PERFORMANCE ANALYSIS OF ROUNDABOUTS IN STRONGLY CONSTRAINED ENVIRONMENT. CASE STUDIES IN URBAN AREAS.

Granà Anna
Researcher – D.I.I.V. – Dipartimento di Ingegneria delle Infrastrutture Viarie- Università di Palermo
Facoltà di Ingegneria - Viale delle Scienze (Parco d'Orleans)
90128 Palermo (ITALY)
tel: +39 091 488062 – fax: +39 091 487068
email: granan@ing.unipa.it; gransergio@libero.it

Giuffrè Tullio
PhD student - DIIAR – Sezione Infrastrutture Viarie
Politecnico di Milano – P.le Leonardo Da Vinci 32
20133- Milano (ITALY)
tel: +39 02 2399 6701 – fax: +39 02 2399 6720
email: tullio.giuffre@polimi.it

ABSTRACT

The roundabout installations in urban areas are often conditioned by the existing constraints of different kind (particularly physical and topographical ones), compelling road engineers to make “compromise solutions” compared with the traditional geometric design standards of roundabouts; operational performances and risk conditions, in their turn, can be quite different from those known for modern roundabouts.

By the way, similarly to the wide range of local situations, a wide range of geometric layouts can be recognized in the existing not-conforming roundabouts; in these installation operational conditions still maintain some typical roundabout operating characteristics (first of all, traffic along the circulatory roadway), but, on the other hand (for example, for some movements), look like those typical of stop-controlled intersections.

The peculiarity of this kind of circular intersections, referred to as “Roundabout Inspired Intersections” (Granà and Giuffrè, 2004), makes very complex the conceptual formulation of intersection operations. It also increases the uncertainty to evaluate performances of the infrastructural organization, either in terms of efficiency of operational conditions or in regard to road safety.

Starting from these considerations, in a previous research (Granà, 2002) the opportunity to define for the subject intersections suitable risk indexes was considered.

Moreover, the general goal of this study is to explain and to value traffic operations and driver behaviours at not-conforming roundabouts, as above specified (RII).

For this purpose, three real case studies in Palermo City (corresponding to the same number of existing RI intersections), different for geometric layout and for type of give-way control (old priority rule: give way to entering vehicles and off-side priority: give way to circulating vehicles), have been examined.

The methodological approach assumes that operational performances at RI Intersections are intermediate between roundabouts and stop-controlled intersections and that methodologies suited to latter types of intersections, applying them to the single movement passing through the intersections, can be used in the analysis of RI Intersections.

Although results are not yet generalizable because of the little number of observations, they underline the capability of the suggested methodology to analyze operational conditions and to evaluate performances of atypical not-conforming schemes of intersections, for which a large range of cases can rise depending on traffic demand, geometrical configuration of the intersection and traffic control.

Keywords: roundabout, performance analysis, movements, priority of streams, operational performances.

PERFORMANCE ANALYSIS OF ROUNDABOUTS IN STRONGLY CONSTRAINED ENVIRONMENT. CASE STUDIES IN URBAN AREAS

PREMISE

The growing territorial diffusion of roundabout intersections, particularly later on the introduction of the off-side priority rule for circulating traffic ("the French system") in place of the old priority rule for entering traffic, is directly attributable to some characteristics of this type of intersection and in particular to:

- the flexibility of geometric features of roundabouts (central island radius, circulatory roadway width, possible coupling in the case of small roundabouts, etc), that allows the installation also in complex road intersections;
- the possibility of integration of the speed control criterion into road geometric design, that is a basic requisite to: i) assure the necessary consistency between speed and road environment passed through (that is necessary to make road environment coherent to the fixed speed limit); ii) improve road safety.

Nevertheless, the installation of roundabouts in urban areas is particularly conditioned by existing constraints of different kind (physical and topographical ones), that render necessary to make "compromise choices" relating to one or more geometric features of roundabouts.

This matter is very frequent in countries, as Italy, where disagreements between urbanization and growth of road network have produced the proliferation of not-conforming roundabouts, characterized by geometric features and operational conditions quite different from those observed at modern roundabouts.

