TURBO-ROUNDABOUT GENERAL DESIGN CRITERIA AND FUNCTIONAL PRINCIPLES: CASE STUDIES FROM REAL WORLD

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ABSTRACT

Compared with usual roundabouts the main advantages of turbo-roundabouts are the reduction in the number of potential conflicting points and the lower speed of passing vehicles through the intersection; they both can improve road safety conditions at the junction. Also, the physical delimitation among lanes limits the side-by-side accident risk. These aspects make turbo-roundabouts more appropriate than roundabouts when a higher level of safety has to be guaranteed, particularly in presence of relevant pedestrian and two-wheels traffic volumes.

In a previous paper authors proposed a theoretical approach to evaluate turbo-roundabouts capacity founded on gap acceptance theory. In particular, to model in a realistic way traffic conditions at turbo-roundabouts, simulations have been developed starting from behavioral parameters (critical gap and follow-up time) obtained by field observations on the few existing turbo roundabouts. The determination of the advantage domain (in terms of capacity) of turbo-roundabouts compared with typical ones and the way to value performance indicators (delays, queue lengths and levels of service) more consistent with real operational conditions of turbo roundabouts were also proposed.

The present paper has three main objectives:

1. to discuss general design criteria and functional principles of turbo roundabouts;
2. to give the geometric design principles of the central island and circulating lanes;
3. to present three case studies from real world concerning the conversion of existing roundabouts into turbo roundabouts.

Although results of the study cannot be generalized, by methodological point of view they can be useful to the practitioners and to the road administrations in decision making about the conversion of existing intersections.

GEOMETRIC FEATURES OF TURBO ROUNDABOUTS

Turbo roundabout is a particular type of roundabout where lanes are bounded by traffic signs and by non-mountable curbs installed at entering and at circulating lanes. Turbo-roundabouts have also a very particular shape to accomplish the splitting of traffic streams, in order to prevent traffic from weaving. As a result of the lane dividers, turbo roundabouts force circulating traffic flows to spiral trajectories thus each entering lane is specialized only in particular turning maneuvers and drivers have to choose their direction (i.e. the correct lane on the approaches) before they enter the intersection and the appropriate lane on the circulating roadway. At last, a turbo roundabout does not allow U-turn maneuvers.

Several layouts of turbo roundabout are possible (see examples in Figures 1 and 2). The basic turbo roundabout shape is thought for intersections between a major road and a minor road with less traffic. In particular, Figure 1b shows an example of spiral roundabout where two entries are characterized by three entering lanes and one exit lane (*1*)(*2*).

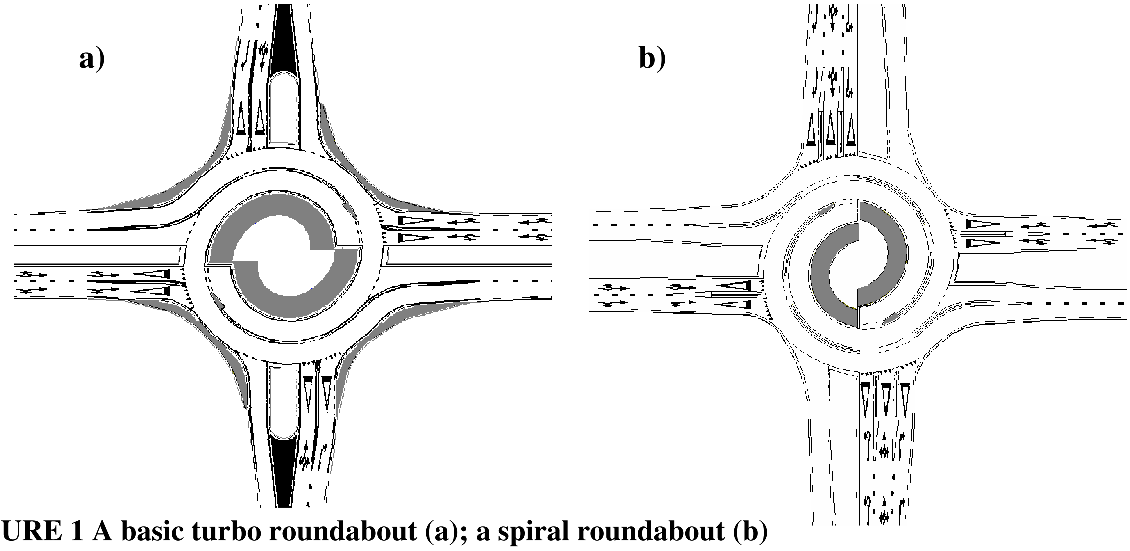

FIGURE 1 A basic turbo roundabout (a); a spiral roundabout (b)

FIGURE 2 Rendering of a turbo roundabout

Differently from what happens in usual modern roundabouts (where vehicles move side by side, each in the proper lane, reach the give-way line and then they set the trajectory and complete their maneuvres toward the wanted exit) at turbo roundabouts users are forced to preselect the correct lane even at dozens of meters before they enter the intersection. Figure 1 shows that right-turn vehicles from the minor road are requested: i) to drive along the outer entering lane; ii) to get onto the outer circulating lane; iii) to address to the leg close to that they come from. Through vehicles (and left-turn vehicles) have to select the inner entering lane, to get onto the inner circulating lane and then they are able to address to the required exit.

