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Comparing Performances of Turbo-roundabouts and Double-lane Roundabouts

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Abstract

Starting from assumptions regarding the arrival process of circulating streams and according to models based on the gap-acceptance theory, the paper is aimed at comparing operational performances between basic turbo-roundabouts and double-lane roundabouts. The paper proposes applications of the Hagring model for entry capacity estimations at double-lane roundabouts and turbo-roundabouts, these latter, in particular, featured by movements with only one or two conflicting traffic streams. This model allows to use, in fact, a bunched exponential distribution to quantify the distribution of major vehicle headways; it also considers specific values different by each lane for behavioural parameters, minimum headway and conflicting traffic flow on circulating lanes.

The results obtained for the two cases examined, although influenced by the underlying assumptions, especially with regard to user behaviour at turbo-roundabouts, can give information about the convenience in choosing, at a design level, a basic turbo-roundabout rather than a double-lane roundabout. The comparison developed in this paper, indeed, can be helpful in selecting the type of roundabout and in particular in evaluating performance benefits that are obtainable from the conversion of an existing double-lane roundabout to a turbo-roundabout with similar footprint of space.

Keywords: turbo-roundabout, traditional roundabout, operating performaces

1. Introducation

1.1 Introducing the Problem

Turbo-roundabouts represent a new type of circular intersection which were designed to improve safety performances at modern roundabouts, already widely spread in the world, without compromising their efficiency. The turbo-roundabout is a specific kind of spiralling roundabout developed in The Netherlands by Fortuijn in the late 1990's. Fortuijn developed turbo-roundabouts in an attempt to deal with the drawbacks of double-lane roundabouts: while double-lane roundabouts have a higher capacity than single-lane roundabouts, they have the disadvantage of a higher driving speed through the roundabout and lane changing on the ring, hence raising the crash risk. Turbo-roundabouts were, indeed, introduced to deal with the entering and exiting conflicts occurring at double-lane roundabouts; these conflicts are eliminated at turbo-roundabouts by directing drivers to the correct lanes before entering the intersection and introducing spiral lines that guide them to the correct exit. On design principles and geometric elements of a turbo roundabout, as well as different variants of the turbo-roundabout progressively introduced in The Netherlands, can be seen e.g. Fortuijn (2009a). Other European experiences with turbo-roundabouts are referred by Brilon (2008) and Tollazzi et al. (2001).

An exhaustive evaluation of safety performances at turbo-roundabouts is not yet available because turbo-roundabout installations are still recent. It follows that the design choice between a standard double-lane roundabout or a basic turbo-roundabout can be carried out through convenience evaluations in terms of operating performances. Operating performance evaluations at turbo-roundabouts can be more complicated than roundabouts. It is should be specified that, although in both circular intersections entering vehicles must give priority to circulating vehicles, drivers before entering the turbo-rundabout have to make necessarily the choice of their destination, being forced to enter in circulating lanes physically separated by raised lane dividers.

1.2 Relevant Concepts on Capacity Models at Roundabouts

A starting point for evaluating operational performances at roundabouts and turbo-roundabouts can be represented by capacity methods for two-way-stop-controlled intersections, where vehicles on major streams have priority and vehicles on minor streams are controlled by stop. There are two primary capacity models for describing this traffic situation and computing capacity estimates: linear or exponential empirical regression models, based on observed geometric and traffic flow parameters; analytical capacity models based on gap acceptance theory. However, capacities estimated through these models can widely differ between one model and another (see e.g. Al-Madani & Saad, 2009).

Empirical regression models are based on traffic observations surveyed during short time intervals (e.g. one-minute intervals) in oversaturated conditions; then a linear or exponential regression equation is fitted to the data or a multivariate regression equation needs to be developed to take account of variation in the data caused by user behavior and geometric design features. In order to develop a regression model each traffic pattern and/or geometric situation have to be surveyed; for this purpose, a large number of operational data have to be collected. Nevertheless, empirical regression models may have poor transferability to other countries or at other times (see e.g. Pratelli & Al-Madani, 2011). Moreover, regression models do not facilitate the comprehension of the underlying traffic flow theory of determining and accepting gaps upon entering the intersection (Rodegerdts et al., 2007). According to gap acceptance models, drivers before entering the intersection have to choice an acceptable gap on the major stream; the minimum gap accepted by minor-stream drivers is the critical gap. It should also be noted that, when bunched vehicles moving along a major stream form a vehicular block, minor-stream drivers can enter the conflicting stream having priority, only when the gap following the last vehicle in the block is equal to or greater than the critical gap (Tanner, 1962). The driver behaviour variability makes that the critical gap is not a constant value, but is represented by a distribution of values. Moreover, estimation procedures for critical headway do not require sites with oversaturated conditions. Another behavioural parameter is the follow-up time, defined as the time headway between two consecutively entering vehicles, utilizing the same gap in major or circulating traffic flows at roundabouts; it can be directly surveyed on-field (Rodegerdts et al., 2007). The arrival headways in conflicting stream have to be evaluated for modeling gap-acceptance process. Thus capacity models founded on the gap-acceptance theory need to specify the probability distribution of headways between vehicles in the major stream. Capacity models homogeneous each other should be used by manoeuvre type, especially where intersections perform multiple turning movements.

Technical literature proposes exponential arrival headway distribution models: negative exponential distribution, shifted negative exponential distribution and shifted negative bunched exponential distribution. The latter was introduced by Cowan (1975; 1987) and was adopted by several authors; see eg Troutbeck (1990). Properties of the bunched exponential distribution, or otherwise known as Cowan's M3 headway distribution, were also explained by Luttinen (1999). Hagring (1998) derived the capacity of a minor traffic stream hampered by independent major streams (to cross or in which a minor stream has to merge), each of these latter featured by a bunched exponential distribution. This dichotomized distribution assumes that a proportion of all vehicles are free within each major stream and have a displaced exponential headway distribution; bunching models for parameter estimations were developed by several authors; in this regard, the reader is invited to consult the specialized literature on the subject.

1.3 Research Aims and Specific Objectives of the Paper

Recent technical literature has already proposed some studies aimed at comparing schemas of roundabouts with different geometric configuration or mode of operation, but with similar footprint of space. In the absence of suitable models to interpret the operation mode and, more in general, operating performances of schemas from time to time considered, models developed for similar patterns of intersection have been often used (see Giuffrè et al., 2012; Mauro & Branco, 2010; Giuffrè et al., 2008). The question also relates to turbo-roundabouts that, as anticipated, are of recent conception and realization.

In this paper Authors intended to assess operational performances of turbo-roundabouts and double-lane roundabouts. The schemes of standard turbo-roundabout and double-lane roundabout here examined to compare performances are shown in Figures 1 and 2. Greater consistency in assumptions was evidenced with reference to the arrival process of traffic major streams on the ring. Furthermore, for pursuing the above stated objective, entry capacity estimations were obtained by applying models founded on the gap acceptance theory. In order to analyze and compare operating performances between the circular intersections depicted in Figures 1 and 2, the Hagring capacity formula was applied to the schemes under examination (Hagring, 1998). It must be said that the convenience of the two types of roundabouts here considered was estimated in terms of degree-of-saturation and mainly in terms of delay experienced by entering vehicles, considering the latter related to the level of service quality.

