IMPRENSA DA UNIVERSIDADE DE COIMBRA
COIMBRA UNIVERSITY PRESS

ASSESSMENT METHODOLOGIES

ENERGY, MOBILITY AND OTHER REAL WORLD APPLICATION

PEDRO GODINHO
JOANA DIAS
EDITORS

Microsimulation for traffic calming schemes assessment – a case study

Joana F. Dourado and Ana M. C. Bastos Silva[1]

Abstract

The accidents' data in Portugal show an urgent need to improve the safety of vulnerable users in urban areas. In 2013 73% of the total pedestrians fatalities registered in urban areas occurred in local roads (ANSR, 2014). Many urban roads are multifunctional, used by vulnerable users and motorized traffic, which results in substantial differences in speed and degree of protection, producing a drastic asymmetry between the mobility of motor vehicles and the safety of vulnerable users. Traffic calming appears as a useful tool to mitigate this problem.

In Portugal, recent legislation allows the implementation of urban traffic calming schemes particularly adapted for residential areas: 30 km/h zones and shared spaces (woonerf zones or home zones). With this in regard the existence of a minimum standardized methodology for the implementation of these schemes is essential to ensure an adequate selection of the urban area and a proper choice of the physical measures and road environmental changes to implement.

"Before and after" studies are essential evaluation approaches of the transformed urban areas. Nevertheless, before the implementation of these schemes it would be helpful to have an idea on the impact of these measures without having to disturb the real system. Using microsimulation models it is possible to represent the reality with high detail, simulating the real network conditions and developing a perform analysis with computer representations.

[1] Civil Engineering Department, University of Coimbra
e-mails: joana.dourado@uc.pt, abastos@dec.uc.pt

http://dx.doi.org/10.14195/978-989-26-1039-9_6

The feasibility and applicability of these concepts were tested in the development of a real case study, where changes were proposed to some areas of the neighbourhood Norton de Matos in Coimbra and a micro-simulation model was built to evaluate the local and peripheral effects of such traffic calming schemes. A methodology for implementing such interventions in residential areas is presented. For that purpose a resident/visitor survey was also elaborated.

The results were particularly interesting. Population showed to be aware of the speed impacts and open to the implementation of such measures, defending the speed control and the safeguard of the pedestrians in residential areas. In a general analysis the evaluation of the results showed that the application of traffic calming measures would not generate a significant increase of the inter-zonal travel times, achieving however significant reductions in through traffic volumes and speeds within the study case area.

Keywords: Microsimulation, Traffic Calming, 30 km/h Zone, Home Zones

1. Introduction

The accidents' data in Portugal show the urgent need to improve the safety for vulnerable users in urban areas. When dealing with multifunctional areas one must take in consideration the following: 1. the appropriate speed is usually the lowest of the speeds adequate to the individual functions (Avenoso and Beckmann, 2005); 2. In collisions with pedestrians, if the collision speed is less than 30 km/h, more than 90% of those struck survive (SWOV, 2012). With this in regard, traffic calming appears as a useful tool to achieve the required safety conditions (Ewing, 1999; van Schagen, 2003).

Traffic calming can be translated in a set of infrastructural physical measures that change the driver's behavior inducing lower speeds and greater awareness of vulnerable road users.

The principles of traffic calming date back to the beginning of the 1960's. Since then different solutions and measures have been tested: segregation of traffic and pedestrians, shared space solutions, 30 km/h speed limit complemented with measures like: speed humps, chicanes, raised intersections, and others. See authors: Hass-Klau (1992), Danish Road Directorate (1993), Ewing (1999), Schepel (2005), TSO (2007), SOWV (2010), IMTT (2010).

In Portugal, recent legislation allowed the implementation of urban traffic calming schemes: 30 km/h zones and shared spaces (*woonerf* zones). The first 30 km/h zones in Portugal were implemented recently in Lisbon in the end of 2013 (Nunes da Silva and Lajas Custódio, 2013). With this in regard the existence of a minimum standardized methodology for the implementation of these schemes is essential to guarantee not only that they are well implemented but also that the chosen areas are suitable.

