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OPERATION ANALYSIS OF INNOVATIVE ROUNDABOUT LAYOUTS

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Abstract

This paper focuses on the capacity evaluation of several roundabout models, namely the turbo, flower, target and four-flyover roundabouts. Some of these layouts are innovative solutions and remain as theoretical concepts. The study followed a microscopic approach, based on the Aimsun software. A reference model of an existing conventional multilane roundabout was assembled, calibrated and validated based on field data. It was found that the performance of the turbo, flower and four-flyover roundabouts mostly depends on the directional flow of the entry traffic, especially under heavy demand. The target model presents the best performance for most of the demand scenarios analysed.

Keywords: roundabout, capacity, layout, Aimsun

1 Introduction

Roundabouts are generally well-accepted for their capacity, safety and environmental advantages over other at-level intersections. However, their operation is associated with some problems related to the interpretation of the driving rules, leading to the incorrect selection of the entry, circulatory and exit lanes. These complications usually result in a large number of traffic conflicts and in some small collisions that tend to increase with the number of lanes and with the demand level [1]. This topic has earned the concern of the scientific community in the search of ways to improve the safety of roundabouts, without undermining traffic fluidity. One of the most publicized examples is the turbo-roundabout. This concept, which emerged in the Netherlands in the late 1990s, centres around the creation of continuous spiral circuits using raised dividers at the entries, exits and inside the circulatory carriageway. Despite its significant safety performance [2], its efficiency in terms of capacity is limited to very specific and unusual traffic demand spectra [3, 4]. Such limitations have justified the search for new alternative solutions, such as the flower, target and flyover roundabouts [5-7]. This research focuses on the evaluation of these new solutions as alternatives to the conventional roundabout layouts.

2 Development of a reference model

2.1 Methodology

The study compares four alternative layouts: turbo, flower, target and four-flyover roundabouts (Figure 1). The last two types are still theoretical concepts, which excludes before-and-after analyses methods based on field data. This way, the study relies on microsimulation analyses, based on the Aimsun software, to evaluate and compare the roundabouts for two

types of scenarios: (i) variation of traffic load on the network; (ii) variation of the directional traffic split. The study was based on a real case scenario to provide a more realistic analysis of the problem. The selected site is in Coimbra, Portugal, at one of the entrances to the city (Almegue roundabout). The current layout is located on a rectangular public square with three circulatory lanes and four approach branches. The posted speed limit on the different approaches varies between 40 and 90 km/h.
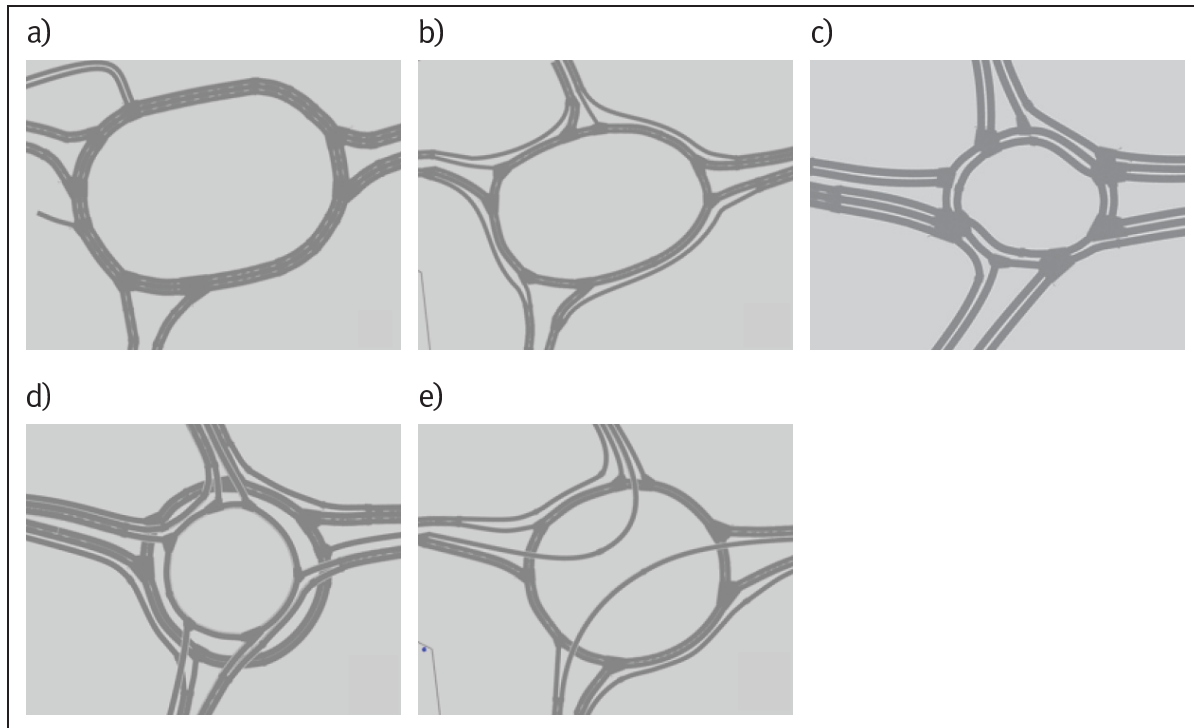