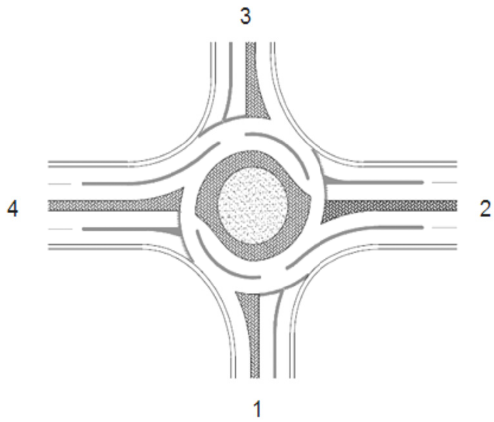


Figure 1. Basic turbo-roundabout

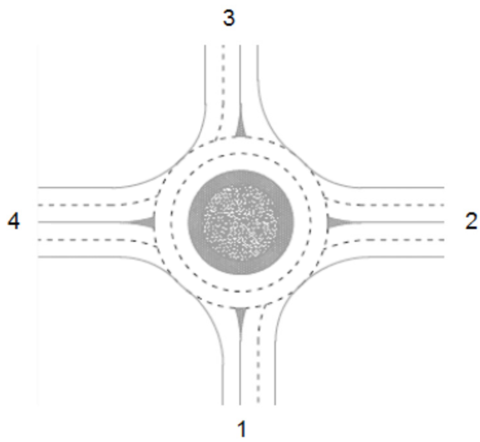


Figure 2. Double-lane roundabout

Description: schemes of standard basic turbo-roundabout (Figure 1) and double-lane roundabout (Figure 2) under examination; it should be noted that a priority was created for legs: legs 2 and 4 are here assumend as major entries and legs 1 and 3 as minor entries.

2. Method

In order to obtain a selection criterion for a given distribution of traffic demand, operational performances of schemes in Figures 1 and 2 were examined. The approach adopted to compare the two types of circular intersection was derived from the method developed by Mauro and Branco (2010) and also applied to compare operating performances between circular patterns of intersection, albeit different from those here studied. More specifically, the approach before quoted was adopted in order to obtain domains of convenience for the turbo-roundabout and the double-lane roundabout examined in undersaturated flow conditions and to evaluate operating advantages deriving from the choice of one or the other roundabout scheme. It should be noted that, not only this paper reports a comparison between geometric patterns of intersection different from those considered by the above cited Authors, but also different assumptions were made on conflict patterns between entering and circulating vehicles; this concerns, in particular, traffic flows faced by left turning movements from minor roads and models adopted to perfom capacity estimations. Moreover, for comparison purposes, the suitability for the selected schemes was evaluated estimating both the degree-of-saturation and the control delay. The discussion relating to the outcome of the comparison and the procedure followed for this purpose, will be preceded by a brief description of the capacity models for turbo-roundabouts and double-roundabouts, with particular reference to those applied here, with the appropriate adjustments made in relation to the specificities of the intersections under examination.

2.1 Capacity Models for Basic Turbo-roundabouts

Among capacity models for estimating entry capacity at turbo-roundabouts the linear empirical regression model proposed by Fortuijn and Harte (1997) must necessarily be mentioned. This model is based on a modification of the model derived some time earlier for entry capacity estimations at roundabouts (see Bovy et al., 1991). Fortuijn afterwards modified the factor that in Bovy model describes the effect of the circulating traffic on entry capacity, by splitting it into two parts: one for the roundabout lane with the higher volume and one for the roundabout lane with the lower volume; for a brief summary of the model, see Fortuijn (2009b). The values of aforementioned factors were then determined from observations on a turbo-roundabout built by the provincial authorities of South Holland. This model permits capacity calculations for the different legs in various types of turbo-roundabouts and delays found when traffic flow is not saturated. However, as confirmed by results of studies carried out by Brilon and Bäumer (2004), it is reasonable to conclude that an approach based on the gap acceptance theory can express the relationship between circulating traffic flow and entry capacity in a more realistic way. Mauro and Branco (2010) used the capacity model developed by Brilon et al. (1997), based on the theory of the gap acceptance; they adapted to turbo-roundabouts this model and assumed one entering lane and one circulating lane for the circular intersections that they decided to compare. A further criterion for entry capacity estimations at turbo-roundabouts was also proposed and used formulations founded on the gap-acceptance theory for unsignalized intersections (see Giuffrè et al., 2009). Among other models to evaluate entry capacity, Hagring model (1998) is worthy of note. Hagring (1998) developed, indeed, a more general formula for capacity estimations at multi-lane intersections which takes into account behavioural and traffic flow parameters differentiated by conflicting stream; he presented a generalization of the earlier gap-acceptance models by extending Troutbeck's model (1986) to provide the expression below, rewritten to adapt it to intersection patterns under examination and in accordance with the assumptions made in this study as before stated. Thus entry lane capacity can be derived estimating capacity of a minor stream hampered by independent major streams (to cross or in which a minor stream has to merge), each featured by a shifted negative bunched exponential distribution, also referred to as Cowan's M3 headway distribution:

