A simulation procedure for the assessment of traffic management impacts on urban road safety

A. Nuzzolo & P. Coppola

Department of Civil Engineering, University of Rome "Tor Vergata", Italy

Abstract

Recent statistics and research projects have shown that road accidents are one of the greatest cause of death in Europe. Moreover, almost half of these deaths takes place in urban areas, where the conflicts between different traffic components (i.e. vehicles, pedestrians, cyclists, etc.) are bigger. One of the levels which local authorities can handle to contain the phenomenon is Traffic Management, i.e. the set of all those measures reducing traffic volumes and conflicts among traffic streams, reducing vehicles speed and so on.

Models and simulation procedures have been proposed in the literature to predict the risk and/or the rate of accidents on the elements of a road network. However, very few of them have been calibrated in urban contexts. In this paper, we present a simulation procedure for the assessment of the impacts of traffic management measures on urban road safety. The procedure consists of two main modules: the former aiming at the estimation of traffic flow on links and at junctions, the latter estimating by means of performance functions of urban road safety, the accident frequency on each element of the network given the average daily traffic flows. Specification and calibration results of road safety functions based on data gathered in the urban area of Rome (Italy) are presented. Preliminary applications of the procedure to the case study are discussed.

1 Introduction

The enormous welfare costs related to deaths and injuries in road accidents, have led in the last years to a great number of studies and research projects focusing
on road safety. It has been estimated that road accident deaths are the eighth cause of death in the World and could become the third one in the future if any prevention policies will not be undertaken (World Health Organization, 1996).

In 1997 the European Commission has endorsed the program “Promote road safety in the EU: the program 1997-2000” [7] aiming at reducing road accident deaths of 40% within the year 2010. As a consequence, in many European countries road safety programs started up, supported both by local authorities (e.g. [5]) and by the European Commission itself (e.g. [6]).

The results of such researches show that it is not possible to isolate single specific causes of road accidents, but it is rather a combination of factors, namely the complex system “Vehicle-Driver-Environment” (Figure 1), which determine the higher or lower probability of accident on a given element of the network. Therefore, an integrated approach consisting of strategic actions aiming at removing relevant factors is needed to improve road safety in an efficient and effectiveness way.

![Figure 1: Road accident factors.](image)

It has also emerged that in EU countries (see Table 1), on the average, the 66% of road accidents happens in urban context due to mainly two reasons. On the one hand, on urban roads, conflicts between traffic streams are bigger then on extra-urban roads, and, on the other hand, in urban network, typically, different traffic components (e.g. pedestrians, cyclists, motorists, automobiles, etc.) are promiscuous. Thus, an effective strategic-plan to improve road safety cannot avoid to facing the problem in the urban context. Here, the main factors of road accidents are the “driver” and the “environment” components. These can be handled by means of reducing the exposition of people to the risk of accident, (i.e. reducing the vehicleKm’s on the network), by reducing the conflicts among traffic streams and traffic components, promoting educational campaign and so on. In general, four classes of road safety measures (i.e. set of actions of the
same typology) can be identified. These can be outlined according to the following topics:

- **Emergency**, including the set of measures aiming at improving the first-aid medical services in case of accident (e.g. first-aid patrols, direct-communication-line to hospitals, etc.);
- **Enforcement**, including the set of actions enforcing the respect of driving rules (e.g. speed limits, priority rules at junctions, etc.) and/or enforcing the control of drivers psycho-physical status (e.g. use of drugs or alcoholics);
- **Education-Encouragement**, including the set of measures aiming at sensitizing people on road safety phenomenon (e.g. educational campaign, radio and television program, etc.
- **Engineering**, including the set of actions aiming at reducing the risk of accident by means of interventions on Traffic Management and on road infrastructures.

<table>
<thead>
<tr>
<th></th>
<th>Number of urban road accident</th>
<th>Total number of road accidents</th>
<th>% of urban road accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>23,344</td>
<td>38,956</td>
<td>59.9%</td>
</tr>
<tr>
<td>Belgium</td>
<td>27,509</td>
<td>50,744</td>
<td>54.2%</td>
</tr>
<tr>
<td>Denmark</td>
<td>5,140</td>
<td>8,373</td>
<td>61.4%</td>
</tr>
<tr>
<td>Finland</td>
<td>4,639</td>
<td>7,812</td>
<td>59.4%</td>
</tr>
<tr>
<td>France</td>
<td>91,088</td>
<td>132,949</td>
<td>68.5%</td>
</tr>
<tr>
<td>Germany</td>
<td>246,617</td>
<td>388,003</td>
<td>63.6%</td>
</tr>
<tr>
<td>Greece</td>
<td>Not available</td>
<td>22,800</td>
<td>n.a.</td>
</tr>
<tr>
<td>Ireland</td>
<td>4,818</td>
<td>8,117</td>
<td>59.4%</td>
</tr>
<tr>
<td>Italy</td>
<td>133,851</td>
<td>182,761</td>
<td>73.2%</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Not available</td>
<td>5,500</td>
<td>n.a.</td>
</tr>
<tr>
<td>Holland</td>
<td>6,334</td>
<td>11,437</td>
<td>55.4%</td>
</tr>
<tr>
<td>Portugal</td>
<td>Not available</td>
<td>48,300</td>
<td>n.a.</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>173,945</td>
<td>237,168</td>
<td>73.3%</td>
</tr>
<tr>
<td>Spain</td>
<td>46,369</td>
<td>83,586</td>
<td>55.5%</td>
</tr>
<tr>
<td>Sweden</td>
<td>9,015</td>
<td>15,626</td>
<td>57.7%</td>
</tr>
<tr>
<td><strong>EU</strong></td>
<td><strong>772,669</strong></td>
<td><strong>1,165,532</strong></td>
<td><strong>66.3%</strong></td>
</tr>
</tbody>
</table>

Traffic Management measures for road safety in urban areas consist of measures oriented both to the demand and to the supply. The former ones aim at improving road safety by diverting the demand on collective modes of transport from individual ones. In this respect, Travel Demand Management (TDM) policies (e.g. parking policies, pedestrian zones, etc.) as well as those policies aiming to improve the quality of collective transport modes, can be outlined as road safety measures "demand-oriented". On the other hand, examples of road safety actions
oriented to transportation supply typically are the modification of ways of circulation aiming at reducing conflicts at junctions, the identification of ranking among network links so to identify priority rules, and so on. Typically the modeling tools for the assessment of the impacts of traffic management policies, with only very few exceptions (see, for instance, the software-package SafeNET [10]), do not allow for the explicit simulation of the phenomena related to road accidents, they rather make use of parametric and qualitative analysis. In facts, it is common practice to assume road accidents as proportional to the total number of vehiclesKm’s, albeit, in some cases, this could lead to erroneous evaluation.

In the next sections, a simulation procedure for the assessment of the impacts of traffic management measures on urban road safety is presented. This procedure consists of two main modules. The former aims at the estimation of traffic flow on links and at junctions given the transportation network supply and the travel demand. The latter allows to estimating, by mean of performance functions of urban road safety, the frequency of accidents on each element of the network given the traffic flows.

The paper is organized as follows. In section 2 the overall modeling framework is presented. Section 3 reviews the state-of the-art of urban road safety modeling. Section 4 reports on the calibration results of the performance functions estimated for the case study of Rome and presents preliminary results of applications of the simulation procedure to the case study. In Section 5 conclusions are drawn and the perspectives of future research are discussed.

2 The proposed simulation procedure

The simulation procedure proposed for the assessment of the impacts of traffic management measures on urban road safety consists of two main modules: the transportation system module and the road safety module (Figure 2).

**Figure 2: Schematic representation of the simulation procedure proposed.**
The transportation system module consists of:

- a demand model simulating drivers travel choices such as trip frequency, destination, mode and path and allowing to estimating the O-D trip-by-car matrix for given reference periods (i.e. the morning peak hour and the average working-day of the year);
- a supply model simulating road network topology and traffic performances at link and junction level;
- a demand-supply interaction model which allow to estimate average daily total (ADT) traffic and the hourly-base peak traffic flows for each link and for each turning movement at junctions.

In the following sections, the focus is on the road safety module. For sake of brevity, the transportation system module [4] will be not described. Given the ADT traffic flows the road safety module allows to estimating the accident frequency on each link and at each junction of the network. To this aim, performance functions of urban road safety are adopted. These are described in the next section.

3 Performance functions of Urban Road Safety

The performance functions of urban road safety are the main components of the Road Safety module (Figure 2). This section reports on a review and a classification of the Urban-Road-Safety (URS) functions proposed in the literature.

In recent years, different model specifications to estimate the number of accidents in urban networks have been proposed. These, albeit limited in number if compared to the ones relative to extra-urban roads, allow to identifying common elements of classification.

Firstly, urban road safety models can be classified according to the output variables. We can distinguish among accident-frequency and accident-rate models: the former estimating the average number of accident in a given reference period (typically a year); the latter estimating the average number of accidents per million or per thousand of vehicles. In general, most of the model specifications proposed in the literature are of the first type (i.e. accident-frequency models), however, examples of accident-rate models have been developed in Sweden [2] and in Denmark [3].

Moreover, we can distinguish between macroscopic and microscopic models. The macroscopic models [1] link the number of road accidents in a given study area, typically on a year base, to urban “macro-variables”. These variables can be related, on the one hand, to the transportation system (e.g. the average speed on the road network, the total number of junctions, etc.) and, on the other hand, to population and/or activity system (e.g. the distribution of population over age classes, car availability, etc.). These models can be specified by means of
regression analysis but in general result not transferable to contexts different from those for which they have been calibrated.

On the other hand, microscopic models consider explicitly the single elements of the road network, namely links and junctions, and estimate the number of road accidents based on traffic speeds and flows on each element. In doing so, they require a higher degree of complexity in specification and calibration, and a greater computational effort in validation and application. However, they result more easily transferable since they do not depend on attributes, specifics of the study area on which they have been calibrated.

Microscopic models can be specified both for links and junctions. Link models mainly relate the number of road accidents to traffic volume and to average speed on the link [12]. Junction models, on the other hand, express the number of accident as a function of traffic flows on the turning movements at junction. In doing so, different typologies of urban junctions can be considered: priority crossroads and staggered junctions [9]; 4-arms signalized junctions [8]; 3-arms signalized junctions [13]. In some cases, the average speeds on the arms approaching the junction are also considered [10].

Junction models can be further distinguished according to the traffic component considered (e.g. only vehicle flows or vehicle plus pedestrian flows), and according to the level of aggregation of the turning movement at the junction. Following the research studies carried on at the TRL (Transport Research Laboratory, UK) two levels of modeling specification can be identified.

At the first level, traffic flows approaching a given junction from the different arms are aggregated. Accordingly the proposed functional form of accident-frequency is the following one:

\[
A = k[Q_v]^\alpha [Q_p]^\beta
\]

where:

- \( A \) represents the accident frequency at the junction;
- \( Q_v \) is the total vehicles flow, given by the sum of the flows on all the traffic streams approaching the junction;
- \( Q_p \) is the total pedestrian flow, given by the sum of the pedestrian flows crossing the arms of junction;
- \( k, \alpha \) and \( \beta \) are duly calibrated parameters.

Second-level road accident models do not treat the junction as a whole but make distinction among different turning movements. Groups of turning movements, which could be involved in a given accident-scenario are identified. For each scenario, \( i \), the accident-frequency, \( A_i \), is estimated by means of a specific model.

The global accident-frequency at the junction is finally given by the summation of the accident frequencies over all the groups of turning movements (i.e. the accident-scenario, \( i \)) identified:

\[
A = \sum_i A_i
\]
An example of an accident scenario for a 3-arm junction is depicted in Figure 3. Here the “conflicting” turning movements belonging to the given scenario are highlighted using bold lines. A comprehensive set of accident-scenarios and the relative calibrated parameter can be found in [8] and [9] for 4-arms junctions and in [13] for 3-arm junctions.

![Figure 3: Turning movements (depicted in bold) belonging to a given accident-scenario for a 3-arm junction.](image)

### 4 The case study of Rome

For the case study of Rome, the observed accident-data available were relative to a temporal interval that resulted to be inadequate to estimating models of the second-level type. Therefore, only first-level accident-models (see equation 1) have been calibrated. The results are reported in Table 2 for four topologies of junctions.

<table>
<thead>
<tr>
<th>Typology of junction</th>
<th>( k )</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-arms not signalized</td>
<td>0.425</td>
<td>0.629</td>
</tr>
<tr>
<td>3-arms signalized</td>
<td>0.014</td>
<td>1.496</td>
</tr>
<tr>
<td>4-arms not signalized</td>
<td>0.310</td>
<td>0.625</td>
</tr>
<tr>
<td>4-arms signalized</td>
<td>0.048</td>
<td>1.350</td>
</tr>
</tbody>
</table>

As it can be seen, the magnitude of the parameter \( k \) (see equation 1) for not-signalized junctions is one order higher than for signalized junctions.
Conversely, the power $\alpha$ of the total flow of vehicles, $Q_r$, results bigger than 1 for signalized junctions and lower than 1 for not-signalized ones. Note that pedestrian flows are not considered in the specification since observed data on such typology flows were not available.

For preliminary applications, two functional specifications have been outlined: the “first-level" (see equation 1) and the “second-level" models (see equations 2) previously introduced. As a matter of facts, the first-level models are those calibrated ad hoc for the study area whose parameters are reported in Table 2; the second-level models are those calibrated on data relative to United Kingdom cities, whose functional specification are reported in [8], [9] and [12].

![Comparison between observed and estimated number of accidents](image)

Figure 4: Comparison between observed and estimated number of accidents (case study: V distric of the city of Rome – Year 2000).

The histograms depicted in Figure 4 report a comparison between the observed number of accident in the year 2000 and the estimates provided by the models adopted. As it can be seen, the first-level models reproduce the observed data better than the second-level models. This result was to be expected since the second-level models have not been calibrated on observed data specific of the city of Rome, but in a different urban context (i.e. UK cities).

A second set of application has been carried on in order to evaluate the response of the models to Traffic Management policies. In doing so, the network topology of the study area has been modified. In facts, in order to reduce the number of conflict points at junctions, one-way links have been created and traffic lights have been introduced for some junctions. As consequence, the total number of vehicleKm's does increase. Thus, a traditional parametric analysis, according to which the number of accident on the network is proportional to vehiclesKm’s, would estimate an unreliable increase of the accident frequency. Surprisingly, such a result is obtained also using the first-level models: an increase of about 5% of accident frequency is estimated, as reported in Table 3. This is due the
very nature of first-level models, which do not take into account of the conflicts between traffic streams at junctions, but consider only total traffic volumes.

Table 3: Urban Road Safety models response to Traffic Management policies.

<table>
<thead>
<tr>
<th></th>
<th>N. of accidents</th>
<th>% changes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base scenario</strong></td>
<td>183</td>
<td>-</td>
</tr>
<tr>
<td><strong>Traffic management policies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(first-level URS-models)</td>
<td>192</td>
<td>+4.9%</td>
</tr>
<tr>
<td><strong>Traffic management policies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(second-level URS-models)</td>
<td>165</td>
<td>-9.8%</td>
</tr>
</tbody>
</table>

As a matter of facts, owing to the changes in network topology introduced, a reduction of accident frequency has to be expected. In fact, this happens when second-level URS-models, which explicitly consider conflicts among traffic streams at junctions, are applied. Indeed, using such models a reduction of about 10% in accident frequency is estimated (see Table 3).

5 Conclusion and further research perspectives

In this paper, a simulation procedure for the assessment of the impacts of Traffic Management measures on urban road safety has been presented. The procedure consists of two main modules: the Transportation System module and the Road Safety module. The Transportation system module consists of demand, supply and demand-supply interaction models, which allows to estimating traffic flows on links and at junctions for the average day of the year. The Road Safety module consists of performance functions of road safety that provides the accident frequency on each element of the network, given the average daily total traffic flows.

Urban Road Safety (URS) models, proposed in the literature, have been reviewed and some classification criteria have been introduced. According to such criteria, distinction is made between “first-level” models, which treat the traffic flows at junctions as a whole, and “second-level” models, which explicitly consider conflicts among traffic streams at junctions.

The calibration results of first-level accident models for four typologies of junctions, based on data gathered in the fifth district of the city of Rome, have been presented.

Accident estimates using the calibrated “first-level” models match the observed data better than the “second-level ones which have been simply transferred from UK cities contexts for which they have been originally calibrated. An analysis of the response of such models with respect to Traffic Management measures (e.g. modification of network topology, introduction of priority rules, modification of the traffic light setting at junctions, etc.) has then been carried on. Preliminary results show that “first-level” URS-models appear to be inadequate to evaluating
the impact of Traffic Management measures on accidents frequency, since they do not take into account of traffic streams conflicts at junctions. On the other hand, "second-level" models give reasonable response with respect to Traffic Management policies: a decrease of about 10% of the frequency of accidents with respect to the Traffic Management measures introduces, has been estimated. An improvement of the "second-level" models for the case study of Rome constitutes, therefore, the core of further work.

6 Acknowledgments

The authors wish to thank Stefano Giovenali and Roberto Gigli (S.T.A. - Rome) for having allowed the access to the accidents data by means of which the models presented have been calibrated.

7 References