In comparison with usual roundabouts, the main benefits of a turbo roundabout are:

a) lower number of potential conflicting points among vehicles (*3*) (*4*); for example, a four leg turbo roundabout is characterized by ten points of conflict, whereas a two-lane roundabout is characterized by twenty-two points of conflict (see Table 1);
b) slower speeds along the ring;
c) lower risk of side-by-side accidents.

Starting from these considerations, turbo roundabouts can be installed as an alternative of modern roundabouts especially when a high level of safety has to be guaranteed, for example where bicyclist and pedestrian traffic are not slight (*5*).

TABLE 1 Points of conflicts at unsignalized intersections, roundabouts and turbo roundabouts

Number of legs	number of conflicting points		
	Unsignalized intersection	Two-lane roundabout	Turbo roundabout
3	9	16	7
4	32	22	10

The characteristic shape of the central island (see Figure 3) is designed through arcs of circumferences with different centre and radius. The geometric design follows subsequent steps:

1. single out the center of the intersection (or the intersection point among crossing roads);
2. select the width of the lane and the semi-width of the safety island among lanes (curb and shoulder), which sum corresponds to the distance between C_1 and C_2: $\overline{C_1C_2} = \overline{\Delta R}$
3. position C_1 and C_2 centers symmetrically as to the intersection point among the road axis;
4. fix the value of the first radius and put $R_1 = R_4$; the other radius values are defined by the relation: $R_i = R_{i-1} + \Delta R$. In particular, it results (see Figure 3):

$$\begin{cases} R_3 = R_2 + \Delta R \\ R_2 = R_1 + \Delta R \\ R_6 = R_5 + \Delta R \\ R_5 = R_4 + \Delta R \end{cases}$$

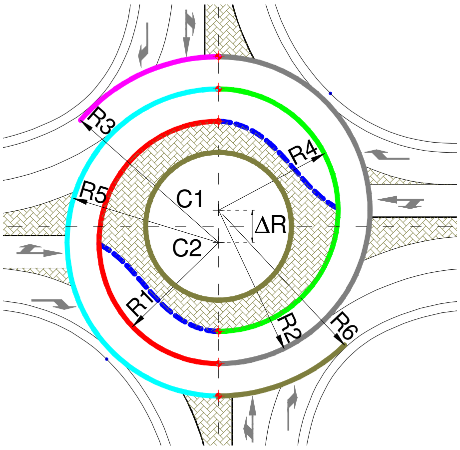

FIGURE 3 Geometric design of the turbo roundabout

In order to built a turbo roundabout scheme with a continuous variation of curvature of circulating lanes, in some cases a spiral can be applied by turns. Considering that the width of circulating lanes has to be kept constant along its development, it follows that the curve has to be marked by a constant step equal to the transversal spacing between the lanes. The last characteristic belongs to the Archimedean spiral (see Figure 4), which equation is the following:

$$R = a \cdot \theta \qquad (1)$$

where R is the radial distance from the origin, a is the parameter of the curve and θ is the polar angle (i.e. the angle corresponding to the point with curvature $1/R$).

The Archimedean spiral represents the trajectory of a point P moving with a constant speed along a half-line pivoting with constant speed on the point O. Any half-line originating from the point O (i.e. the origin of a system of Cartesian axes) intercepts equal segments on the Archimedean spiral: $\overline{OA} = \overline{AB} = \overline{BC} = \dots$.

The well-known parametrical equations of the spiral are as follows:

$$x = R \cdot \cos\theta = a \cdot \theta \cdot \cos\theta$$

$$y = R \cdot sen\theta = a \cdot \theta \cdot sen\theta$$

In order to determine the step of the spiral K, denoting with n a natural number (n = 1,2,3,…), it is required to assume the following conditions:

$$R_n = a \cdot \theta_n$$

$$R_{n+1} = a \cdot \theta_{n+1}$$

$$K = R_{(n+1)} - R_n = a \cdot (\theta_{n+1} - \theta_n) = 2\pi \cdot a$$

By these relations the value of the a parameter can be obtained, considering that the step K of the spiral is known: $a = \frac{K}{2\pi}$

The length of the spiral can be obtained by the following equation:

$$L = \frac{1}{2} \cdot a \cdot \left[\theta \cdot \sqrt{1+\theta^2} + \ln\left(\theta + \sqrt{1+\theta^2}\right)\right]$$

