ABSTRACT

Traffic assignment/simulation models are widely applied in transport planning and traffic management operations, particularly in the scope of urban networks, but their application is, in many cases, complex and resource demanding, forcing end users to search the best balance between the level of data collection efforts and the required accuracy of the model results. However, in the absence of relevant references that show how the different kind of errors affect the outputs of the models, traffic models construction and validation has become an “art”, where the user experience is essential to guarantee efficient modeling processes and results.

In the current paper a methodology which allows simulating and assessing the impacts of quantification modeling errors is presented. This methodology was tested through the development of a SATURN simulation model applied to the road network of a medium size Portuguese city (COIMBRA).

KEY WORDS

Modelling, simulation, errors, traffic, SATURN

1 Introduction

Traffic simulation models are widely applied in transport planning and traffic management operations, particularly in the scope of urban networks, but their application to real problems is, in many cases, complex and resource demanding. For that reason, transportation planners support the process of construction, calibration and validation of traffic models on guidelines that specify the minimum acceptable levels of similarity between the real world systems and the models, presented in internationally accepted documents [1, 2].

However, none of these manuals, or other relevant documents, indicate how the different types of errors affect the quality of the model estimates. That also implies the practical inexistence of recommendations about the level of accuracy required for the inputs of the models. This situation makes the process of construction and validation of a traffic simulation model an art, in which the user experience is essential to make it efficient and cost-effective.

By definition, any model is a simplification of reality [3] and the existence of differences between the outputs of a model and the real world is, therefore, implicit to every model. According to [4], two main categories may be considered. In the first one are included all those kind of errors that surge upstream the representation of a specific real world system - these are the specification and computerized model errors, whose consequences over the accuracy of the estimates are accessed under the processes of conceptual model and computerized model validation, usually undertaken by the development team; In the second category are included the errors associated with the representation of a specific system – the simplification and quantification errors, whose implications are accessed under the operational validation process. These kinds of errors are, to a certain way, controllable by the end-users, and implicate a compromise between the accuracy of the estimates and the development cost.

The current approaches for assessing the impact of quantification errors are essentially of analytical [5] or simulation [6] kind. This paper presents a simulation-based methodology that allows understanding how quantification errors affect the performance and applicability of the models. This methodology was developed and tested using as a workbench a traffic simulation model developed specifically for this research, representative of the road network of Coimbra - Portugal, using the SATURN software, but its core is generic and may be easily applied to other kind of traffic models, namely to the microscopic ones.

2 A methodology to access the effects of quantification errors

2.1 Methodology conceptual framework
Let us consider the state of a real world system $Y_{R1} = f(X_{R1})$ whose performance is described by a variable set $Y_{R1}$ and caused by explanatory variables $X_{R1}$. One model tries to reproduce the relations observed between the explanatory and the dependent variables, forming a potentially perfect virtual system. This is a mathematical description of the problem, where is assumed that a set of simplifications are made, part of them inherent to the kind of model itself, while others are assumed by the user. Also, the stochastic nature of some of the explanatory variables implies the existence of quantification errors. This way, the prediction of the system state depends on the explanatory variables $X_{E1}$ and the actual virtual representation of the system, that is $Y_{A1} = g(X_{E1})$.

The methodology presented in this work implies, in a first step, the development of a traffic simulation model representative of a real world system, through a process that should follow as closely as possible the state-of-practice, especially in what concerns to the calibration and validation processes, and where, inevitably, errors of different kinds are made. However, after this phase, it will be assumed that the obtained “possible” model $Y_{A1}$ is, actually, a “perfect” model, in which no quantification errors were made, and, consequently, all coded values are exact. This is a virtual reference system and can be considered the perfect representation of a possible reality ($Y_{R2}$), very close to the one that was modeled.

The second step consists on running the reference model several times in batch mode, in each of the cases affected of a variety of typologies, levels and combinations of quantification errors, generated in a structured and systematic fashion, in such a way that they are representative of situations possible to occur in real modeling processes conducted under good practice principles (systems $Y_{A2(i)}$).

The final step consists of qualitative and quantitative analyses of the cause-effect relations observed between the different kinds of errors introduced and the corresponding estimate discrepancies (differences between $Y_{A1}$ and the systems $Y_{A2(i)}$), trying to characterize them in function of a set of factors related to the intrinsic characteristics of the errors themselves, of the road network and its operational conditions.

### 2.2 Quantifying the effect of errors

Although until now no assumptions were made on the model type, the following points are model-specific. The analyses were made upon a conventional, static traffic assignment model of a medium size city, but the same process can be easily applied to other kinds of traffic models. To quantitatively evaluate the effect of the errors three questions need to be addressed:

- **a)** Selection of the real world measures: it is usually preferable to conduct the validation having in mind the measures that will be used in the decision making process [7]. In traffic assignment models, “traffic flows” is usually the preferred measure (but the measure “travel time” could also be used);

- **b)** Selection of the goodness-of-fit statistics: many authors discuss the relative merit of different validation statistics [8]. However, when making pairwise comparisons of observed ($o_i$) and simulated ($s_i$) traffic flows, the GEH statistic seems to be a consensual choice. It is a variation of the qui-square statistic that has the advantages of avoiding divisions by zero and being independent of the order or the values:

$$GEH = \sum_{i=1}^{N} \frac{2(o_i - s_i)^2}{(o_i + s_i)}$$

- **c)** definition of the validation criteria: the more well-known validation guidelines used in transportation planning studies are the ones presented in the Design Manual for Roads and Bridges [1], initially defined for the economical assessment of new trunk roads in the United Kingdom; in the EU MUSIC project [9] those

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**Figure 1: Schematic representation of the analyses methodology**

- Real world system $Y_{R1}$
  - Quantification errors
  - Other errors
- Alternative real world system $Y_{R2}$
  - No quantification errors
  - Other errors
- Approximate model $Y_{A1}$
- Reference model $Y_{A1}$
- Simulation of quantification errors
- Approximate models $Y_{A2(i)}$
- Reference results
- Assessment criteria
- Quantification of the errors’ impact
- Model practical applicability
- