

A Design Method for Pedestrian Areas by a Simplified Approach to Predict the Future Traffic Scenarios

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Abstract. The interest in sustainable mobility and active modes has increased in the last years. A strong measure to encourage citizens towards sustainable transport choices is to promote and enlarge pedestrian areas, that appears to be the most radical and feasible measures against the modal choice towards transit and private traffic because of a reduction of noise and air pollution levels but also because of a dramatic decrease of the safety risk of vulnerable users. However, the design of a new pedestrian area will have an impact on future vehicular traffic flows that need to be evaluated. In this paper a simplified method to predict the future traffic scenarios following the establishment of a pedestrian area is presented. Results by this method have been compared with those provided by a conventional traffic demand model and a sensitive analysis employing different assignment techniques has been carried out. It is believed that the use of this method may help urban road designers and city planners in identifying critical traffic scenarios induced by new pedestrian areas and in studying suitable countermeasures to reduce traffic congestion in surrounding areas.

Keywords: Pedestrian area design · Sustainable mobility · Simplified methods

1 Introduction

In the past years, interest into sustainable mobility and active modes has increased [1] and Governments have set goals to increase active mode share [2]. In 2015, the governments of 193 UN member countries approved the Agenda 2030 for Sustainable Development, whose essential elements are 17 objectives: the theme of sustainable mobility, which falls under objectives 3 (Health and well-being), 9 (Business, innovation and infrastructures) and 11 (Sustainable cities and communities) [3].

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The realization of pedestrian areas is one of the many ways of applying sustainable mobility and it is the most radical and feasible measure for a defined reason: because it prohibits the transit of public and private traffic [4]: only vulnerable users (in particular pedestrian and cyclist, except for vehicles that carry out an emergency service or used by disabled people) are allowed, changing so the actual paradigm which is vehicular center-based [5]. Pedestrian areas are mostly located in the city center or in strategical urban areas, where the main social and economical activities are located: according to the literature, the 60% of pedestrians use pedestrian areas for leisure purposes [6].

Although the environmental aspects are of primary importance, the major impacts in terms of road safety [7] must not be neglected because this also leads to an increase of the number of pedestrian and consequentially to a reduction of private cars, as it has been shown in Pontevedra, Spain [8]. In addition to a reduction of air pollutants and noise pollution levels in the areas where this measure is envisaged, there is also a drastic reduction in the risk [9], associated with any accidents since the exposure factor with vehicular traffic plays a secondary role [10]. To assess the pedestrian safety, it is essential not only to focus on the vehicle-pedestrian accidents, but also on pedestrian-pedestrian conflicts [11], bearing in mind the pedestrian attitudes and perceptions [12]. However, it is worth to be highlighted that the interactions with cyclists, who travel at a higher speed, and the increasingly use of electric scooters (increasingly present in all European cities) have risen several concerns among urban managers.

In order to simulate this type of interventions, performing software tools are required since it is necessary to predict a realistic future traffic scenario and evaluate the corresponding safety impacts [13]. Due to the high complexity of creating and managing these traffic demand models, in this article a simplified method, which can be useful for road designers and managers, is proposed. The novelty of the proposed method is to estimate both new distribution and magnitude of the flow rates modified by the construction of a pedestrian area, starting from the identification of the inhibited maneuvers and relative flow rates, without the use of traffic simulation software.

2 Framework of the Method

2.1 Description of the Method

The best way to predict the citizens' habits and attitudes to move, in order to design or redevelop our cities by promoting interventions that push towards sustainable mobility choices, is to develop a travel demand model, i.e., a mathematical model that is able to capture of the features describing trips (purpose, departure time, origin, destination, mode and route).

Following these premises, if one is interested in study a typical worst case urban traffic scenario (early morning peak-hour due to commuting traffic) one of the most well-known approaches, is based on a four-stage model that describes the total travel choice as a succession of partial choices. The model can be represented by the following relation (Eq. 1) [14]:

$$d^i(h, s, o, d, m, k) = n^i(o)p^i(x/osh)p^i(d/osh)p^i(m/dosh)p^i(k/mdosh) \quad (1)$$

where:

- $n^i(o)$pi(x/osh) is the generation model.
- $p^i(d/osh)$ is the distribution model.
- $p^i(m/dosh)$ is the modal choice model.
- $p^i(k/mdosh)$ is the route choice model.