Figure 1   Models of the different roundabout layouts (non-uniform scale) a) Existing roundabout; b) Flower; c) Turbo; d) Target; e) Four-flyover

2.2 Construction of the O/D matrix

The construction of the OD matrix focused on the morning peak period, between 7h30 and 9h30. In order to obtain the directional traffic flows, waiting queues and free-flow speed distributions, the following data was collected: a) manual traffic counts in specific sections, b) video footage at selected entries, and c) vehicles licence plates, d) free-flow speeds using a LIDAR. The data collection was carried out on two consecutive days, involving 14 daily participants. The traffic counts were segregated by periods of 15 minutes and by vehicle classes: light-duty vehicles (i.e. passenger cars), heavy-duty passenger vehicles (i.e. buses), light-duty trucks, and two-wheeled vehicles. This procedure yielded a total of 32 O/D matrices corresponding to every 15-minute period and vehicle types.

2.3 Calibration

The codification of the network was based on existing cartography and aerial photos. Five models were created: (i) existing layout, considered as the reference layout; (ii) flower-type layout; (iii) turbo-roundabout layout; (iv) target layout, and (v) four-flyover layout. All models have similar sizes to eliminate the dimension variable from the results.
Given that the main objective of the work was not to accurately reproduce a real scenario, but to compare the performance associated with the various layouts, it was not deemed necessary to develop an exhaustive calibration. Thus, only two calibration aspects were adjusted:

speed distribution and gap-acceptance behaviour. Speed distribution values were established based on the actual distribution of the free-flow speed, which were recorded with the mobile LIDAR in several sections of the intersections. This way, the desired speeds of the simulation vehicles are drawn from a truncated normal distribution: $v_{min} = 36$ km/h, $v_{max} = 129$ km/h, $\mu = 74$ km/h and $\sigma = 25$ km/h. In the ring, where posted speed limit is 40 km/h, simulated vehicles are allowed to reach 50 km/h, mirroring the observed speeds. The local value for the reaction time, that controls the gap acceptance behaviour, was found by imposing incremental variations to its base value to minimize the difference between the simulated and the observed queue lengths at the various entries. At the end of this process, the value of 0.69 seconds was chosen, with the program default being 0.75 seconds, resulting in queue lengths differences of less than 10 %.

2.4 Validation

The validation of the model was based on the application of an independent indicator (not used in the calibration). For this, simulated and observed average travel times for the most important paths were compared. Travel times measured on-site (by matching of licence plates) are about 11 % higher than the simulation outputs, which was considered acceptable given the type of analysis intended.

2.5 Definition of scenarios

Two types of analysis were considered: (1) variation of the directional split at the entries; (2) variation of the total traffic demand. The first set of scenarios evaluates the effect of the directional split on the entry, assuming the same distribution for the various entries (Table 2). An additional scenario was considered (scenario 0) where the actual traffic load was collected in the field sessions, totalling 8 scenarios. The second analysis covers the effect of the network load variation on each of the alternative solutions, using incremental coefficients of the O/D matrix, 5 % increments until reaching 150 % and 10 % increments after that.