$$C_e = 3600 \cdot \sum_j \frac{\varphi_j \cdot Q_{c,j}}{3600 - \Delta_j \cdot Q_{c,j}} \cdot \prod_k \left(\frac{3600 - \Delta_k \cdot Q_{c,k}}{3600} \right) \cdot \frac{exp\left[-\sum_l \frac{\varphi_l \cdot Q_{c,l}}{3600 - \Delta_l \cdot Q_{c,l}} \cdot \left(T_{c,l} - \Delta_l \right) \right]}{1 - exp\left(-\sum_m \frac{\varphi_m \cdot Q_{c,m}}{3600 - \Delta_m \cdot Q_{c,m}} \cdot T_{f,m} \right)} \tag{1}$$

Although symbols in Equation 1 have the usual meaning, appropriate explanations are however opportune. It should be noted, therefore, that j, k, l, m, are indices for conflicting lanes which are repeatedly the same lanes; C_e is the entry lane capacity, in pcu/h; φ is the parameter representing the proportion of free traffic within the major stream; Q_c is the conflicting traffic flow, in pcu/h; T_c and T_f are the critical gap for circulating lane (s) and the follow-up time (s), respectively; Δ represents the minimum headway of circulating traffic (s). Thus the Hagring model (1998) resulted appropriate to evaluate entry lane capacity at turbo-roundabouts: the Hagring model allows to assume, indeed, a shifted negative bunched exponential distribution in each circulating stream along circulatory carriageway, considering values (lane-by-lane) for behavioural parameters, minimum headway and conflicting traffic flow on (one or two) lanes in the circulatory carriageway. It must also be emphasized here that at a basic turbo-roundabout vehicles entering the intersection from right and left lanes at major entries (and from right lane at minor entries) face only one antagonist traffic stream; vehicles entering the intersection from left lane at minor entries face two antagonist traffic streams.

2.1.1 Entry Capacity at Turbo-roundabouts

This section focuses on assumptions made for evaluating entry capacities at turbo-roundabout shown in Figure 1. The Hagring model in Equation 1 was specified in relation to values of conflicting traffic flow (moving on the inner circulating lane $Q_{c,i}$ or the outer circulating lane $Q_{c,e}$) faced by subject entry approach drivers, and to T_c, T_f and Δ values. For turbo-roundabout, the values based on an empiric research on turbo-roundabouts installed in the Netherlands were used (see Fortuijn, 2009b); collected values for critical gap and follow-up time were differentiated by entry and by entering lane. According to Fortuijn (2009b) only for the left entering lane at minor entries (entries 1-3 in Figure 1) two critical gap values (one for the inner circulating lane and one for the outer circulating lane) were considered. The Tanner bunching model was used for estimating φ parameter (Tanner, 1962). Right-lane capacity and left-lane capacity of entries 2-4 (see Figure 1), as well as right-lane capacity of entries 1-3 (see Figure 1) were estimated considering the circulating traffic flow in the outer lane ($Q_{c,e}$) at the subject entry approach from time to time considered:

$$C_e = Q_{c,e} \cdot \left(1 - \frac{\Delta \cdot Q_{c,e}}{3600} \right) \cdot \frac{exp\left(\frac{-Q_{c,e}}{3600} \cdot \left(T_c - \Delta \right) \right)}{1 - exp\left(\frac{-Q_{c,e}}{3600} \cdot T_f \right)} \tag{2}$$