"Before and after studies" are essential elements for the evaluation of the transformed urban areas. Nevertheless before the implementation of these schemes it would be helpful to have an idea on how these changes will affect the urban area without having to disturb the real system. Recently some research works have been using microsimulation to assess traffic calming impacts (Yousif *et al.*, 2013; Ghafghazi and Hatzopoulou, 2014).

The present article focuses on traffic calming measures, such as Woonerf zones and 30 km/h zones, which have potential application in multifunctional residential areas. The applicability of these concepts is tested by developing a case study in the neighborhood Norton de Matos, in Coimbra. Then to assess the impacts of the proposed measures a microsimulation model is proposed as a useful tool.

2. Traffic Calming Schemes in Residential Areas

2.1. The Woonerf Zones

In woonerf zones pedestrians, cyclists and motorized traffic share the same area, without the separation between carriageway and sidewalks.

Concerns with urban design are present and the layouts of the streets may include areas for children to play, seats, parking places and vegetation providing not only environmental improvements but also creating obstacles for higher speeds. It should be impossible for cars to drive very much faster than walking pace (in Portugal, speed limit is 20 km/h) otherwise, the scheme may give a false feeling of safety for pedestrians and cyclists (Hass-Klau, 1992).

The main function of the woonerf zone should be residential and the traffic terminating or originating from the area should not exceed the 100 vehicles/h (Hass-Klau, 1992; de Witt and Tallens, 2001). The targeted areas can be individual streets or a set of small streets. The entrances and exits of the woonerf zone shall be recognizable with the specific sign and changes in infrastructure and the landscape.

Many studies have been done to evaluate the benefits and costs of these schemes. Although the construction costs can be high, there are many benefits (Hass-Klau, 1992; van Schagen, 2003). Study cases made in the UK and in the Netherlands (Biddulph, 2010; SOWV, 2003) pointed out reduction of vehicles speed, increase in the feeling of safety and actual reduction in reported injury accidents, some of these findings even in more affordable projects.

2.2. The 30 km/h zones

The 30 km/h zones appeared as an alternative to the woonerf. The traditional separation between the carriageway and sidewalks is established, but it is imposed a 30 km/h speed limit and the streets are treated with traffic calming measures like: gateway treatment, speed humps, chicanes, raised intersections, raised crosswalks and changing surface pavement texture and colors (TSO, 2007; Hass-Klau, 1992).

These zones are well fitted for both access and distributor urban streets (TSO, 2007) especially in residential areas and roads passing in front of schools and shopping areas (ETSC, 2008).

In terms of effectiveness, according to studies of the Institute for Road Safety Research, SWOV (2010), Netherlands, the average number of crashes decreases by about 25% when 50 km/h speed limit is redesign as 30 km/h Zone. In the UK, the Transport Research Laboratory (TRL) reviewed results from 250 zones in England, Wales and Scotland (Webster and Mackie, 1996). The main findings indicated that average speeds reduced by about 15 km/h, annual accident frequency fell by 60% and traffic flow in the zones was reduced by 27%, causing the increase of 12% in the surrounding boundary roads.

2.3. Combining the two schemes

In terms of rehabilitating the street life and activities and discourage car use, the woonerf zones are more efficient than simple traffic calmed streets (Biddulph, 2012) imposed by vertical signing. However its implementation conditions are restrictive. With that in regard, combining 30km/h zones with smaller woonerf areas inside them may be a good approach.

Public participation is an essential key for the acceptance of the traffic calming measures implementations (van Schagen, 2003). The integration of the residents in the elaboration of the projects allows unheard concerns to be raised, creating more adequate and acceptable solutions (Biddulph, 2003) and stimulating the relations between authorities and population, enforcing the community feeling.

3. Methodology Approach

This study focused on the definition and evaluation of a proposal for the transformation of an existing neighborhood through the use of traffic calming measures. The methodology was based on five key stages (Figure 1): (i) selection of the intervention area; (ii) diagnosis; (iii) development of the solution; (iv) impact assessment using a microsimulation model; (v) analysis of the results.

3.1. Case Study Area

The selected case study concerns the neighborhood Norton de Matos and the surrounding streets, located in Coimbra, Portugal (Figure 2). This is a multifunctional residential area: it has not only housing, but also one basic school, a cultural center and many markets, coffee shops, and other facilities;

It is crossed by some local and major distributor roads, which creates conflicts between local activities and through traffic.

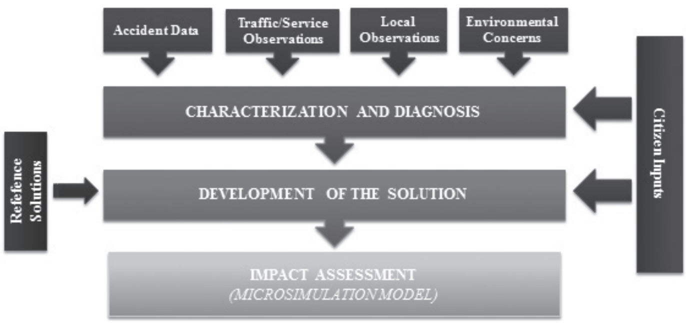

Figure 1: Methodological approach (from Dourado, 2013)

Figure 2: Study area, with the highlight of the intersections studied with more detail (from Dourado, 2013)

Due to lack of resources it was not possible to study the entire area with detail. Instead it was chosen the most interesting and problematic zone to analyze with more detail and more generic analyses and solutions for the remaining area. The zone chosen was the set of intersections between the distributor streets “Vasco da Gama”, “Macau”, “Mouzinho de Albuquerque” and “Daniel de Matos”. This zone was chosen due to the presence of many facilities (the school, the cultural center and many cafes) and high through traffic volumes (Figure 2).

3.2. Characterization and Diagnosis

In order to develop an adequate solution for this residential area a diagnosis was first made (Figure 1). This diagnosis was based on five categories (Hoyle, 1995 quoting Smith *et al.*, 1980):

1. *Citizen inputs* based on residents and visitors surveys: a survey based on a 5-point scale was made to ascertain residents and visitors' satisfaction and perceived safety as pedestrians, easy of parking, use of the street by children to play (Biddulph, 2010) and degree of acceptance of possible approaches to the space occupancy changes.
2. *Traffic/Service observations:* road hierarchy, traffic volumes, traffic speed, parking conditions, public transport supply.
3. *Records: accident data*. The accident data was provided by official entities (ANSR) and included accidents between vehicles and vehicles and pedestrian.
4. *Local observations of resident and visitor activities;*
5. *Environmental concerns:* access for pedestrians, visual quality and noise.

3.3. Development of the solution

Given the non-existence of support manuals with neither built examples of 30 km/h zones nor woonerf zones in Portugal, the development of the solution was based on international best practices, particularly in northern/central Europe.

3.4. Microsimulation Model development

Microsimulation is a dynamic and stochastic modeling of individual vehicle movements within a transport system/network. These models simulate vehicle-by-vehicle, updating their position, speed, acceleration, lane position and other state variables on time steps as they interact with each other and with the environment (traffic signals, road geometry, etc.) (Gettman and Head, 2003). These interactions are modeled using complex algorithms (microscopic models) that describe some maneuvers and behaviors. The three fundamental sub-models are: lane changing, car following and gap acceptance.

In traffic analysis, the microscopic traffic simulation models are being increasingly used (Habtemichael, 2013). Simulation-based studies allow investigating hypothesis on safety and efficiency of traffic operations under controlled environment and different traffic conditions (Lee *et al.*, 2004 and Abdel-Aty *et al.*, 2006).

The development of a simulation model involves five steps (Vilarinho and Tavares, 2012): model codification, verification, calibration, validation (it should be used different data or performance indicators from the calibration) and scenario testing.

4. Characterization and Diagnosis Results

4.1. Data collection

Accident data: 14 accidents were recorded from 2007 to 2011, being 6 collisions with pedestrians and 8 collisions between vehicles, all resulting in light injuries. The majority of these accidents occurred in the streets “Vasco da Gama”, “Macau”, “Daniel de Matos”. This data refers only to accidents with injured people or situations that required the police presence, so there may have been other less severe accidents not reported.

Traffic volumes: traffic volumes during the morning rush hour were globally the most higher. The most frequented street was “Rua Mouzinho de Albuquerque" with approximately 600 vehicles per hour arriving to the intersection. In both intersections, the traffic circulated fluently, so no capacity problems were recorded. During the afternoon, although the global volumes were a bit lower, the congestion level of the intersections was higher, due to illegal parking near the facilities.

Speed: The average speeds measured in three sections: "Daniel de Matos", "Mouzinho de Albuquerque" and "Macau" in free flow speed conditions, with no stopping or decelerating at the intersections or crosswalks, were between 38 km/h and 45 km/h and the percentile 85 was between 42 km/h and 51 km/h. However the range of speeds recorded in the same locals could go from 25 km/h to 60 km/h or more.

Parking conditions: Just outside the facilities there is not enough parking during the peak hours. However, there are free spaces in almost every street in the area during all day. Most of the parking places are not formalized.

Access for pedestrians: The minimum sidewalk width of 1,5 m is not respected everywhere and some pedestrian paths are degraded.

Local activities, visual quality and noise: The study area offers a good social environment. Inside the neighborhood Norton de Matos, some of the squares have suffered recent improvements, offering places for socialization. The discomfort caused by the vehicles noise, it is more significant in the distributor streets.

Citizen inputs: the sample included young people, adults and older people. The majority of residents interviewed were retired and in the case of the visitors they were young or active people. Nevertheless their opinion did not differ radically in most of the answers. The majority of people feel that cars pass too fast in the residential area, causing unsafety feelings. When asked about possible changes in the neighborhood, both residents and visitors showed good acceptance: almost 80% agreed with the 30 km/h speed limit in that area, 77% agreed with the implementation of traffic calming measures in the major streets and 82% answered affirmatively when asked if they agreed with giving the priority to pedestrians in local access streets.

4.2. Discussion of the Diagnosis Results

The characterization work and diagnostic allowed confirming that although there are no serious problems of road safety, the quality of life of the neighborhood has been deteriorating in time with the car invasion, thus justifying a global intervention in order to defend and promote the presence of vulnerable users and the improvement of local life quality.

Registered accidents reflect the existence of conflicts between vehicles and pedestrians on the major distributor roads. The speed measurements reinforce these findings. Although the average values are not very high, they may be sufficient to cause accidents with serious consequences, considering that this is an area with many facilities and strong presence of pedestrians (including children). Also the high range of speed values in the same street suggests that the road design is permissive, allowing driving behavior depending almost exclusively from driving personal style, which can vary drastically and also be unpredictable.

The through traffic tends to be another problem. Although it was not possible to assess the weight associated with this traffic component (which would require making origin/destination surveys), it is expected to be significant. Although the measured traffic volumes may not be very high in terms of road capacity, they tend to be high for a residential area. The priority given to the major distributor roads that cross this area, allowing high speeds, may encourage the presence of through traffic.

The illegal parking near the facilities (school and cultural center) creates conflicts in the intersections justifying an intervention. Also reorganizing the parking offer in the neighborhood is a way of not only maximizing the offer but also of improving the public space quality.

5. Development of the Solution Proposal

The proposed solution seeks to respond to three major objectives:

- Eliminate/decrease the through traffic;
- Speed control and homogenization;
- Decrease conflicts and accidents.

The basic principle of the solution concerned the protection of the vulnerable users and urban experience over vehicle mobility, without affecting the accessibility. With this in regard the global solution includes two strategies of intervention: (i) Creation of a 30 km/h zone covering the entire neighborhood; (ii) Identification of restrictive areas inside the neighborhood to transform into woonerf zones.

5.1. Redefinition of the road hierarchy

The first task focused on the redefinition of the road hierarchy in the study area, downgrading some of the current major distributor roads that cross the center of the neighborhood - Streets “Vasco da Gama”, “Daniel de Matos”, “Macau” and “Mouzinho de Albuquerque”. This changes aims to affect the traffic conditions (increasing travel times) on these streets to discourage the through traffic, sending it to the peripheral major distributor roads.

5.2. New circulation plan

The definition of a new circulation plan (Figure 3) was made, which included the alteration of some traffic direction changes and creation of one way roads. The aim was to create a group of closed circuits inside the area, in order to eliminate the long rectilinear trajectory that links street Mouzinho de Albuquerque and Macau (the major crossing axis).