The generation model provides the number of significant trips (and therefore the demand flow) made in the period h for the reason s by the generic user belonging to category i with origin in the area o. The generation model expressed by relationship (1) consists of the following terms:

- n^i (o) is the number of people belonging to category i.
- p^i (x / osh) is the percentage (probability) of users moving.

The distribution model, on the other hand, makes it possible to estimate the percentage of trips made by users belonging to category i who, starting from the area or for reason s in period h, go to destination d. The modal choice model allows to estimate the percentage of individuals belonging to category i who, moving from the origin or destination d, for the reason s, in the time period h, choose the mode of transport m. The route choice model allows to determine the percentage (probability) of individuals of category i who, moving between o and d, for the reason s, in the time slot h and with the mode m, choose the path k.

These methods of forecasting the transport demand are very time consuming to develop since they require a huge amount of data from Census and from traffic counts and survey. Especially for small cities and municipalities where this modelling effort is not already available, it can be useful to seek for alternative engineered approaches to evaluated future traffic scenarios. For this reason, a simplified method was created and can be summarized in the fundamental steps listed below.

- In a preliminary stage, road nodes near the pedestrian area where a modification of the traffic rules or a suppression of one or more accesses has occurred and related inhibited manoeuvres, need to be identified. It is necessary also to detect those manoeuvres (and therefore the relative flow rates for which traffic counts exist) which, due to this change in traffic, in the ex-post scenario, they will be inhibited.
- For each inhibited maneuver it is necessary to identify at least two alternative routes consistent with the traffic rules in the new traffic scenario.
- For each of these new routes it is necessary to calculate the relative travel time by means of a typical internet-based on-line navigation program.

- Following the identification of the main nodes and alternative routes for the inhibited maneuvers and the related travel times, it is necessary to understand what the distribution of the initial inhibited flow will be on these new routes that are created in the ex-post scenario.
- Flow distribution can be preliminarily estimated by re-arranging in an increasing order the travel times (Tt) corresponding to decreasing flow rates related the j^{*th} alternative route (see Fig. 1). Ad a matter of fact, it is essential to remember that shorter travel times should correspond to greater flow rates.

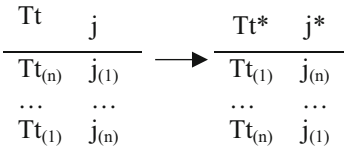

Fig. 1. Index correspondence scheme

- The calculation of the distribution of the flow rates of the inhibited maneuvers is performed assuming an inverse proportionality with the travel time (Eq. 2) and the entire procedure is managed on an iterative basis in order to provide a stable estimation of the traffic flows:

$$F_{kj} = F_k \frac{Tt_{kj^*,i}}{\sum_{j^*} Tt_{kj^*,i}} \tag{2}$$

where:

F_{kj} is the inhibited flow due to the inhibited manoeuvre k^{th} on a specific ordered alternative route j* [veic. eq/h].
F_k is the total inhibited flow due to the inhibited maneuver k^{th} [veic. eq/h].
$Tt_{kj^*,i}$ is the travel time corresponding to the specific ordered alternative routes j* due to the inhibited maneuver k^{th} [min];
i is the value of the iteration.

Within the specific iteration step, the inhibited flow rates must then be added to basic or pre-existing flows (that represent the actual scenario, derived from traffic counts or traffic simulations) and so it is possible to calculate the new travel times. With these new times a new distribution of the inhibited flow rates has been recalculated in the next iteration step. In the picture below (Fig. 2), a flow chart of the computational procedure is conveniently reported.