The conceptual framework of this kind of circular intersections - "Roundabout Inspired Intersections", as named in a previous work to distinguish them from modern roundabouts (Granà and Giuffrè, 2004) – is quite difficult because of range of geometric layout assumed by them and the corresponding large variety of urban situations in which they are installed.

Moreover, the performance evaluations of these intersections can result unreliable, both in relation to effectiveness and in relation to road safety; that is why literature doesn't offer method specifically tested to estimate operational conditions for atypical schemes of junctions and rough adaptations of methodologies produced for other kind of intersections (for example, for roundabouts) can rise unacceptable approximations in results.

Performance evaluations are nevertheless necessary to study the numerous existing RI Intersections and, in particular, to carry out the preliminary analysis to their transformation.

Starting from these considerations, in a previous research (Granà, 2002) the opportunity to define for the subject intersections suitable risk indexes was considered; in the present paper, by the examination of some case studies, a methodology suited to interpret and to evaluate functional characteristics of not-conforming roundabouts - "Roundabout Inspired Intersections", RII, as mentioned before – will be proposed.

METHODOLOGICAL APPROACH

The basic concepts of the approach adopted in this paper is that operational conditions of RI Intersections, as shown by field observations, are intermediate between roundabouts and stop-controlled intersections; therefore, it can be hypothesized that performance analysis of the single movement passing through the RI Intersections can be made by typical methodologies of conforming intersections (roundabouts or twsc intersections).

In fact, differently from modern roundabouts, in RI Intersections is possibile to distinguish a major street, from which streams have absolute priority over the circulating traffic, and a minor street, from which the entry is controlled by the yield or stop sign.

Moreover, apart from provenance, circulating traffic can be stopped at give-way sign to complete the left turn movement; the same kind of traffic control can be present for through traffic from minor street.

Therefore, by a functional point of view, the main difference between RI Intersections and modern roundabouts comes from hierarchy of priority between streams passing through the intersection. In fact, for RI Intersections it can be observed as follows:

- for the major street streams, right-turning traffic and through traffic are movements of rank 1; left-turning traffic, in relation to own traffic control, can be movements of rank 1 or 2;
- for the minor street streams, right-turning vehicles always correspond to movements of rank 2; through traffic and left-turning traffic can be movements of rank 2 or 3, in relation to the traffic control.

All these considerations confirm that operational conditions at RI Intersections are intermediate between roundabouts and two-way stop-controlled intersections. Moreover, considering operational performances, the quality of the service depends on the quality of different movements, each one of them is characterized by own priority rank of right-of-way.

Starting from the above considerations, the methodology proposed for the analysis of the RI Intersections has considered for each movement the preliminary calculation of:

a. conflicting traffic flows ($q_{c,ij}$), which is the total flow rate of a single fictitious stream, computed as the sum of flow rates to which right of way must be given and to which weighting factors have to be attributed in relation to their influence on the subject movement.

Literature data have been considered as a reference for the attribution of the weighting factors. When it is applicable, relevant indications reported by HCM (HCM 2000) for two-way stop-controlled intersections have been assumed; nevertheless, considering geometric design of the examined intersections and the trajectory of movements, a weighting factor equal to 1 has been generally attributed to left-turning traffic from the major street.

b. potential capacity of movements of rank different from 1, computed in accordance with Harders's equation (see Harders, 1968; HCM 2000, charter 17, eq. 17-3):

$$c_{p,ij} = q_{c,ij} \cdot \frac{e^{-\frac{q_{c,ij} \cdot t_{c,ij}}{3600}}}{1 - e^{-\frac{q_{c,ij} \cdot t_{f,ij}}{3600}}} \tag{1}$$

where:

$c_{p,ij}$ = potential capacity of movement *ij* (veh/h)

$q_{c,ij}$ = conflicting flow rate for movement *ij* (veh/h)

$t_{c,ij}$ = critical gap (sec)

$t_{f,ij}$ = follow-up time (sec)

Assumptions about critical gap and follow-up time have been made in reference to the specific movement as it will be described later.