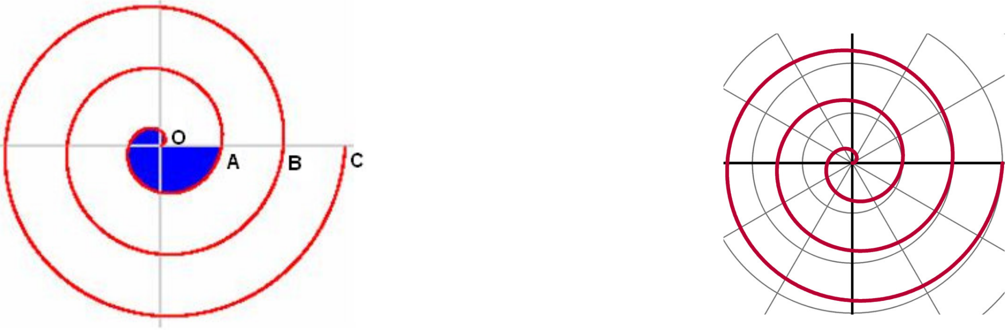

FIGURE 4 The Archimedean spiral

CAPACITY COMPUTATION

From the point of view of operational performances, considering the physical separation of lanes and their specialization with regard to the type of maneuver, the simple capacity at a turbo roundabout entry has to be computed starting from capacity values of entering lanes, suitably weighed each other in relation to respective degree-of-utilization (*6*).

In order to compute the simple capacity of northbound and southbound approaches, i.e. the minor road (see Figure 1a), it needs to compute separately the right-turn lane capacity ($C_{E,R}$) and the through and left-turn lane capacity ($C_{E,TLT}$). With this object in view, the following two equations can be applied:

$$C_{E,R} = 3600 \cdot \left(1 - \frac{T_{\min} \cdot Q_{c,e}}{3600}\right) \cdot \frac{1}{T_f} \cdot e^{-\frac{Qc,e}{3600}\cdot\left(T_g - \frac{T_f}{2} - T_{\min}\right)} \qquad (2)$$

$$C_{E,TLT} = 3600 \cdot \left[1 - \frac{T_{\min} \cdot (Q_{c,e} + Q_{c,i})}{3600}\right] \cdot \frac{1}{T'_f} \cdot e^{-\frac{Qc,e+Qc,i}{3600}\cdot\left(T'_g - \frac{T'_f}{2} - T_{\min}\right)} \qquad (3)$$

where:
$C_{E,R}$ = capacity of the right-turn lane at the entry E [veh/h];
$C_{E,TLT}$ = the capacity of a through and left-turn lane at the entry E [veh/h];
$Q_{c,e}$ = circulating traffic flow in the outer circle lane in front of the entry E [veh/h];
$Q_{c,i}$ = circulating traffic flow in the inner circle lane in front of the entry E [veh/h];
T_g , $T_g^{'}$ = critical gap, [s], (the values are different for the two entry lanes);
T_f , $T_f^{'}$ = follow – up time [s] (the values are different for the two entry lanes);
T_{min} = the least headway between vehicles moving along the circulating lanes [s].

Figure 5 shows the relation of capacity *vs* circulating vehicles for the two considered lanes. In particular, starting from statistical data processing of behavioral parameters carried out by Fortuijn with regard to minor roads at existing turbo roundabouts (*7*), the values T_g = 3.6 s; T_f = 2.13 s; T_{min} = 2.1 s have been assumed for right turn vehicles and the values $T_g^{'}$ = 3.2 s, $T_f^{'}$ = 2.25 s, T_{min} = 2.1 s have been assumed for through and left turn vehicles.