Table 1 Scenarios considered for the analysis

Scenario	1			2			3			4			5			6			7		
Turn	L	S	R	L	S	R	L	S	R	L	S	R	L	S	R	L	S	R	L	S	R
%	0	100	0	12.5	75	12.5	25	75	0	0	75	25	25	50	25	0	50	50	50	50	0

L – left turn; S – straight; R – right turn.

3 Analysis of the results

Although the simulation model allows for a broad set of indicators, the analyses shown here are limited to the assessment of the overall capacity, corresponding to the sum of the entries capacities. The existing solution was taken as the reference solution.

3.1 Effect of the directional distribution

To test how each layout is affected by the directional split of the entry traffic, for each of the 8 cases refered above, a very large demand was assigned to each entry. To facilitate the comparative analysis, the different scenarios were grouped as follows: (A) scenarios 1, 2 and 5: uniform relative increase of traffic volume of left and right-turns; (B) scenarios 5, 3 and 7: simultaneous reduction of right-turn traffic volume and increase in left-turn traffic volume; (C) scenarios 1, 3 and 7: increase in left-turn traffic volume, with null right-turn; and (D) scenarios 1, 4 and 6: increase in right-turn traffic volume, with null left-turn (Figure 2).
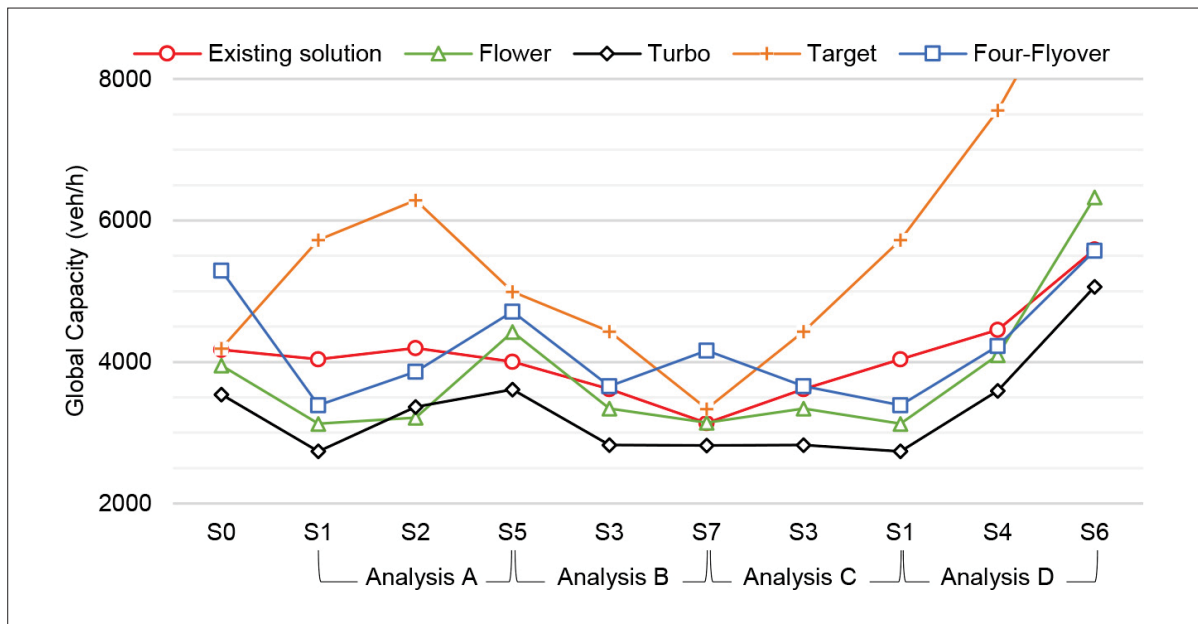
Figure 2 Capacity of the existing solution and studied layouts