For the analysis of movements of rank 3 using a storage space, a two-stage gap-acceptance process has been considered in accordance with the analytical model offered by HCM 2000 for twsc intersections (HCM 2000, chapter 17); so, for each stage, the potential capacity has been computed considering values of conflicting traffic flows, critical gap and follow-up time suited to the subject stage.

The method offered by HCM 2000 for twsc intersections (HCM 2000, eq. 17-38) has been used to estimate the control delay of each particular movement; as it is known, it considers the waste of time for deceleration of vehicles from free-flow speed to the speed of vehicles in queue and acceleration to depart from the stop line, the time in case spent queuing up and at the stop line waiting for execution of the manoeuvre.

THE CASE STUDIES IN URBAN AREAS

Three real case studies of RI Intersections in Palermo City have been selected to assess the applicability of the proposed method. Geometric characteristics and type of give-way control were as follows:

– the first intersection (see figure 1), Diodoro Siculo Square (RII_1), results from five-leg organized around a central island with a very small radius (3,6 m), typical of small roundabouts.

All approaches are one-way only (three are entry approaches and two are exit approaches).

Streams entering from approach 3 have absolute priority, whereas entering vehicles coming from approaches 2 and 4 are controlled by stop sign. The intersection is on a level grade.

Depending on geometric layout and type of give-way control, the different movements at the intersection are characterized by the following rank of priority:

Movement	Priority	Number of Stages	Movement	Priority	Number of Stages
3/1	1	-	2/5	2	1
3/5	1	-	4/1	2	1
2/1	2	1	4/5	2	1

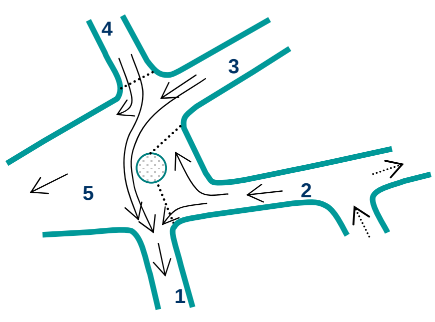


FIGURE 1 RII_1

TABLE 1 Traffic flow matrix of RII_1

O/D	1	2	3	4	5
1	0	0	0	0	0
2	68	0	0	0	148
3	204	0	0	0	528
4	92	0	0	0	60
5	0	0	0	0	0

Table 1 shows the peak 15 min flow rates (veh/h) of each movement; the flow rates were recorded during the peak 15 min of the early peak hour (7.30-8.30 a.m.).

- The second one (see figure 2), Oreto Intersection (RII_2), is a pseudo-roundabout having a large elliptic central island (d_{min} = 41,7 m e d_{max} = 80,7 m). In the subject intersection, it is possible to identify a major street (way 2/3 and way 3/2), consistent with a divided suburban two lanes highway.
  Close to the intersection area, major street lanes are divided by a large triangular traffic island (l_{max} = 32 m); a storage space between the central island and the triangular one is passed by the major/minor left-turning vehicles and by through traffic from minor.
  The minor street (approach 1) has four lanes divided by a central island; the entry is controlled by the stop sign. On the opposite side of the minor street there is an entry (BL) into a service road, along which there are commercial stores. The intersection is on a level grade.
  Depending on geometric layout of intersection and type of give-way control, the different movements are characterized by the following rank of priority:

Movement	Priority	Number of Stages
2/1	2	1
2/3	1	-
2/BL	1	-
1/2	2	1
1/3	3	2

Movement	Priority	Number of Stages
1/BL	3	2
3/1	1	-
3/2	1	-
3/BL	2	1

The flow rates (veh/h) of each movement, recorded during the peak 15 min of the early peak hour (7.30-8.30 a.m.) are shown in table 2.