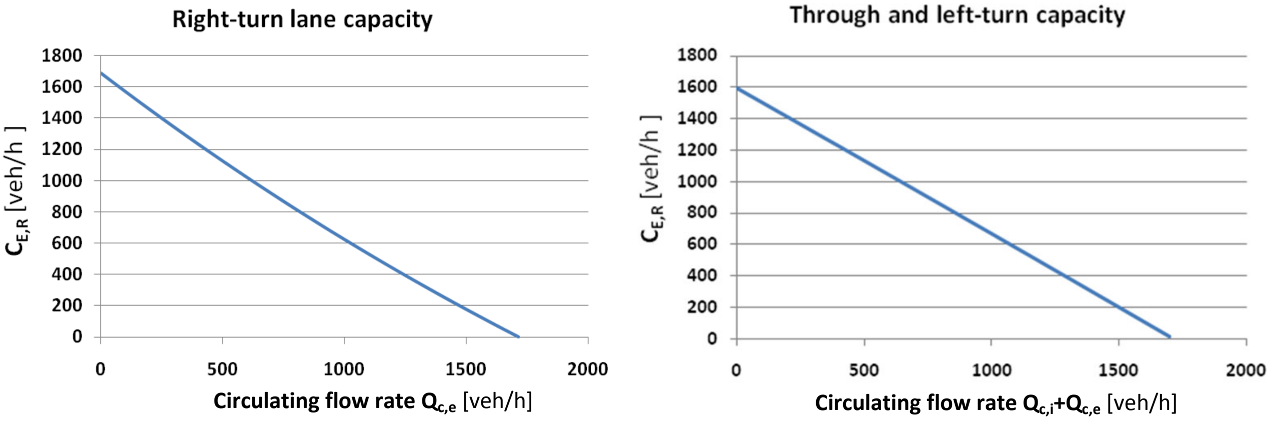

FIGURE 5 Lane Capacity

In the paper above cited (*6*) authors observed that each entering lane at turbo roundabout is characterized not only by different values of the capacity (C_i), but also by a different flow rate (Q_i); it results that the degree-of-saturation ($x_i = Q_i/C_i$) can differ between lanes of the same entry and then the total entry capacity is not a simple sum of the single lane capacities. For these reasons the effective entry capacity can be obtained by the following equations:

$$X = \max\left(\frac{Q_i}{C_i}\right) = \max(x_i) \quad \mathrm{i}=1,2 \tag{4}$$

$$\rho_i = \frac{x_i}{X} \tag{5}$$

$$C_E = \sum_{i=1}^{n}\rho_i \cdot C_i = \frac{\sum_{i=1}^{n} Q_i}{X} = \frac{(Q_{E,R} + Q_{E,TLT})}{\max[\frac{Q_{E,R}}{C_{E,R}}, \frac{Q_{E,TLT}}{C_{E,TLT}}]} \tag{6}$$

where:
x_i = degree-of-saturation at the lane *i* (demand flow rate/capacity ratio);
X = degree-of-saturation at the critical lane (lane marked by the highest demand/capacity ratio between the examined lanes);
ρ_i = utilization ratio at the lane *i*;

$Q_{E,R}$ = demand flow rate of the right-turn lane at the entry E;
$Q_{E,LTL}$ = demand flow rate of a through and left-turn lane at the entry E.

The following Figure 6 exemplifies the variation of entry capacities as a function of the utilization degree at lanes under given boundary conditions. The surface in Figure 6 has been developed through balanced flows at circulating lanes: $Q_{c,i} = Q_{c,e} = 500$ veh/h; the right-turn lane capacity is $C_{E,R} = 1127$ veh/h; the through and left-turn lane capacity is $C_{E,TLT} = 671$ veh/h.

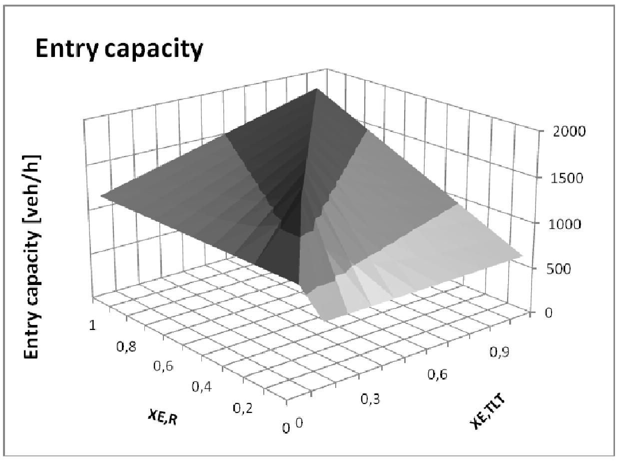

FIGURE 6 Entry capacity

CONVERSION OF EXISTING ROUNDABOUTS INTO TURBO ROUNDABOUTS: SOME CASE STUDIES FROM REAL WORLD

Three case studies concerning geometric and functional conversion of existing roundabouts into turbo roundabouts will be examined; they regard three large diameter intersections of the road network of Palermo City, characterized by irregular geometry.

These schemes are also quite different for their operational conditions and with regard to the context where they are put in: the first one (*Einstein Square*) is in urban area, but the other two roundabouts (*El Alamein Fallen Square* and *Simon Bolivar Square*) are placed in suburban area.

Einstein Square

From the geometric point of view the actual roundabout placed in *Einstein Square* is characterized as follows (see Figure 7a):

- variable width of circulating roadway, on average equal to 15 m;
- very large pseudoelliptical central island (area equal to 12,770 m^2);
- three lane roadway at entry A (quadrant South/West);
- two lane roadway at entry C (quadrant North/East);
- slight deflection of trajectories, particularly for vehicles coming from entries A and B.

Entering, circulating and exiting traffic flows are particularly high, because the roundabout sorts out traffic coming from Palermo City ring road to downtown. During the peak hours, for example, more than 2800 veh/h reach entry A.

On field surveys and the following functional analysis allowed to highlight very low level-of-service at entries; that could be ascribed both to the traffic demand level and to roundabout geometric design. Then, the considered roundabout has been redesigned inserting new specialized lanes at some entries and along the ring (where this was allowed by local constraints) and carrying out actually a semiturbo roundabout (see Figure 7b). Specifically, the current planimetric situation remains the same in the N/E and S/E quadrants, except for geometric changes in the curvature of the central island just opposite the entry C and for the installation of a new safety island. On the contrary, in the N/W and S/W quadrants new lanes have been planned to channel the traffic better than at present as like as a turbo roundabout; in particular a new left-turn lane for vehicles coming from the entry B and a new circulating lane opposite the entry A. Moreover, radii of curvature at the central island opposite entries A and C have been increased and a raised traffic island has been installed at the entry C.

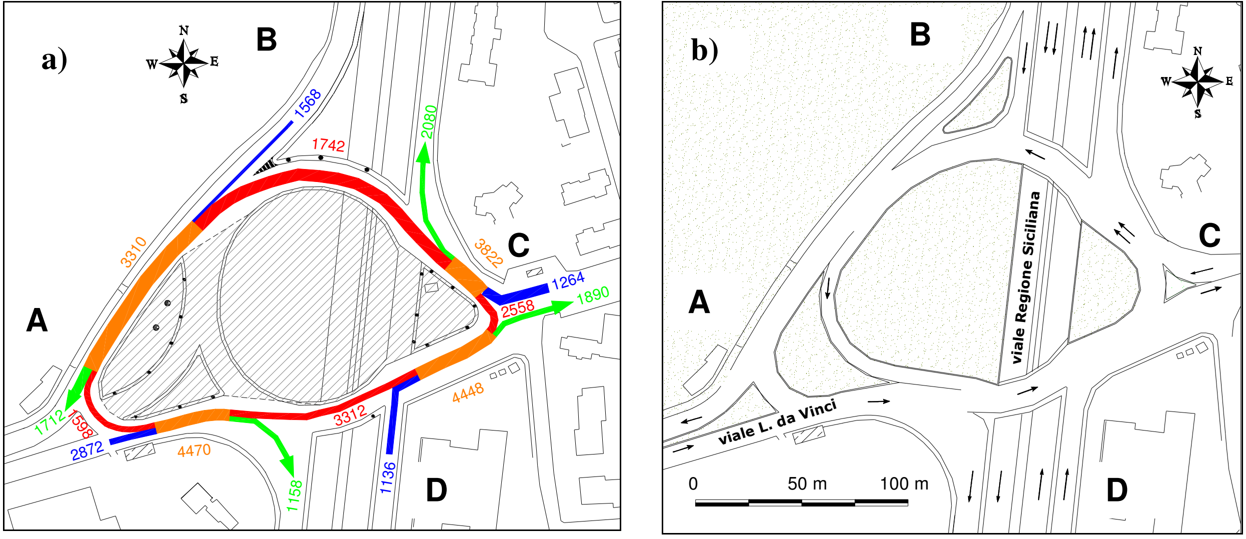

FIGURE 7 Einstein Square: a) the existing situation with traffic flowchart (time interval 8:30-9:30); b) the planned solution.

The main benefit of the new scheme is that vehicles coming from entry B and going to exit C do not come into direct conflict with vehicles entering from entry A (the critical one); so vehicles coming from entry A are faced by a conflicting traffic flow clearly lower than at present. It results that the suggested solution allows to reduce circulating vehicles opposite the entry A with a percentage near to 62 per cent in the time interval 8:30÷9:30 and near to 37 per cent in the time interval 9:30÷10:30 (see Table 2).

The entry A capacity has been obtained through the well-known relation developed by Brilon et al. (*8*) for usual modern roundabouts with three entering and circulating lanes, because no raised division exists among lanes. Critical gap and follow-on time have been assumed equal to 4.1 s and 2.9 s, respectively; minimum headway has been assumed equal to 2.1 s. After computing the entry capacity, it has been possible to determine the queue length in accordance with HCM 2000, chapter 17 (*9*).

Table 2 summarizes results obtained through analysis carried out both for the existing situation (i.e. the roundabout) and for the planned solution (i.e., the semiturbo roundabout). The last one allows to determine both an important increase of entry capacity (both in the time interval 8:30÷9:30 and in the time interval 9:30÷10:30) and a large decrease of the queue length (i.e. near to 59 per cent in the hour interval 8:30÷9:30 and near to 44 per cent in the hour interval 9:30÷10:30).

TABLE 2 Entering and circulating traffic flows at entry A.