Flower-type roundabout

In general, except for some specific scenarios, the capacity of the existing roundabout tends to be higher than the capacity of the flower-type roundabout. As expected, this tendency inverts whenever the right turn movement is higher (scenarios 5 and 6), with capacity gains of around 11 % and 13 %, respectively, when compared to the conventional roundabout. Although scenario 4 presents 25 % of right turns, the flower has an overall capacity loss of 8 %, due to a lesser flexibility the driver has to choose the entry lanes. These results reveal the privileged domain of the flower-type roundabouts, since, in the case of a 3-way roundabout, it can only be competitive in relation to the conventional roundabout when the right-turn traffic is greater than 25 %. Also, this amount of traffic can still increase significantly for two-way solutions.

Target-type roundabout

Regardless of the distribution scenario, the target always reaches a higher capacity than the reference roundabout. Having segregated lanes for the right turns is one of the factors that explain this performance (analysis D). An example are the scenarios 4 and 6, with an increase of 70 and 80 %, respectively, when compared to the existing solution. Therefore, this layout tends to be better than the conventional multilane roundabout, responding well to diverse scenarios of traffic split scenarios. However, it requires the construction of an additional roundabout on upper level, resulting in high construction costs and considerable impacts on the landscape. Nevertheless, this is a potential solution for intersections under very high traffic demand and where the lack of space is not an issue.

Four-flyover roundabout

As expected, when the left-turn traffic increases, the performance of this solution also increases, e.g. 30 % in scenario 7. However, when the amount of left turns is minimal or even non-existent, with the consequent increase in right turns or straight movements, there are significant capacity losses, especially when most of the traffic continues straight (scenario 1), since in practical terms it means the loss of an entry lane. Nevertheless, this is an unusual and unrealistic scenario. Overall, this solution has a narrow application domain. The advantages relative to the traditional solution are obvious when the amount of left turns is significant, ideally associated with right turns on the secondary road. This solution is only competitive

when left turns are higher than 25 % and this amount rises considerably for solutions with only two lanes.

Turbo-roundabout

Regardless of the scenario adopted, the best performance is obtained by the existing conventional roundabout. These results are in line with other studies [3]. The minor reduction of capacity is observed when the increment of right turns increases. Scenario 6, which shows a smaller variation of around 10 % compared to the conventional roundabout, highlights the relevance of right turns.

3.2 Effect of the saturation

This section consists on the analysis of the various solutions relative to the variation of the traffic load in the network. Only the results of scenarios 2, 6 and 7 are shown, representing one common scenario and two others showing the importance of the right and left turns, respectively. Figure 3 shows the results related to scenario 2 subjected to a systematic increase of traffic load in the network, for the several types of roundabouts. This scenario has a directional split with 75 % of the trips for the straight movement and 12.5 % for left and right turns, respectively. Results show the high performance of the target model, particularly under high traffic demand. Even for 200 % loads, the target solution did not reach saturation, while the turbo saturated for a load close to 100 %. The turbo model consistently presents the worse performance, since this model favours the splits with a high proportion of right turns. The flower, four-flyover and existing solution models present entry flows that are very close to each other and are lower than those reached by the target. Saturation is achieved for a higher network load, about 130 %, reaching capacities between 5000 and 5500 veh./h.
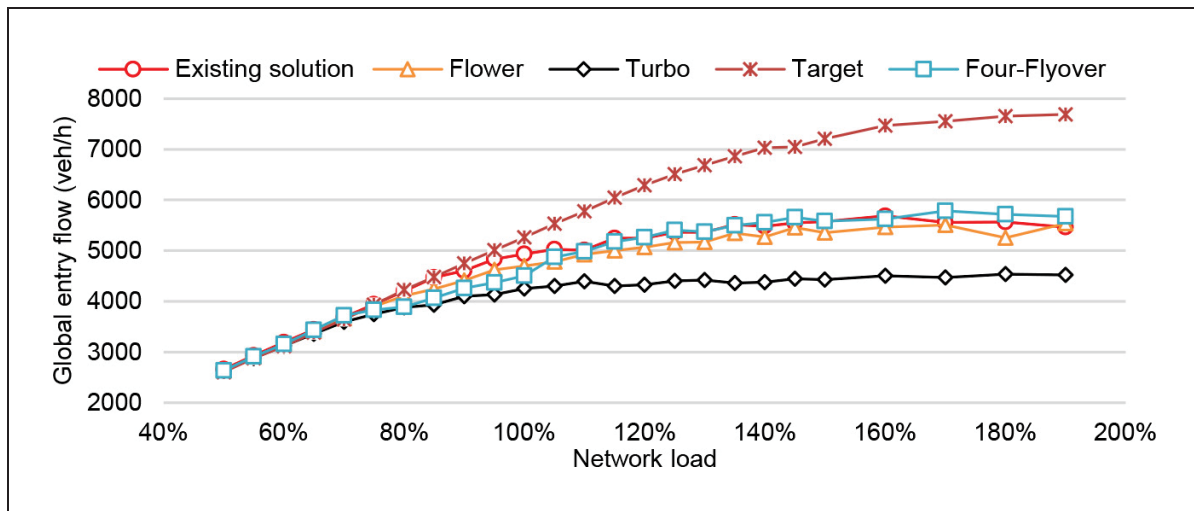