TABLE 2 Traffic flow matrix of RII_2

O/D	1	2	3	BL
1	0	84	84	16
2	229	0	1068	80
3	356	836	0	32
BL	0	0	0	0

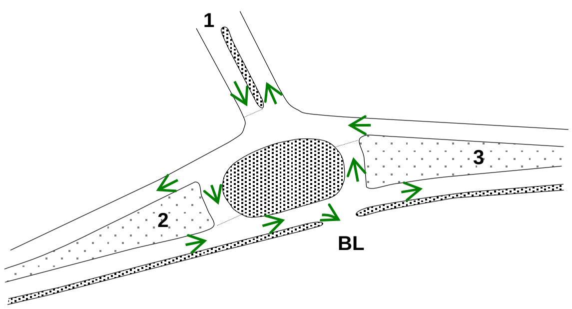


FIGURE 2 RII_2

- The last one (see figure 3), Armstrong Square (RII_3), is a 6-leg pseudo-roundabout having an elliptical central island of medium size (d_{min} = 15 m e d_{max} = 25 m).
  Streams entering from approaches 1, 2 and 5 have absolute priority (the approach 2 is one-way only). The approaches 3, 4 and 6 are one-way only (in particular, 3 and 6 are entry approaches and 4 is an exit approach) and are controlled by the stop-sign.
  As in the previous intersection, some movements use the storage space by the central island and consist of two parts, each one of them is controlled by the stop-sign.
  All approaches have two-way lanes. The intersection is on a level grade.
  The ranking of the different movement resulting from geometric layout and type of give-way control is the following one:

Movement	Priority	Number of Stages
2/1	2	1
2/4	1	-
2/5	1	-
1/4	2	1
1/5	2	1
5/1	1	-

Movement	Priority	Number of Stages
5/4	2	1
3/1	3	2
3/4	2	1
3/5	2	1
6/1	2	1
6/4	3	2

The flow rates (veh/h) of each movement, recorded during the peak 15 min of the early peak hour (7.30-8.30 a.m.), are shown in table 3.

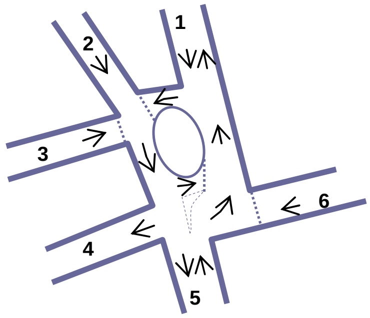


FIGURE 3 RII_3.

TABLE 3 Traffic flow matrix of RII_3.

O/D	1	2	3	4	5	6
1	0	0	0	32	28	0
2	84	0	0	96	124	0
3	32	0	0	32	36	0
4	0	0	0	0	0	0
5	272	0	0	48	0	0
6	44	0	0	36	0	0

CONFLICTING TRAFFIC FLOWS IDENTIFICATION AND BEHAVIOURAL ASSUMPTIONS

Apart from movements having right of way, the possible manoeuvres present at the examined RI Intersections are referable to four basic schemes:

A. Left-turning traffic from the major street
B. Right-turning traffic from the minor street
C. Through traffic on the minor street
D. Left-turning traffic from the minor street.

For each one of them, the conflicting traffic flows and the behavioural parameters (critical gap t_c and follow-up time t_f) have been assumed as follows.

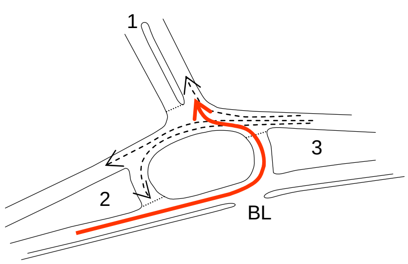
A. Left-turning traffic from the major street

The left-turning traffic from the major street is considered in the analysis when, depending on the geometric design and the traffic control, it is a movement of rank 2 (see Figure 4).

In this case, the major left-turn movements has to give way to all the streams coming from the opposing approach on the major street; these also include the major right-turning vehicles (in absence of a triangular island and a yield or stop sign) and the opposing major left-turning vehicles which have to comply with a stop sign beyond the entry point of the subject movement.

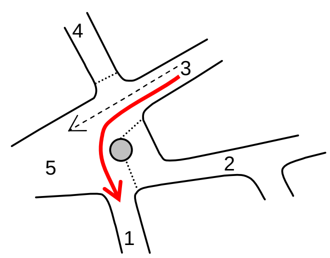
In analogy to twsc intersections, each conflicting stream is characterized by a weighting factor equal to 1. Likewise, the values for the critical gap and the follow-up time are assumed respectively equal to t_c =4,1 s and t_f =2,2 s; these values have been applied to left-turning vehicles from the major street independently of the number of existing lanes (HCM 2000, Exhibit 17-5). No adjustment for heavy vehicles has been applied to these basic values because of the observed low incidence of heavy vehicles in the traffic stream.