Left-lane capacity estimations at minor entries 1-3 (see Figure 1) was estimated, instead, considering circulating traffic flows in the outer ($Q_{c,e}$) and in the inner lane ($Q_{c,i}$) on the circulatory carriageway:

$$C_e = \left(Q_{c,e} + Q_{c,i} \right) \cdot \left(1 - \frac{\Delta \cdot Q_{c,e}}{3600} \right) \cdot \left(1 - \frac{\Delta \cdot Q_{c,i}}{3600} \right) \cdot \frac{exp\left(\frac{-Q_{c,e}}{3600} \cdot \left(T_{c,e} - \Delta \right) \frac{-Q_{c,i}}{3600} \cdot \left(T_{c,i} - \Delta \right) \right)}{1 - exp\left(\frac{-\left(Q_{c,e} + Q_{c,i} \right)}{3600} \cdot T_f \right)} \tag{3}$$

Notations in Equations 2 and 3 have the same meaning as in Equation 1. It must be said that for each gap acceptance parameter a weighted mean was assumed starting from values surveyed by Fortuijn (2009b) and so specified:

-left entry lane at major entry (entry 2 or 4): $T_{c,e}$ = 3.60 s, T_f = 2.26 s, = 2.10 s;

-right entry lane at major entry (entry 2 or 4): $T_{c,e}$ = 3.87 s, T_f = 2.13 s, = 2.10 s;

-left entry lane at minor entry (entry 1 or 3): $T_{c,i}$ = 3.19 s, $T_{c,e}$ = 3.03 s, T_f = 2.26 s, = 2.10 s;

-right entry lane at minor entry (entry 1 or 3): $T_{c,e}$ = 3.74 s, T_f = 2.13 s, = 2.10 s;

2.2 Capacity Models for Double-lane Roundabouts

Literature presents several operational models used for analysing performances at roundabouts. One of the first models was developed by Harders (1968); afterwards the same model was introduced into different edition of the Highway Capacity Manual (2000; 2010). Brilon et al. (1997) used the Tanner capacity equation (1962) for uncontrolled intersection adjusting it to needs of roundabout analysis. More recently, Brilon (2005) focused on the empirical regression of on-field experimental data and reached a simplified form of the capacity equation derived from the Siegloch's equation (1973); values for behavioral parameters were also proposed by Brilon (2005). Recent adaptations of the Siegloch's equation for capacity estimations of right and left entry lanes opposed by two conflicting lanes are reported in NCHRP 672 (2010).

A comprehensive summary of operational models can be found in the NCHRP 572 as drawn up by Rodegerdts et al. (2007). A recent estimation of gap acceptance parameters for roundabout capacity model applications is reported by Gazzarri et al. (2012).

2.2.1 Entry Capacity at Double-lane Roundabouts

This section focuses on assumptions adopted for evaluating entry capacities at double-lane roundabout in Figure 2. How to enter a roundabout is well known: entering vehicles face one or two circulating streams, depending on the entry lane by which they come from. It has been noted here that, although preferable, drivers do not have to preselect their entering lane in relation to their destination. So entry capacity estimations at the double-lane roundabouts under examination were obtained adding capacities of each entering lane. The shifted negative bunched exponential distribution (or Cowan's M3 headway distribution) was assumed to model circulating traffic flows; moreover, each entry lane capacity was calculated by using the Hagring model (1998) easily adapted to consider not only a single circulating stream (for estimating right-entry lane capacity by Equation 2), but also two circulating traffic streams (for estimating left-entry lane capacity by Equation 3).

In this manner, the circulating traffic flow was divided in the inner stream and the outer stream, the latter consisting in vehicles exiting from the intersection at the exit immediately after the considered entry approach. T_c and T_f were assumed equal to values reported in section 2.1.1 for right and left lanes at entries 1-3; this is due to manoeuvre schemas at a double-lane roundabout are considered analogous to those observed for the minor road of a turbo-roundabout. Δ was assumed equal to 2.10 s.

3. Comparing Basic Turbo-roundabouts and Double-lane Roundabouts to Evaluate Operational Benefits

In representing operating conditions at the intersections under examination, two traffic situations were analysed; the corresponding O-D matrices in percentage terms are reported in Table 1 (see case 1 and case 2). Assumptions concerned traffic demand: Q_{e2} was set equal to Q_{e4} and Q_{e1} was set equal to Q_{e3}; the cases with the overall entry flow coming from major entries (Q_{e2}+Q_{e4}) less than the overall entry flow coming from minor entries (Q_{e3}+Q_{e1}) were excluded.