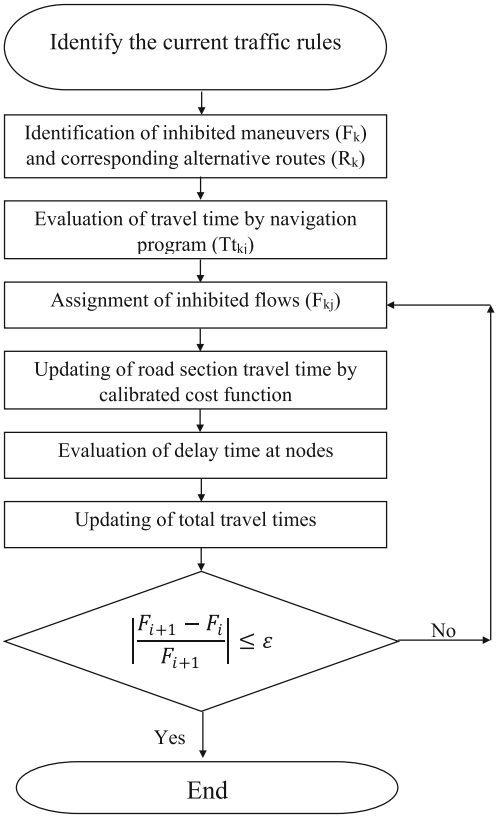

Fig. 2. Flow chart of the simplified method for the evaluation of redistributed flows.

2.2 Description of the Assignment Method

The process of allocating given number of trips to the transportation network is usually referred to as traffic assignment [14, 15].

In this study references are made to five types of traffic assignment: the first is expressed by equation (Eq. 2); the other four (which will be described in the followings) are the *User Equilibrium Assignment* (UE), *System Optimum Assignment* (SO), *All Or Nothing Assignment* (AON) [16], *User Equilibrium/System Optimum Assignment neglecting free flow travel times*.

The problem of the *User Equilibrium Assignment* is equivalent to the minimization of the following nonlinear equation:

$$V_k(F_{kj}) = \sum_{j=1}^{n} \int_0^{Fk_j} Tt_{kj} dF_{kj} \tag{3}$$

where:

$V_k(F_{kj})$ is the total volume between the origin and the destination of the inhibited maneuver k^{th} on a specific alternative route j [veh];
F_{kj} is the inhibited flow due to the inhibited maneuver k^{th} on a specific alternative route j [veh. eq/h].
Tt_{kj} is the travel time of the inhibited maneuver k^{th} on a specific alternative route j [h].

The travel time in (3) can also be expressed as:

$$Tt_{kj} = Tt_{0,kj} + a_{kj}F_{kj} \tag{4}$$

where:

$Tt_{0,kj}$ is the travel time of the inhibited maneuver k^{th} on a specific alternative route j in the free flow conditions [h];
a_{kj} is a proportionality coefficient expressed as in the following equation [h^2/veh]:

$$a_{kj} = \frac{Tt_{0,kj}{}^2}{F_k} \tag{5}$$

After solving the integral in Eq. (3), it is possible to solve the system (6):

$$\begin{cases} \min : V_k(F_{kj}) = \sum_{j=1}^{n} \left(Tt_{0,kj}F_{kj} + a_{kj}\frac{F_{kj}}{2}^2 \right) \\ F_k = \sum_{j=1}^{n} F_{k,j} \end{cases} \tag{6}$$

where:

F_k is the total inhibited flow due to the inhibited maneuver k^{th} [veh. eq/h].

Regarding the second assignment method, the problem of the *System Optimum Assignment* is equivalent to the minimization of the following nonlinear equation:

$$V_k(F_{kj}) = \sum_{j=1}^{n} F_{kj}Tt_{kj}(F_{kj}) \tag{7}$$

And the final system to resolve, follow the same step to solve the system (6):

$$\begin{cases} V_k(F_{kj}) = \sum_{j=1}^{n} F_{kj}\left(Tt_{0,kj} + a_{kj}F_{kj}\right) \\ F_k = \sum_{j=1}^{n} F_{k,j} \end{cases} \tag{8}$$

As it can be easily observed by examining the equation's set (8) if the alternative routes are only two, the expressions provide a closed-form solution with a perfect balance between unknown flows and number of equations. However, if the number of alternative paths is greater than two, it is necessary to introduce additional conditions on unknown traffic flow by making use of the following relationship (9):

$$F_{kj} = F_k \frac{a_{kj^*,i}}{\sum_{j^*} a_{kj^*,i}} \tag{9}$$

where $a_{kj^*,i}$ is the same proportionality coefficient expressed as in the Eq. (5) in this chapter [h^2/veh]: it is essential to arrange in an increasing order this coefficient corresponding to decreasing flow rates related the j*th alternative route (see Fig. 3). In fact, it is essential to remember that shorter travel times correspond to greater flow rates.