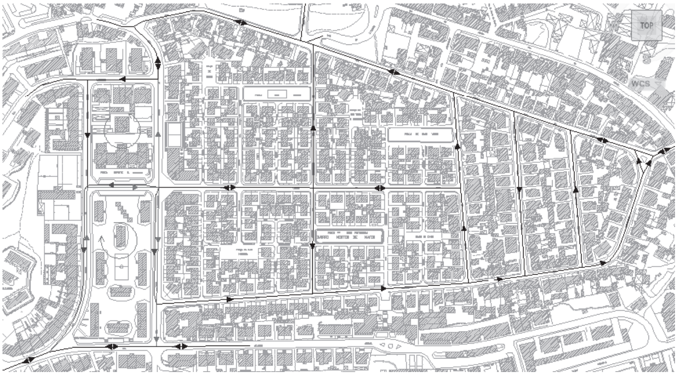

Figure 3: New circulation plan (from Dourado, 2013)

5.3. The 30 km/h Zone

With the definition of the 30 km/h zone, a new legal speed limitation is imposed, which contributes to the increase of safety without high prejudice of the motor vehicles circulation. This includes the application of the road signal and the implementation of traffic calming measures in the distributor roads, such as: chicanes by reorganizing the parking spaces alternately on each side of the street, raised platforms in the intersection and raised crosswalks. A detail solution was made for a group of intersections in the neighborhood (Figure 4): pavement elevation until the sidewalks height, colorful and textured pavements and enlargement and safeguard of the sidewalks, reposition of crosswalks, lighting improvement.

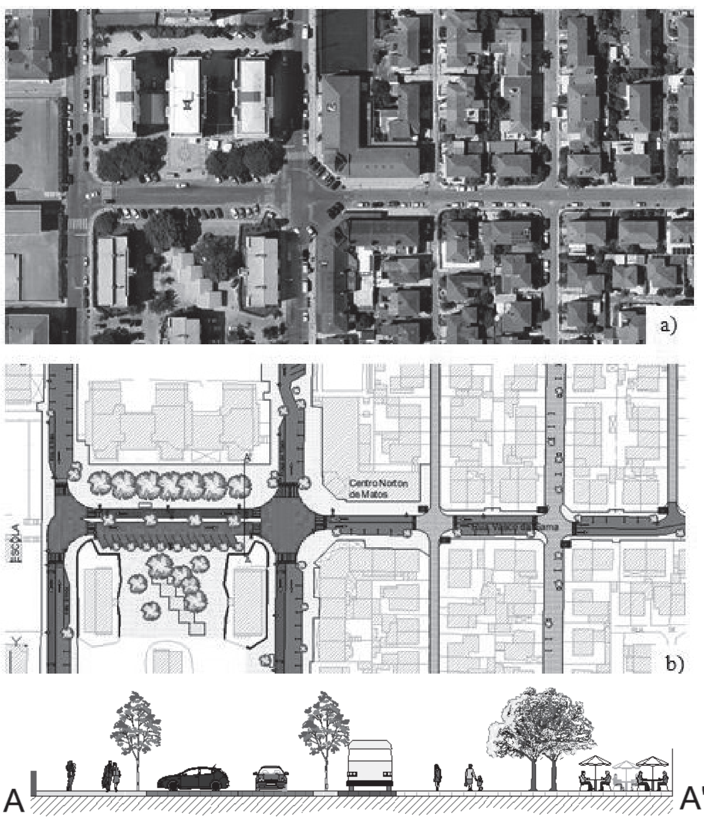

Figure 4: Solution proposed for the study area: a) present situation; b) proposed project plant and traverse cutting of the proposal for the intersections. (from Dourado, 2013)

5.4. Woonerf Zones

Creation of woonerf zones inside the 30 km/h zone, in local access streets and squares inside the neighborhood (smaller streets in figure 4, b)). Delimitating the parking places in these streets and adding some street furniture, without blocking the circulation of the resident's cars or emergency vehicles, creating good spaces for children to play and neighbors to socialize. The entries in these streets should be signalized with the respective road signal and raised platforms in the intersections can contribute to a gate effect. Parking inside these zones should be restricted to the residents.

5.5. Complementary measures

To respond to the parking supply problems one suggests some parking management measures, like: *kiss&ride* near the school, charging tariffs and time limitations, spaces reserved to residents.

For the public transport in this particular area, one proposes the creation of bus lanes for the existing public transport routes.

6. Impact Assessment using a Microsimulation Model

Given the impossibility of making before and after analysis, one opted to build a simulation model using the software *Aimsun*, from *Transport Simulation Systems®* in order to assess the possible effects of the proposed measures.

Thus, two scenarios were created:

- The Current Situation - reference scenario;
- Proposed Solution - incorporating amendments to traffic directions and the resulting impedances from maximum speed changing.

6.1. Building the model

In order to assess the impacts of the proposed solution for the study area one decided to expand the codified area to some surrounding spaces. Thus, for the simulation the study area became delimited by "Rua do Brasil", "Estrada da Beira", "Av. Mendes da Silva" and "Av. Cónego Urbano Duarte".

The codification of the area was based on air photographs and cartography, courtesy of the Municipality of Coimbra. Additionally centroids were defined to represent traffic origin/destination in the network. Also, bus circuits were established.

The O/D matrix was deduced from the collected data sample of traffic volumes. Due to the lack of data, the calibration of the model was made in a qualitative way, based on local observations, known dynamics of the area and using for quality control purposes the traffic volumes recorded in the studied intersections. As this exercise was mainly a comparative study to evaluate the magnitude of the effects resulting from the application of the proposed solution compared to a reference situation, it was considered not particularly relevant to reliably simulate the real circulation conditions. The software does not allow a detailed representation of all traffic calming measures (i.e., pavement elevation). To overcome this, one represented impedances in speed in the sections were the measures were supposed to be implemented.

6.2. Performance Indicators

To answer the objectives of the study one selected the following indicators: total travel time, total travel distance; traffic volumes assigned to each arc of the network; average speed in the network; average density of the network.

At the same time, the selection of the routes by the model for each O/D pair was analyzed.

6.3. Simulation results and discussion

As previously referred there were selected two scenarios: a reference scenario and the proposed solution. Even taking into account possible mismatches with the real situation, the simulation results (see Figure 5) corresponded generally to the expectations:

- General decrease of traffic volumes inside the neighborhood Norton de Matos, especially in the street Vasco da Gama (interior segment of the neighborhood);

- Significant increase of traffic volumes in some surrounding streets of the neighborhood;

- Significant increase of traffic volumes in the street Daniel de Matos (targeted street in the solution) and in the segment of the Street Vasco da Gama, that links the two targeted intersections.


a)


b)

Figure 5: Network traffic assignment: a) reference situation; b) after changes. Traffic volumes increase with the darkness of the lines and density (veh./ Km) increases with thickness (from Dourado, 2013)

In terms of routes choice, there were registered alterations. As an example, the O/D pair “Portela/Solum”, which corresponds to south/north centroids, shows a clear reduction in the slice of traffic that crosses the neighborhood - from 31.87% to 12.39% (Figure 6). It is also possible to see the adoption of a new route using the street “Paulo Quintela”, which has suffered from traffic volumes increase after the creation of the 30 km/h zone.

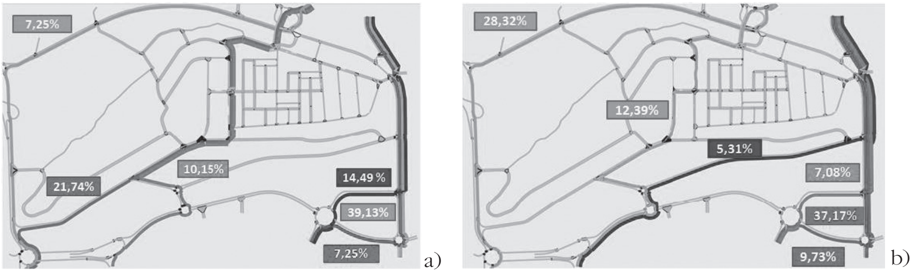

Figure 6: Routes choice for Portela/Solum O/D pair. a) reference situation, b) after alterations (from Dourado, 2013)

The global performance indicators show interesting results: the total travel time increased 2,35% (from 202,65 h to 207,41 h), the total travel distance remained approximately constant, the average speed in the network decreased from 50.01 km/h to 49.08 km/h and the average density of the network slightly increased from 4.36 vehicles/km to 4.48 vehicles/km.

The simulation results allowed concluding that the measures introduced in the neighborhood would not cause drastic changes in the average global speed neither in the average travel time correspondent to the area of influence of the intervened zone. Although these results cannot be generalized for other situations, these conclusions are especially important to help mitigate the idea that traffic calming measures penalize significantly the general community circulation. This means that it may be possible to delimit areas subject to traffic calming measures without causing significant disturbances in the local mobility and accessibility.

Nevertheless it is important to highlight the possible less positive effects of this proposal: the migration of traffic and conflicts/accidents to other peripheral streets inside the neighborhood. It is essential to guarantee that there are conditions to accommodate this traffic and that the speed control measures are efficient. In this case, the proposed measures to these streets are expected to respond to these demands.

7. Conclusions

Through the study of foreign experience, namely north and center European countries, it was possible to determine extremely positive results associated with the implementation of traffic calming in residential areas.

In order to test the applicability of these concepts a study case was developed. A set of integrated measures was proposed to the neighborhood Norton de Matos. The solution definition was preceded by a diagnosis based on population surveys complemented with local observations and collection of traffic and speed data. To assess the impacts of the proposed measures to the target area and to its influential zones, a microsimulation model was built with Aimsun Software.

There are still some aspects of this study that should be taken into account in the analysis and assessment of the results:

- The isolated study of the target area without contemplating the adjacent areas may be a limitation in terms of results interpretation and in the definition of the solutions;

- The difficulties in the data collection for the diagnosis showed to be a limitation not only for the proposal definition but also for the construction of the simulation model. The impossibility to use an O/D matrix representative of the real traffic demand conditioned significantly the quality and robustness of the results analysis.

Despite the difficulties, the microsimulation showed to be an effective tool for evaluating the potential effects of proposed amendments. The results are in line with the expected, indicating the effectiveness of traffic calming solutions and identifying some less desirable effects.

This work is not a finished product. One can identify a set of actions that should be further developed: the extension of the zone (in terms of detailed solution) and an extensive data collection to build, calibrate and validate the microsimulation model. These two actions are essential to assess the overall effects associated with the implementation of the 30 km/h zone and other measures.

Acknowledgements: This work has been carried out in the framework of projects EMSURE - Energy and Mobility for Sustainable Regions (CENTRO-07--0224-FEDER-002004).

References

Abdel-Aty, M., Dilmore, J. and Hsia, L., Applying Variable Speed Limits and the Potential for Crash Migration. Transportation Research Record, 1953, pp. 21–30, 2006.

ANSR. (2014). Relatório Anual de Vítimas a 30 dias- 2013. ANSR.

Avenoso, A. and Beckmann, J., The Safety of Vulnerable Road Users in the Southern, Eastern and Central European Countries (The "SEC Belt"), European Transport Safety Council, Brussels, 2005.

Bastos Silva, A., Vasconcelos, L., Correia, G. and Santos,S., Microssimulação Aplicada aos Estudos de Acessibilidade. 7º Congresso Rodoviário Português (CRP), 10 a 12 de Abril, Lisboa, 2013.

Biddulph, M., Evaluating the English Home Zones Initiatives. Journal of the American Planning Association, 76:2, 199-218, 2010.

Biddulph, M., Street Design and Street Use: Comparing Traffic Calmed and Home Zones. Journal of Urban Design, 17:2, 213-232, 2012.

Biddulph, M., Towards Successful Home Zones in the UK. Journal of Urban Design, 8:3, 217-241, 2003.

Danish Road Directorate, An Improved Traffic Environment – A Catalogue of ideas. Ministry of Transport, Denmark, 1993.

De Wit, T. and Talens, H., Traffic Calming in the Netherlands, CROW, the Dutch National Information and Technology Centre for Transport and Infrastructure, 2001.

Dourado, J.F., Soluções de Acalmia de Tráfego com Potencial de Aplicação em Áreas Residenciais Multifuncionais, Master Dissertation on Civil Engineering under the suppervision of Professor Ana Maria César Bastos Silva, University of Coimbra, 2013. Written in portuguese.

ETSC-European Transport Safety Council, Shlow! Show me How Slow- Reducing Excessive and Inappropriate Speed Now: a Toolkit. European Transport Safety Council. Brussels, 2008.

Ewing, R., Traffic Calming: State of the Practice, Institute of Transportation Engineers, Washington. 1999.

Gettman, D. and Head, L., Surrogate Safety Measures from Traffic Simulation Models. Transportation Research Record, 1840, pp. 104-115, 2003.

Ghafghazi, G. and Hatzopoulou, M., Simulating the air quality impacts of traffic calming schemes in a dense urban neighborhood. Transportation Research Part D 35 (2015) 11–22. 2014.

Gomes, G., May, A. and Horowitz, R., Congested Freeway Microsimulation Model Using VISSIM. Transportation Research Record, 1876, pp. 71–81, 2004.

Habtemichael, F.G. Improved Active Traffic Management System for Motorway Safety and Efficiency: Benefits of Reducing the Driving Task Difficulty, Thesis specifically prepared to obtain the PhD Degree in Transportation Systems under supervision of Professor

Luís Guilherme de Picado Santos, Universidade Técnica de Lisboa, Instituto Superior Técnico, Lisboa, 2013.

Hass-Klau, C. et al., Civilised Streets- A Guide to Traffic Calming, Environmental & Transport Planning, Brighton, 1992.

Hoyle, C. L., Traffic Calming. American Planning Association. Michigan, 1995.

IMTT- Instituto de Infra-Estruturas Rodoviárias, Disposições Normativas. Medidas de Acalmia de Tráfego, Instituto de Infra-Estruturas Rodoviárias, 2010.

Lee, C., Hellinga, B. and Saccomanno, F., Assessing Safety Benefits of Variable Speed Limits. Transportation Research Record, 1897, pp. 183–190, 2004.

Nunes da Silva, F. and Lajas Custódio, R. Zonas 30 – Segurança Rodoviária, Vida e Vitalidade para os Bairros da Cidade de Lisboa, 7º Congresso Rodoviário Português (CRP), 10 a 12 de Abril, Lisboa, 2013.

Schepel, S., Woonerf revisited - Delft as an example, International Childstreet2005 Conference, Delft, 2005.

Smith, D. et al., State of the Art Report: Residential Traffic Management, U.S. Department of Transportation Federal Highway Administration, Report No. FHWA/RD-80/092, 1980.

SWOV- Institute for Road Safety Research, SWOV Fact Sheet- Zones 30: Urban Residential Areas. Leidschendam. 2010.

SWOV- Institute for Road Safety Research. SWOV Fact Sheet-Vulnerable Users, SWOV, Leidschendam, 2012.

TSO - The Stationery Office, Local Transport Note 01/07- Traffic Calming. Department for Transport, The Stationery Office, London, 2007.

van Schagen, I., Traffic Calming schemes - Opportunities and Implementation Strategies, SWOV, Leidschendam, 2003.

Vilarinho, C. and Tavares, J.P., Traffic Model Calibration: A Sensitivity Analysis. Compendium of papers of the 15th Edition of the Euro Working Group of Transportation. International Scientific Conference. 10 to 13 December, 2012, Paris. 2012.

Webster, D. and Mackie, A., Review of traffic calming schemes in 20 mph zones. TRL Report 215. Transport Research Laboratory, Crowthorne, 1996.

Yousif, S., Alterawi, M. and Henso, R., Effect of Road Narrowing on Junction Capacity Using Microsimulation, Journal of Transportation Engineering, ASCE/June 2013.

Série Investigação
•
Imprensa da Universidade de Coimbra
Coimbra University Press
2015

mais CENTRO
Programa Operacional Regional do Centro

QREN
QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

• U C •

IMPRENSA DA UNIVERSIDADE DE COIMBRA
COIMBRA UNIVERSITY PRESS