When the left-turning vehicles from the major street aren't blocked by opposing stream (see Figures 5), the movement has rank 1 and it doesn't influence the results of the analysis.



major into minor - $q_{C_{2/1}} = q_{3/1} + q_{3/2} + q_{3/BL}$

FIGURE 4



major into minor (priorità 1)

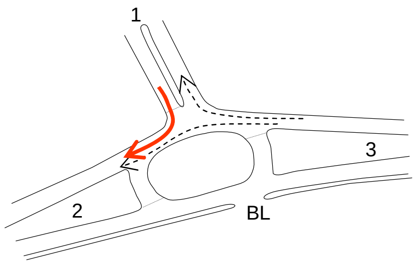
FIGURE 5

B. Right-turning traffic from the minor street

The right-turning traffic from the minor street has to comply with a stop sign before entering the intersections. Therefore, it is a movement of rank 2 (see Figures 6a and 6b).

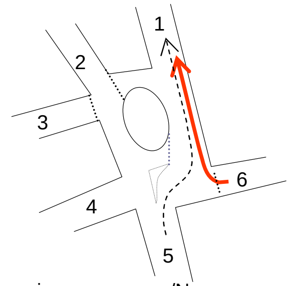
In the observed cases, the subject movement showed strong analogy with the corresponding movement at the twsc intersections. Therefore, the conflicting stream is represented by the major-street through movement in the right-hand lane into which right turners merge, assumed as 1/N of the entire stream (N is the number of the through lanes). Analogously, one-half of the right-turn movement from the major street is also included in the conflicting stream, considering that some of these turns inhibit the subject movement.

Consistently with the established analogy, the critical gap and the follow-up time have been assumed respectively equal to t_c = 6,2 s (6,9 s, for four-lane major streets) and to t_f = 3,3 s (HCM 2000, Exhibit 17-5).



minor into major – $q_{C_{1/2}} = q_{3/2}/N + 0,5\ q_{3/1}$

FIGURE 6a



minor into major - $q_{C_{6/1}} = q_{5/1}/N$

FIGURE 6b

C. Through traffic on the minor street

A movement of rank 3 agrees generally with this kind of stream (see Figure 7a e 7b); in particular case (for example, major street one-way only), the priority has to be given only to streams coming from the left and the corresponding movement has priority of rank 2 (see Figure 7c).

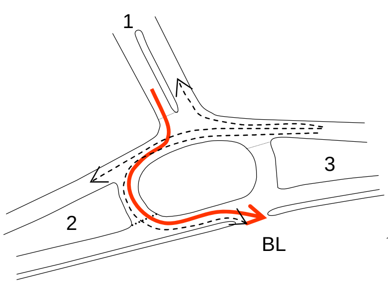
In the examined cases, movements of rank 3 could make use of a storage space by the central island; therefore, the through movement has been assumed to consist of two parts, in each one of them the proper conflicting flows of the major-street have been considered.

The gap acceptance process for each stage of these movements has been considered comparable to that one in the entry into roundabouts. Consequently, the conflicting flows has been assumed equal to traffic passing close to entries (similarly to circulating traffic at roundabouts); a share of the right-turning traffic from the major street (0,5) has been added to conflicting flows to consider the influence of these turning manoeuvres on the subject movement, similarly to the right-turning traffic from the minor street (see above, item B).

In each stage, the critical gap and the follow-up time have been assumed equal to t_c=4,6 s and t_f=3,1 s respectively, in accordance with literature values for entering flows at roundabouts (Luttinen R. Tapio, 2004; HCM 2000).