Figure 3   Effect of the saturation for scenario 2

Scenario 6 (Figure 4) evaluates the performance of the solutions when subjected to a directional split with a high proportion of right turns (50 % straight and 50 % right turns). The performance levels tend to be quite different from those presented above. None of the solutions reached saturation at loading levels close to 200 % and all models have still shown some spare capacity. In the target model, and for a 200 % network load, global entry flow is around 10 500 veh./h, with 9 000 veh./h in the flower model. The other models also achieve results that are considerably higher than those obtained in the previous scenario, namely the turbo-roundabout, which reaches its maximum performance in this case.

Finally, scenario 7 (Figure 5) shows the effect of left turns (50 % straight and 50 % left turns). Compared to scenario 6, there is a very significant reduction of performance for all models under analysis. Also, the equilibrium of the capacity in these scenarios is achieved for lower

network loads compared to the other scenarios, thus lower overall capacity values. The fact that scenario 7 implies a greater volume of left turns translates into higher volumes of conflicting traffic in the circulatory carriageway, thus obtaining saturation points associated with lower loading levels. The four-flyover model shoes the best performance without reaching saturation at 200 % of the network load. At a slightly lower level appears the target model, whose curve tends to stabilize at loading levels close to 140 %, reaching the overall maximum capacity of about 5500 veh./h. The remaining models assume a similar behaviour, reaching saturation levels close to 70 % with global maximum capacities of 3200 and 4200 veh./h.
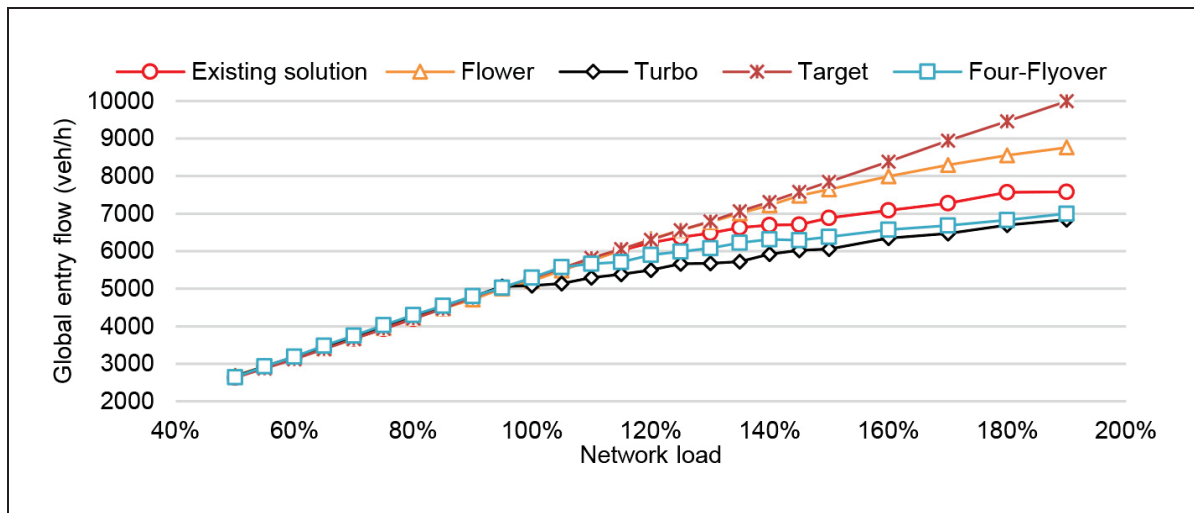