With reference to the entry-lane selection performed by turning vehicles from entries, the following percentages were specified: i) at minor entries 1-3, right-turning vehicles were 90 percent from right-entry lane and 10 percent from left-entry lane; ii) at major entries 2-4, through vehicles were 50 percent both from right-entry lane and from left-entry lane.

Figure 3 shows the outcome of the comparison between the schemes in Figures 1 and 2 in terms of suitability domains obtained for the degree-of-saturation both with reference to the case 1 and the case 2 in Table 1 under undersaturation conditions.

In Figure 3a, corresponding to the case 1 in Table 1, it is possible to note the efficiency of double-lane roundabouts, performing better than turbo-roundabouts almost in the entire range of variation of entering traffic flows. In the Figure 3b it is possible to observe that turbo-roundabouts perform better than double-lane roundabouts when traffic flow coming from major roads maintain high levels; this condition occurs again when medium-to-high traffic flows enter the intersection from entry approaches.

Table 1. Origin/destination matrices of traffic flows in percentage terms

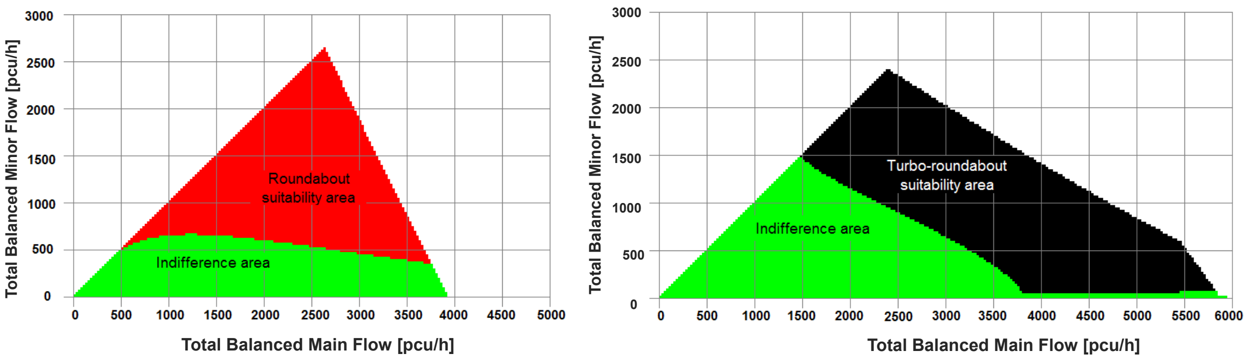
Case 1

O/D	1	2	3	4
1	0	0.33	0.33	0.33
2	0.33	0	0.33	0.33
3	0.33	0.33	0	0.33
4	0.33	0.33	0.33	0

Case 2

O/D	1	2	3	4
1	0	0.65	0.05	0.30
2	0.05	0	0.05	0.90
3	0.05	0.30	0	0.65
4	0.05	0.90	0.05	0

Description: o-d matrices of traffic flows in percentage terms representing flow scenarios, chosen to explore how different traffic patterns can influence operations. In the case 1 traffic flow percentages in o-d matrix were shared equally. In the case 2 percentages of through vehicles from and to major entries were considered significant compared to other turning vehicles; percentages of left and right turning vehicles from minor entries were significant compared to through vehicles from and to minor entries.



a) b)

Figure 3. Suitability domains in undersaturated conditions in terms of degrees of saturation

Description of figure: it has be noted that x-axis represents the variable (Q_{e2}+Q_{e4}); the y-axis represents the variable (Q_{e1}+Q_{e3}); these variables are the basis for constructing suitability domains in undersaturated flow conditions having the following distinction between suitability areas:

degrees of saturation at roundabout less than 90 % than turbo-roundabout

degrees of saturation at turbo-roundabout less than 90 % than roundabout

indifference area

However, most appropriate details about the actual convenience of a pattern on the other can be derived from constructing analogous suitability domains in terms of delay experienced by users, considering the relation between the latter and the level of service quality. In order to perform the comparison between intersections under examination, the control delay at each intersection was computed as follows:

$$\bar{d} = \frac{\sum_{i=1}^{4} d_i \cdot Q_{e,i}}{\sum_{i=1}^{4} Q_{e,i}} \quad (4)$$