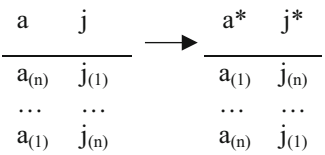

Fig. 3. Index correspondence scheme

It was also seen that it is possible to make a further simplification, which is to neglect travel times as, especially in urban areas, this amount are exceptionally low and negligible quantities. By making use of this simplification, the two assignment approaches (UE and SO) tend to perfectly coincide.

In the *All or Nothing Assignment* users follow the path which present the minimum cost and so the minimum travel times. This model does not appear to be very realistic, especially in nearly saturated road networks, because only one path is chosen, and it ignores the fact that travel times are function of link volume and capacity.

3 Case Study

3.1 Description of the Study Area

The study was conducted in the city of Cassino, an average Italian city with about 36497 inhabitants (Census data) [17] in the Province of Frosinone (Lazio). The city area is mainly flat and without a historic centre: it is still possible identify an urban centre, where the main commercial, administrative and legal activities are located. The city centre is thus characterized by a strong incidence in terms of vehicular flows, which share road areas with consistent cycle-pedestrian flows. These flows are generated by the presence of many attractive activities in the urban centre [8, 12]. Other attractive poles are universities and numerous schools (from kindergartens to secondary schools). It is therefore evident that mobility and the remarkable demand for transport are a central problem in the Municipality and especially in the city centre area.

3.2 Comparison of Flows Before and After the Calibration Phase

The calibration phase is a fundamental step in this analysis. Different traffic counts are available (referring to periods before the Covid-19 pandemic) intersections, which play a strategic role in the urban centre.

With reference to the analysis, 30 traffic zones and 10 external centroids are provided with 14907 trips in a daily basis.

Particular attention was paid to the choice and definition of the cost functions. A BPR function was chosen for the cost functions associated with the links:

$$T_{cur} = T_0\left(a + \frac{F}{C}^{b}\right) \tag{10}$$

where:

T_{cur} is the time travel with the network charged [s].
T_0 is the travel time with the network un-charged [s].
F is the actual flow [veh/h].
C is the capacity [veh/h].

With references to the cost function of the intersection, modified BPR formula was chosen, that is the one defined by Lohse [18]:

$$T_{cur} = \begin{cases} T_0\left(a + sat^{b}\right) sat \leq sat_{crit} \\ T_0\left(a + {sat_{crit}}^{b}\right) + abT_0\left({sat_{crit}}^{b-1}\right)(sat - sat_{crit}) sat > sat_{crit} \end{cases} \tag{11}$$

where:

sat is the ratio F/C [dimensionless].
sat_{crit} is the critic degree of saturation [dimensionless].

For the calibration of the origin-destination (OD) matrix, 46 traffic counts for the morning time window (07:15–08:15) of a typical weekday are used and the traffic demand model is calibrated with the Visum software. Regarding the TPr procedure, the Equilibrium assignment Bi-conjugate Frank Wolfe (BFW) method has been adopted, and for the calibration the Lohse procedure has been used.

Taking as an example this morning time window (07:15–08:15) of a typical weekday, in the pre-calibration phase there is a low agreement between the estimated flows by the forecast transport model (Fig. 4) and the traffic counts available. Therefore (as can be seen in Fig. 5) following the calibration phase, a satisfying correlation between flows estimated with the forecast model and counts on the intersections has been obtained.

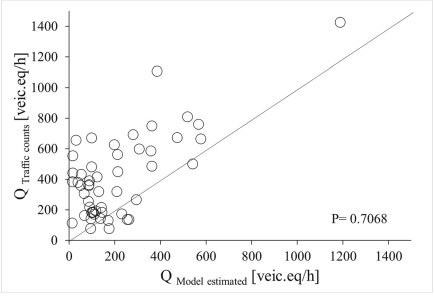

Fig. 4. Comparison of flows before the calibration phase in the morning time window (07:15–08:15) of a typical weekday (P = 0.7068).

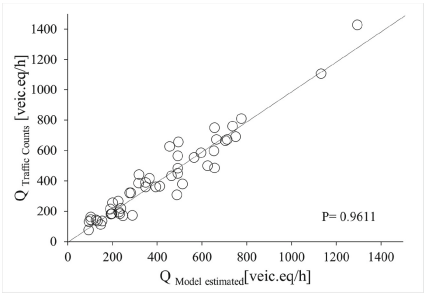

Fig. 5. Comparison of flows after the calibration phase in the morning time window (07:15–08:15) of a typical weekday (P = 0.9611).