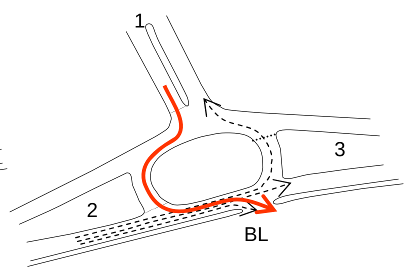
The total capacity for the subject movement (considering the total conflicting flow rate) has been computed by the procedure recommended by HCM (HCM 2000, eq. 17-32, 17-33).

Because of geometric design of intersections (specifically the size of central island), a different gap acceptance process has been hypothesized for through traffic on the minor street having rank 2, for which driver behaviours similar to that one of the corresponding twsc movements have been observed. Then the conflicting flows have been identified according to the above-mentioned hypothesis and the critical gap and the follow-up time have been assumed respectively equal to t_c=6,5 s e t_f=4 s (HCM 2000, Exhibit 17-5).



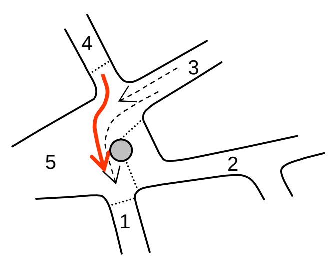
I stage
$q_{C,I_{1/BL}} = q_{3/2} + q_{3/BL} + 0,5\ q_{3/1}$

FIGURE 7a



II stage
$q_{C,II_{1/BL}} = q_{2/1} + q_{2/3} + q_{2/BL}$

FIGURE 7b



minor through
$q_{C_{4/1}} = q_{3/5} + q_{3/1}$

FIGURE 7c

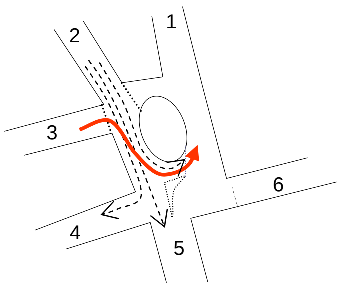
D. Left-turning traffic from the minor street

This kind of movement has characteristics similar to that one just seen for through traffic on minor street. In fact, also in this case, the movement of rank 3 (see Figure 8a e 8b) can use a storage space by the central island and consists of two subsequent parts with right of way to priority streams of major street.

Differently from previous case (through traffic on the minor street), in the second stage the left-turning vehicles merge into the major-street movement in the left-hand lane; the conflicting stream is then represented by the left-turning vehicles on the major street and by the share of the major street through movement running on the left-hand lane (1/N of the entire stream, where N is the number of the through lanes).

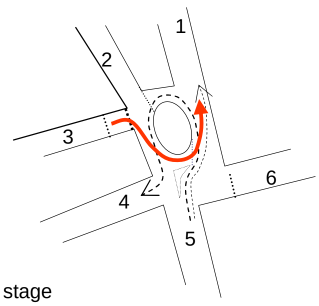
Likewise for the minor street through movement, the values of the critical gap and the follow-up time have been assumed with reference to entering manoeuvres at roundabouts and the total capacity for the subject movement (considering the total conflicting flow rate) has been computed by the procedure recommended by HCM (HCM 2000, eq. 17-32, 17-33).

The case of movement of rank 2, because of the kind of entering manoeuvre and geometric features of intersections (see Figure 8c), has been considered equivalent to minor street left-turning movements at a twsc intersection (HCM 2000, Exhibit 17-4).



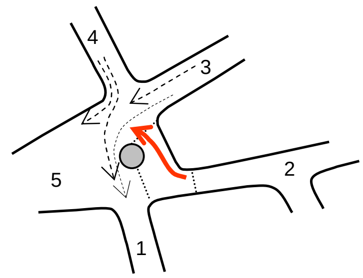
I stage
$q_{C,I_{3/1}} = q_{2/1}+q_{2/4}+q_{2/5}$

FIGURE 8a



II stage
$q_{C,II_{3/1}} = (1/N)\cdot q_{5/1}+q_{5/4}$

FIGURE 8b



minor into major
$q_{c_{2/5}}=2\cdot q_{3/1}+q_{3/5}/N+0{,}5\cdot q_{4/1}+0{,}5\cdot q_{4/5}$

FIGURE 8c

CASE STUDIES RESULTS VALIDATION

For each case study, the application of the previously described method has required the computation of conflicting traffic flows (veh/h) of movements of rank ≥ 2 and the computation of potential capacity (veh/h), by eq. 1. No additional adjustments because of the effects of upstream signals and for impedances have been considered; the examined intersections were, in fact, enough far from signalized intersections and no movement of rank 3 was impeded by any of movements characterized by higher priority forming a queue.