Symbols in the above equation require to be specified in relation to the two circular intersections here examined. In the case of the turbo-roundabout shown in Figure 1, the above parameter was calculated as the weighted mean value of the mean control delay d_i at each entering lane i, estimation of which starts from entry lane capacity $C_{e,i}$ and the degree of saturation. In the case of double-lane roundabout shown in Figure 2, d_i represents the control delay at each entry i, estimation of which starts from capacity of the entry approach in its entirety and the degree of saturation. With these specification d_i estimations were made using the analytical model given by HCM (2000) in chapter 17 to estimate the control delay at unsignalized intersections, which can be also used for roundabouts:

$$d_i = \frac{3600}{C_{e,i}} + 900T\left[\frac{Q_{e,i}}{C_{e,i}} - 1 + \sqrt{\left(\frac{Q_{e,i}}{C_{e,i}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{e,i}}\right)\left(\frac{Q_{e,i}}{C_{e,i}}\right)}{450T}}\right] + 5 \quad (5)$$

where T is the length of analysis time period (h).

Figures 4 and 5 show the domains of convenience in undersaturated flow conditions obtained for control delay in the two situations corresponding to o-d matrices of traffic flows in percentage terms showed in Table 1. The distinction between suitability areas that can be identified in the two cases examined deserves an explanation. The light gray area in Figure 4 shows the situation of convenience for the double-lane roundabout; it represents, being equal entering traffic flows, the situation where delays experienced by users are less than 50% of those experienced by entering vehicles at turbo-roundabouts. The dark gray area in Figure 5 represents the situation of convenience for the turbo-roundabout, wherein delays are less than 50 percent of those experienced by entering vehicles at double-lane roundabouts. The situation in which delays in one of the two intersections are never less than 50% of those in which users can incur at the other intersection is showed in both figures by the area with a shade of gray intermediate between those used to identify the suitability area of the double-lane roundabout (see Figure 4) or the turbo-roundabout (see Figure 5).

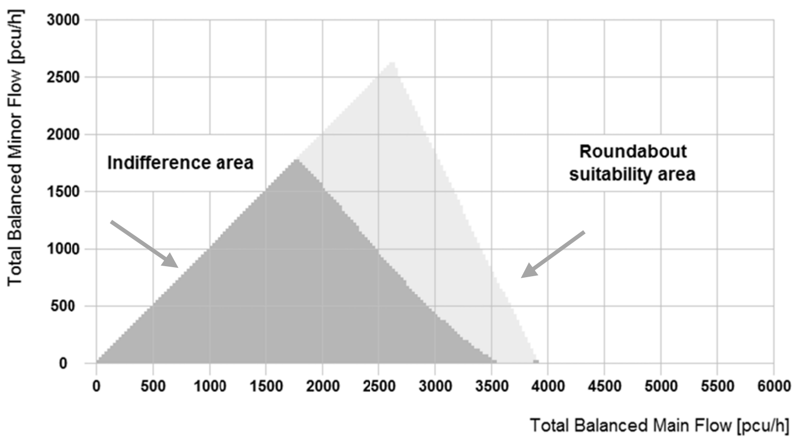


Figure 4. Example of suitability domain in undersaturated traffic conditions: case 1 in Table 1

Description: it has be noted that x-axis represents the variable (Q_{e2}+Q_{e4}); the y-axis represents the variable (Q_{e1}+Q_{e3}); these variables are the starting point for constructing suitability domains in undersaturated flow conditions having the following distinction:

Roundabouts suitability area　　Indifference area

4. Results

It must be said that the convenience of the two intersections under examination was estimated in terms of delay experienced by entering vehicles, the latter being related to measures characterizing operational conditions or describing service quality at unsignalized intersections. Operating convenience of an intersection on the other, with reference to roundabouts here examined (see Figures 1 and 2) was obtained, indeed, preferring the delay experienced by users over the degree of saturation, measuring the former through the control delay.