ENTRY A	8:30÷9:30		9:30÷10:30	
	existing	plan	existing	plan
Entering traffic flow Qe [veh/h]	2872	2872	2224	2224
Circulating traffic flow Qc [veh/h]	1598	610	1454	912
Entry capacity C [veh/h]	670	2029	797	1473
Degree-of-saturation (Qe/C)	1,52	0,56	0,76	0,53
Queue length (95th percentile) [m]	783	38	59	36

El Alamein Fallen Square

High speeds, particularly in the night, characterize this suburban roundabout, because of large size and of irregular geometry; moreover, users do not respect the give-way rule because of insufficient deflection of trajectories. Both circumstances imply clear risks for safety. At the present, main geometric characteristics of this intersection are (see Figure 8a):

- roundabout ring with a variable width;
- pseudoelliptical central island with curvature varying in a wide range;
- sidewalk along the central island perimeter wide about 1.50 m;
- entry A (northbound) with two divided roadways by an irregular safety island near to 15.00 m in length;
- entry B (westbound) having one roadway. A triangular safety island to channel the traffic is installed near the entry, with width and length near to 28.00 m and 26.00 m, respectively;
- entry C (southbound) having two entering lanes; a triangular safety island wide near to 35.00 m and 46.00 m in length is installed.

The planned solution consists in a turbo roundabout with two circulating lanes having the following features (see Figure 8b):

- entry A with a triangular traffic divider 21.00 m wide. The entering roadway has two lanes divided by a safety island (curb and shoulder) wide about 1.50 m. The separation of entering lanes allows to identify one right-turn lane and one through/left-turn lane; occasionally the last one lane can become a right-turn lane because this maneuver is not restrained;
- entry B with a triangular safety island (width 35.00 m; length 40.00 m) in order to channel the traffic. Entering lanes are divided by a safety island large about 1.50 m;
- entry C has a new triangular safety island wide 44.00 m and 100.00 m in length. Differently from the other three entries, at the exiting lanes curbs are not present and then lanes are separated only by traffic signs;
- two circulating lanes face entries A and they are divided (as well as entries); only one circulating lane faces the entry B and C.

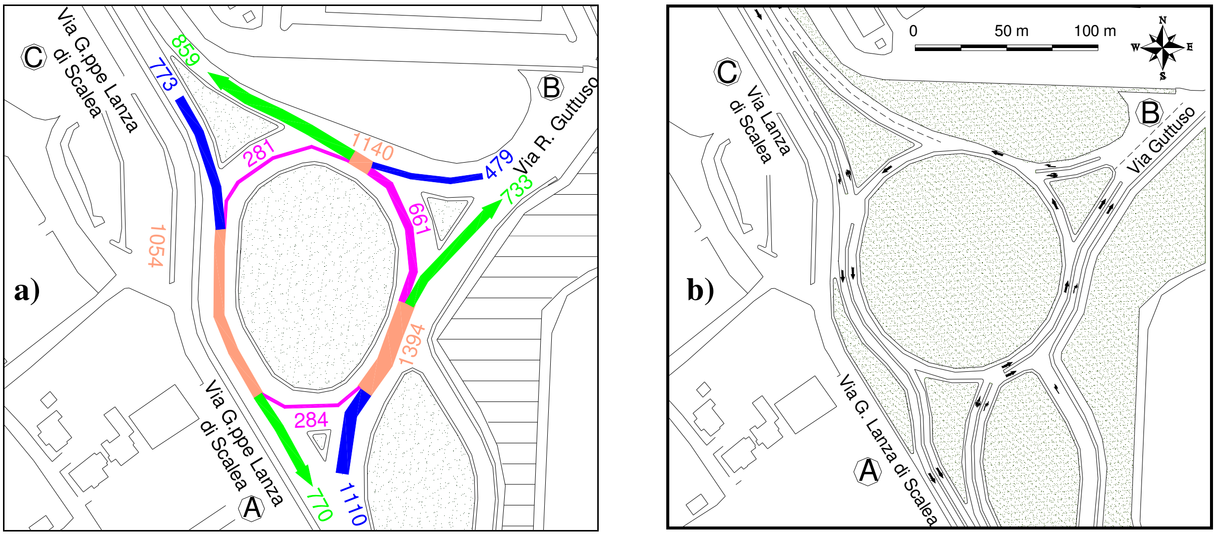

FIGURE 8 El Alamein Fallen Square: a) the existing situation with flowchart (ore 18:30-19:30); b) the planned solution (turbo roundabout with two circulating lane)

Starting from traffic data surveyed on June 2009 and from the deduced O/D matrixes for the time intervals 18:30÷19:30 and 19:30÷20:30, the study of the capacity offered by the turbo roundabout has been carried out through equation 2, 3 and 6. The mean delay values have been also computed by means of the equation suggested by HCM 2000 for unsignalized intersections (*9*). Table 3 summarizes the results of the analysis for the planned solution; they allow to conclude that very good Level-of-Services characterize each entry, also for the peak time interval. Only entry A reaches a Level-of-Service C in the time interval 18:30÷19:30; anyhow it can be considered largely satisfactory.

TABLE 3 Entry capacity and Level-of-Service.

Hour interval	entry	$Q_{E,R}$ [veh/h]	$Q_{E,TLT}$ [veh/h]	Q_E [veh/h]	Q_c [veh/h]	$C_{E,R}$ [veh/h]	$C_{E,TLT}$ [veh/h]	$x_{E,R}$	$x_{E,TLT}$	C_r [veh/h]	L.O.S.
18:30 ÷19:30	A	225	885	1110	284	1241	1065	0.2	0.83	1336	C
	B	198	281	479	942	553	613	0.4	0.46	1045	B
	C	244	529	773	281	1035	1067	0.2	0.5	1559	B
19:30 ÷20:30	A	172	599	771	284	1241	1126	0.1	0.53	1449	B
	B	107	252	359	428	927	971	0.1	0.26	771	A
	C	279	435	714	145	1135	1153	0.3	0.38	1359	A

Simon Bolivar Square

This 4-leg roundabout is placed at the North/West industrial area of Palermo City.

Starting from field observations carried out in July 2006, the considered roundabout can serve effectively the existing traffic demand; unless unusual events, traffic flows do not determine saturation conditions at entries.

The scheme is characterized by a not standard geometric design, especially for the following reasons:

- pseudoelliptical shape for the raised central island;
- variable width for the circulating roadway;
- geometric design of approaching road axes that causes improper perception of roundabout and, by consequence high speeds of entering vehicles;
- large area for weaving maneuvres being the cause of high speeds within the intersection.

For this case, considering the wide size of the present central island, a scheme with two turbo roundabouts placed side by side has been planned; each turbo roundabout has three entries and two circulating lanes (see Figure 9b).

In the new configuration of the intersection, the radius of the central island of each turbo

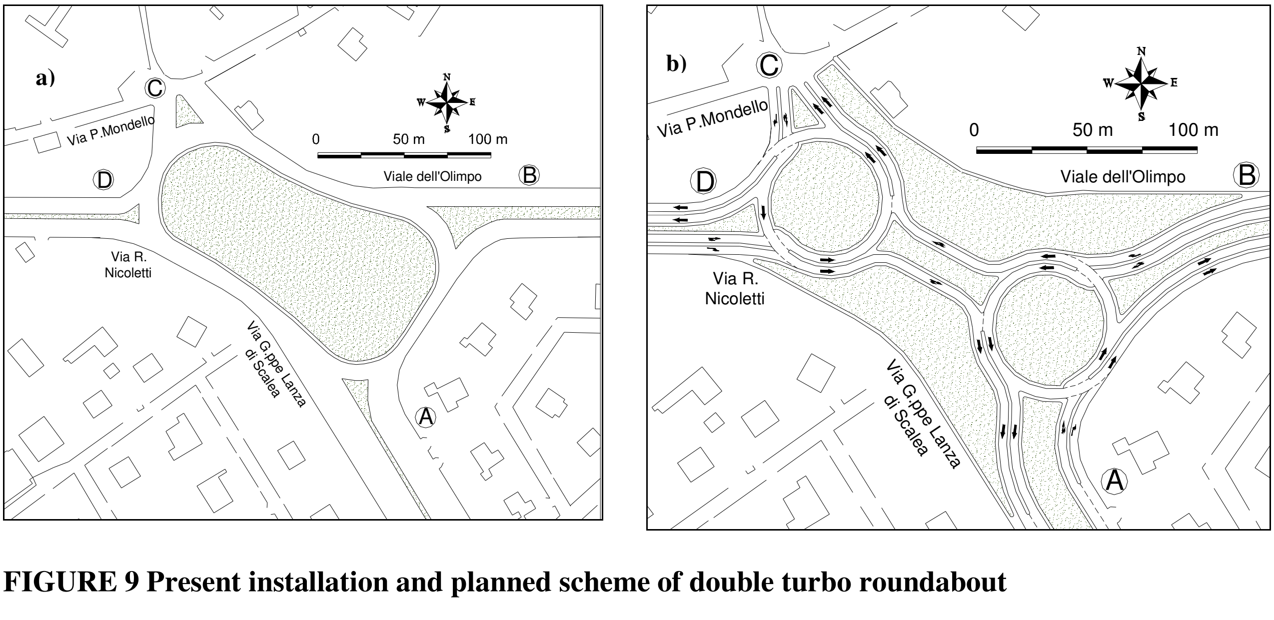

FIGURE 9 Present installation and planned scheme of double turbo roundabout

roundabout is equal to 28.00 m; the auxiliary leg introduced to link the two schemes spreads out about 55.00 m with two one-way divided roadways. Also for this case O/D matrixes have been built by traffic data for the time intervals 18:30÷19:30 and 19:30÷20:30; then simple capacity at each entry has been computed. Results for the planned scheme allow to observe very good Level-of-Services at entries, also for the peak time interval (see Table 4).

