and plan the distances of the crossings from the entrance/exit to the turbo-roundabout. In this case it is necessary to carefully design the pedestrian crossing in a way to include the presence of waiting areas according to dimension of non-motorized vehicle.

These results are the basis for further research in which different solutions for cycling traffic at roundabouts should be considered in order to increase their safety and possibly also the LOS of turbo roundabouts.

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