Considering that, in the examined situations, entering flow rates where enough far from capacity (degree of saturation less than 0,5), the control delay (sec/veh) has been computed for each movement by eq. 17-38, HCM 2000 (model delay).

For validating the hyphothesis assumed in this paper, the model capacity (i.e. the predicted capacity based on traffic and behavioural characteristics assumed) has been tested against the field capacity, i.e. the true capacity measured in the field.

The field capacity has been estimated by Kyte's equation (Kyte et al., 1992, 1997), that is valid for unsignalized intersections which are undersaturated (i.e. no continuous queue):

$$c_n = \frac{3600}{t_s + t_{mv}} \tag{2}$$

where:

c_n = field capacity for the minor stream or minor street approach, veh/h

t_s = the average service delay of vheicles once they arrive at the stop line, s (duration from when a vehicle reaches the stop line until it exits the stop line)

t_{mv} = the average move-up time from second position to reaching the stop line, s .

For each approach of the examined intersections, the service delay has been measured for 5' intervals and averaged for all the minor stream vehicles that passed through the intersection during the interval.

The move-up time has been measured as amount of time from when the previous vehicles exits the stop line until the subsequent queued vehicle reaches the stop line. Considering that the estimate of move-up time needs at least one vehicle queued, enough data points have been collected lengthening till 15 min the period of field observations; for the examined case studies the follow-up time is resulted included between 2,5 s e 3 s.

The quality of goodness of fit has been evaluated by the mean ablosute percent error (Mape), defined as follows:

$$Mape = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{c_m^i - c_f^i}{c_f^i}\right| \tag{3}$$

where n in the number of data points, c_m^i is the model capacity (veh/h) and c_f^i is the field capacity (veh/h).

The R squared value has been also calculated as supplemental parameter of goodness of fit.

The results of computations developed for the three case studies are summarized in tables 4, 5 and 6; the results of the test against the collected field data are elaborated as shown in figure 10.

TABLE 4 RII_1

MOVEMENT	CONFLICTING TRAFFIC (veh/h)	MODEL CAPACITY (veh/h)	FIELD CAPACITY (veh/h)	MODEL DELAY (sec/veh)
(2/1)	454	559	494	12,33
(2/5)	748	305	365	27,48
(4/1)	732	351	349	18,87
(4/5)	264	741	628	10,28

TABLE 5 RII_2

MOVEMENT	CONFLICTING TRAFFIC (veh/h)	MODEL CAPACITY (veh/h)	FIELD CAPACITY (veh/h)	MODEL DELAY (sec/veh)
(2/1)	1224	577	539	15,29
(3/BL)	1377	504	506	12,61
(1/2)	596	452	455	14,77
(1/3)	1809	395	282	16,56
(1/BL)	2423	283	250	18,48

TABLE 6 RII3

MOVEMENT	CONFLICTING TRAFFIC (veh/h)	MODEL CAPACITY (veh/h)	FIELD CAPACITY (veh/h)	MODEL DELAY (sec/veh)
(2/1)	184	993	857	8,96
(6/1)	136	894	855	9,23
(3/5)	158	866	766	9,34
(3/4)	158	866	788	9,32
(3/1)	488	828	720	9,52
(1/4)	304	1268	878	7,91
(1/5)	304	1268	878	7,90
(5/4)	304	1268	878	7,95
(6/4)	800	690	600	10,51