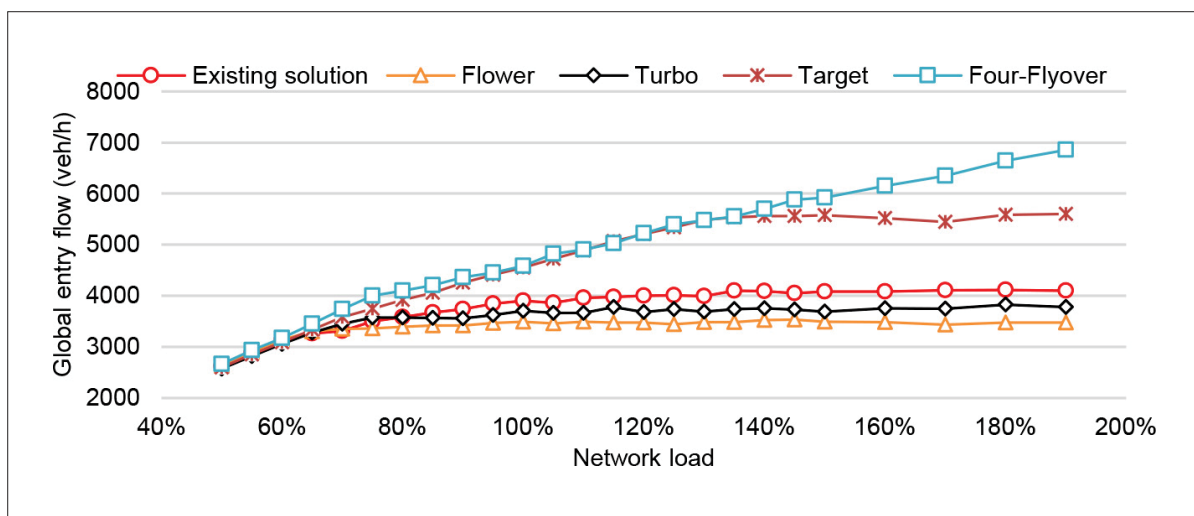**Figure 4**   Effect of the saturation for scenario 6

Figure 5   Effect of the saturation for scenario 7

4 Conclusions

This research focused on the evaluation of the effect that several alternative layouts have in the roundabout capacity. It was found that, for all layouts, the performance is very affected by the directional split of entry traffic, with a loss of capacity, as expected, as the proportion of left turns increases. An exception is the four-flyover model which, due to the segregated routes for left-turn movements, can reach in capacity increases in the order of 30 %. In the other models, the loss of capacity is significant, especially in the turbo model, with losses up to 30 % compared to the existing solution. On the other hand, in the scenarios with right

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turns, it is notorious the capacity gain in the target, flower and turbo models. The target model reaches a capacity gain in the order of 80 %, in scenario 6, where the traffic is equally shared between right turn and straight movements. The flower layout also has a significant increase in its performance compared to the existing solution (13 % in scenario 6). The turbo layout, compared to the existing solution, has a lower performance for all scenarios. Although the target model generally generates the best results, its higher construction cost can only be justified by extreme demand levels in the various entries. The results show that the overall performance of a roundabout strongly depends of its layout and traffic demand characteristics. However, there are other relevant aspects, such as road safety, environmental efficiency and energy consumption, which cannot be neglected in the decision-making process. This justifies the development of an integrated evaluation methodology based on multicriteria analysis, which allows different traffic demand scenarios to determine which of the alternative layouts tends to be the most efficient.

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