TABLE 4 Entry capacity and Level-of-service (18:30 ÷ 19:30; 19:30 ÷ 20:30)

leg	$Q_{E,R}$ [veh/h]	$Q_{E,TLT}$ [veh/h]	Q_E [veh/h]	$Q_{c,e}$ [veh/h]	$Q_{c,i}$ [veh/h]	Q_c [veh/h]	$C_{E,R}$ [veh/h]	$C_{E,TLT}$ [veh/h]	$x_{E,R}$	$x_{E,TLT}$	C_r [veh/h]	L.O.S.
A	35	154	189	120	0	120	1153	1168	0.03	0.13	1433	A
B	69	27	96	120	0	120	1153	1168	0.06	0.02	1604	A
C	9	60	69	163	0	163	1121	1141	0.01	0.05	1312	A
D	214	60	274	52	0	52	1203	1210	0.18	0.05	1540	A

CONCLUSIONS

Turbo roundabouts offer safety conditions potentially higher than usual roundabouts in relation to the particular shape of the central island and of circulating lanes, as well as to the physical separation of lanes both at entries and at circulating roadway.

Models usually applied to value operational conditions at roundabouts are not applicable to turbo roundabouts because of the right-of-way system and the particular conditions of turning maneuvers at turbo schemes. In fact, to value the simple capacity at entries first it needs to compute capacity at each lane constituting the same entry (lane by lane analysis). Moreover, at a turbo roundabout the capacity of a generic entry depends on circulating vehicles, on their distribution by circulating lanes and on the degree-of-utilization of each entering lane characterizing the considered entry.

Besides the above specified benefits, turbo roundabouts in some traffic conditions can offer capacities also higher than usual roundabouts. At this regard three case studies of roundabouts converted into turbo roundabouts have been developed; all the case studies concerned multilane large diameter schemes existing in the Palermo City road network, characterized by an irregular shape both of the central island and of the circulating lanes. Moreover some of the examined cases showed very high traffic flows, others high speed of entering vehicles particularly in the night time.

Each intersection has been examined preliminarily considering the geometric design, the regulation of traffic, the intensity of traffic flows and user behaviors. So for each intersection an alternative layout has been developed applying three schemes: a semiturbo roundabouts, a turbo roundabout with two circulating lane and a double turbo roundabout.

A functional analysis has been carried out in order to verify the compatibility with local traffic demand; for this analysis an appropriate theoretic-experimental model proposed by the authors has been applied.

Results show that very good levels-of-services characterize all the entries at two schemes (*El Alamein Fallen Square and Simon Bolivar Square*). In the remaining case (*Einstein Square*) an increase of capacity has been pointed out for the entry actually characterized by critical conditions; a significant reduction of the queue length has been also estimated.

After all, the study allows to conclude that the conversion of a roundabout into a turbo roundabout, against a limited economic investment (installation of raised curbs and rebordering of the central island) can determine high benefits both for safety (e.g. reduction of the point of conflicts and moderate speeds) and for operational conditions (e.g. good channeling for traffic flows and sometimes an increase of capacity). It is useful to highlight that the obtained results cannot be generalized. When a turbo roundabouts has to be also considered among different alternative plans, an in-depth study to compare performances of usual roundabouts and turbo roundabouts has to be carried out to identify geometric design suitable for the specific needs of the case under examination.

REFERENCES

1. Fortuijn, L.G.H.. Turbo Roundabouts: Design Principles and Safety Performance, CD-ROM. 88th TRB Annual Meeting. Washington D.C. (United States), 2009.
2. Turborotondes, CROW publicatie 257, April 2008.
3. Andrighettoni, C. and R., Mauro. Un nuovo tipo di incrocio a rotatoria [A new type of roundabout] – *Le Strade*, Ed. La Fiaccola, Milano (Italy), Vol. 1/2, No. 1434, 2008, pp. 17-23.
4. Mauro R. and F. Branco. Comparative analysis between turbo roundabouts and roundabouts, CD-ROM. 88th TRB Annual Meeting. Washington D.C. (United States), 2009.
5. Fortuijn, Lambertus (Bertus) G.H. Pedestrian and Bicycle-Friendly Roundabouts; Dilemma of Comfort and Safety- Presented at the Annual Meeting of the Institute of Transportation Engineers (ITE), Seattle, Washington (USA), 2003.
6. Giuffrè O., Guerrieri M. and A. Granà. Evaluating capacity and efficiency of turbo-roundabouts, CD-ROM. In 88th TRB Annual Meeting. Washington D.C. (United States), 2009.
7. Fortuijn, L.G.H. Turbo Roundabouts: Estimation of Capacity. Paper submitted to Transportation Research Record (United States).
8. Brilon, W., Bondzio L. and N., Wu. Unsignalized Intersection in Germany. A State of the Art. *2nd International Symposium for unsignalized intersection*, Portland/Oregon (USA), 1997.
9. HCM 2000, Highway Capacity Manual. Transportation Research Board, special Report 209, edition 2000.