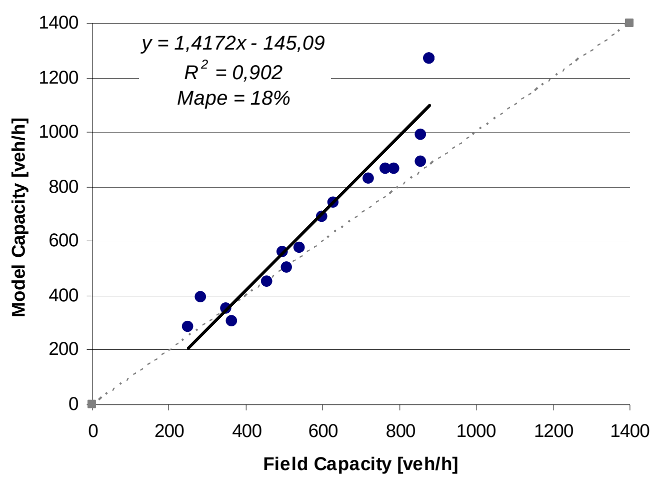


FIGURE 10

CONCLUSIONS

The goodness of fit between model capacity and field capacity values is indicative of the reliability of the hypotheses assumed in the analysis of the main movements at RI Intersections, whether they regard weighting factors conferred to conflicting flows or they concern the gap acceptance process.

Although experimental observations concern only few case studies, the obtained result shows that is possible to extend the applicability of usual analysis method for conforming intersections (e.g. that one suggested by HCM for roundabouts and two-way stop-controlled intersections) even to atypical intersections, i.e. Roundabout Inspired Intersections.

This on condition that for each movement of RI intersections an analogy with the corresponding movement of conforming intersections is established and the appropriate traffic and behavioural parameters (traffic conflicting flows, critical gap and follow-up time) are then deduced.

On searching for the above-mentioned analogy it must be underlined the influence of organization and geometric characteristics and particularly of central island size on definition of weighting factors assigned to different conflicting flows and user behaviour. A relevant example on this matter is the case of left-turning movements from minor street that, as the case may be, are comparable to roundabout entering movements or to a left-turning movement from minor street at twsc intersections.

More in general the obtained results confirm the basic hypothesis of this paper, i.e. the operational conditions of RI Intersections are intermediate between roundabouts and stop-controlled intersections; they also are an encouraging starting point to encode different types of existing not-conforming roundabouts and methods more appropriate to examine performances of their manoeuvres.

From this point of view, the accuracy of the analysis can be increased carrying out an experimental verification of parameters that more can determine uncertainty in the results; between these, in particular, behavioural parameters characterizing each movement (critical gap and follow-up time), assumed in this paper with only reference to literature values.

REFERENCES

- Harders, J. (1968). *The capacity of unsignalized urban intersections (Die Leistungsfaehigkeit nicht signalgeregelter staedtischer Verkehrsknoten*). Schriftenreihe Strassenbau und Strassenverkehrstechnik, Vol. 76, 1968.
- Granà A., “*Criteri di sicurezza per la valutazione preventiva del rischio di sistemazioni atipiche. L’analisi per scenari infrastrutturali*”. In Atti del XXIV Convegno AIPCR, pp. 430-439. Saint Vincent (Aosta), Giugno 2002.
- Granà A., Giuffrè T., “*Accident Phenomenology Valuation at Circular Intersections. Probabilistic Approach to Case Studies in Urban Area*”. In Act of The II International SIIV Conference, Florence - October, 2004.
- Kyte M., Clemow, N. et al. "*Capacity and delay characteristics of two-way stop-controlled intersections*" Transportation Research Record 1320, Transportation Research Board, Washington, D.C., 1992.
- Kyte, M., Z. Tian, Z. Mir, Z. Hameedmansoor, W. Kittelson, M. Vandehey, B. Robinson, W. Brilon, L. Bondzio, N. Wu, and R. Troutbeck. NCHRP Web Document 5: *Capacity and Level of Service at Unsignalized Intersections: Final Report*, Vol. 1—Two-Way Stop-Controlled Intersections. 1997.
- Luttinen R. Tapio, *Capacity and Level of Service at Finnish Unsignalized Intersections. S12 Solutions to improve main roads*. Finnra Reports 1/2004. Finnish Road Administration, 2004.
- Transportation Research Board, “*Highway Capacity Manual – HCM 2000*”, Special report n°209, Washington D.C., 2000.