In Figure 4 representing situations where traffic flow percentages were shared equally (see case 1 in Table 1), it is possible to observe the efficiency of double-lane roundabout compared to turbo-roundabout; it occurs when major entries are featured by high traffic flows entering the roundabout, and minor roads provide for low entering volumes. This condition still occurs when minor roads are featured by traffic flows growing from medium-to-high values.

In the case depicted in Figure 5 corresponding to case 2 in Table 1, turbo-roundabouts are featured by operating conditions advantageous compared to double-lane roundabouts. Low delays are experienced by users at turbo-roundabouts compared to double-lane roundabouts when high traffic volumes come from major roads and low-to-medium traffic flows come from minor roads. This traffic condition still happens when traffic flows coming from minor road continue to grow and middle-to-high values of traffic flows enter the intersection from major roads. In both cases, it is possible to observe that when low-to medium traffic volumes enter the intersection the two intersections perform in an equivalent way.

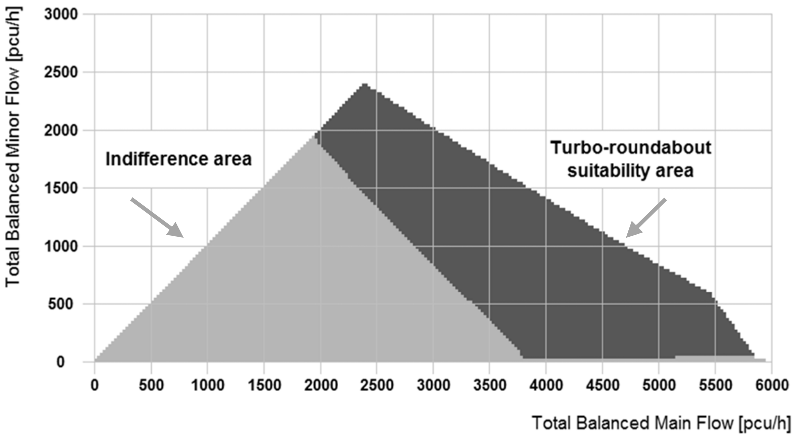


Figure 5. Example of suitability domain in undersaturated flow conditions: case 2 in Table 1

Description of figure: it has be noted that x-axis represents the variable (Q_{e2}+Q_{e4}); the y-axis represents the variable (Q_{e1}+Q_{e3}); these variables are the starting point for constructing suitability domains in undersaturated flow conditions having the following distinction:

turbo-roundabouts suitability area indifference area

5. Conclusions

The primary purpose of this paper consisted in evaluating the convenience in terms of operational performances between basic turbo-roundabouts and double-lane roundabouts. Construction of suitability domains under undersaturation flow conditions (i.e., those conditions in which the demand volumes are less than approach capacity) was then reached for the two intersections under examination in each of the traffic situations explored.

This objective has been pursued making assumptions, found to be coherent by Authors, on the arrival process of circulating streams moving along the ring. Among entry capacity models based on the gap-acceptance theory here considered, applications of the Hagring model (1998) were proposed to evaluate entry capacity at intersections in Figures 1 and 2; for comparison purposes, the same model was specified for evaluating entry capacity at turbo-roundabouts and double-lane roundabouts. It must be said that the convenience of the two intersections under examination was estimated in terms of delay experienced by entering vehicles, considering the relation of this parameter to the level of service quality.

Results obtained for the two cases examined, despite they may be affected by the theoretical assumptions which the study takes as its starting point, showed that better performances at basic turbo-roundabouts than double-lane roundabouts are depending on the balance of entering traffic volumes at the approaches; they occur in particular when a significant share of traffic volumes is handled by major roads. Although there is a need of further cases to be examined in terms of traffic situations, the comparison developed in the paper, at last, can be helpful in choosing basic turbo-roundabout rather than double-lane roundabout and, in particular, to evaluate operating benefits obtainable from the conversion of an already existing double-lane roundabout to a turbo-roundabout with similar space requirements.

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