3.3 Ex-Post Scenario and Redistribution of Flows

The Municipality of Cassino, through the indications of the PUT (Urban Traffic Plan) has provided for the establishment of a Zone 30 (in the city centre) which encloses the pedestrian area inside, built with a partial pedestrianization of Corso Della Repubblica (see Fig. 6).

The adoption of this new traffic rule is likely to generate a strong perturbation in the flow of vehicles. Although there is no direct interaction within the pedestrian area between vulnerable users and vehicles, but there is an indirect interaction which has strong consequences in the surrounding areas (roads) and which can reverberate even at unpredictable distances, to congest roads and itineraries that in the current situation don't present problems, and to unload others.



Fig. 6. A detail of the study area: in green the pedestrian area and in red the Zone 30 in the ex-post scenario. Source: Google Maps pluging in [19]. (Color figure online)

It is necessary to analyse the new routes that will be chosen by drivers to carry out a certain manoeuvre that will be suppressed due to the establishment of the new pedestrian area.

As an example, the current or ex-ante condition (Fig. 7) and the condition of the project or ex post (Fig. 8) have been correspondingly represented. In the condition of the current scenario, in order to be able to travel from point A to point B, or from B to A, road users choose a very direct route, such as to minimize travel times and therefore the cost of transport. In the project scenario, however, with the operation of the pedestrian area and the change in the traffic rules for some roads, road users will be forced to follow alternative routes to carry out their trips between points A and B. Among the possible alternative itineraries, users will choose those with shorter travel times.

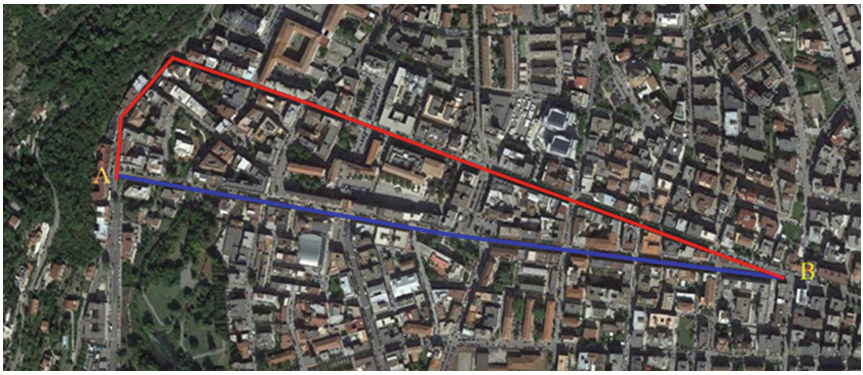

Fig. 7. Two routes to carry out trips between point A and B in the ex-ante condition. Source: Google Maps pluging in [19].



Fig. 8. In the ex-post condition, for the trips between A and B, users will have to choose different paths and will experience different travel times. Source: Google Maps pluging in [19].

4 Results

Following the identification of new itineraries that will affect the road network surrounding the pedestrian area, a comparison between the flows estimated by the proposed simplified method and those provided by a traffic demand model is conveniently reported (Fig. 9). This comparison allows to understand how reliable this simplified method can be compared to the canonical use of traffic simulation software.

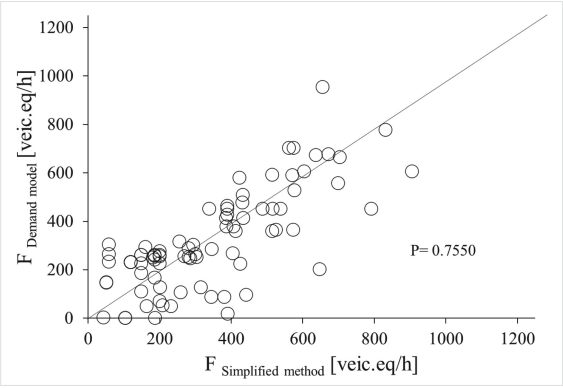

Fig. 9. Comparison between the flows estimated with the simplified method and the flows of the demand model.

A sensitivity analysis has been performed by applying the four assignment methods. In Fig. 10 the comparision between the simplified approach with the UE assignment and the demand model is shown, and in Fig. 11 the SO assignment is implemented in this simplified approach. In Fig. 12 it is possible to notice the results of the *All or Nothing Assignment* Method and in Fig. 13 the UE/SO collapsed Assignment when free flow travel times are neglected.

As it can be observed, the best agreement has been shown by the first proposed simplified Assignment Method that is based on travel time, but good results are also obtained with *User Equilibrium* and *System Optimum Assignment* and also with *User Equilibrium/ System Optimum Assignment neglecting free flow travel times*. The worsts assignment method appears to be the *All or Nothing Assignment* because of its somehow unrealistic hypothesis in a typically congested urban environment.

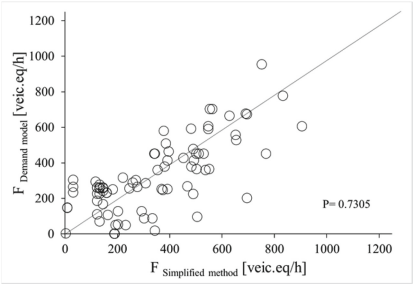

Fig. 10. Comparison of flows between the simplified approach with the User Equilibrium Assignment and the demand model (P = 0.7305).

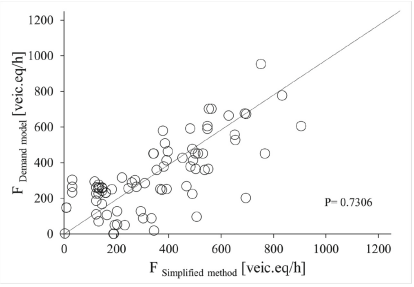

Fig. 11. Comparison of flows between the simplified approach with System Optimum Assignment and the demand model (P = 0.7306).

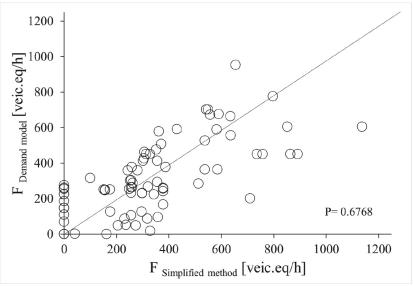

Fig. 12. Comparison of flows between the simplified approach with All or Nothing Assignment and the demand model (P = 0.6768).

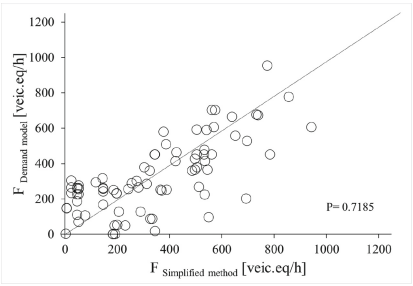

Fig. 13. Comparison of flows between the simplified approach with User Equilibrium/ System Optimum Assignment neglecting free flow travel times and the demand model (P = 0.7185).

5 Conclusions

Following the recent attention paid to sustainable mobility in urban areas, an increasing focus on the design of new pedestrian areas implies the need of new methodological approaches that can be easily used by municipal managers. In this connection a simplified approach to give a comprehensive method to understand the future traffic scenario after the establishment of a new pedestrian area impacting on local vehicular traffic conditions has been presented in this paper.

It is believed that due to the high complexity of developing and handling travel demand models, a simplified method to predict the future traffic scenario after the establishment of the pedestrian area, may represent an effective tool for roads managers and designers in promoting policies based on sustainable mobility.

A travel demand model has been conveniently developed and calibrated and corresponding future traffic scenarios have been compared with results provided by the aforementioned simplified approach employing five different assignment methods. The benchmarking among these different assignment approaches employed within the simplified methodology highlighted that the five methods are almost equivalent in terms of implementation process, but, as it is possible to see, the worst method is that based on too simplified assumptions on route decision processes (the *All or Nothing* approach) than cannot be employed in a congested road network such that of an urban city.

In the future, it is planned to carry out analysis on different peak-hour time period, in order to gain a more refined prediction of the future traffic scenarios on a daily pattern basis. The calibration of the proposed simplified method highlighted two critical aspects that need to be carefully taken into consideration: the first is the overestimation of the vehicle flows (which in the design phase could be an advantage) and the second is the choice of an adequate amount of alternative routes which affects the estimation of traffic flow.

However, it is believed that this method can also be used in a planning phase of the urban road network allowing city roads designers and managers to make decisions about

road safety and to understand how to prioritize interventions and allocate funds in urban areas.

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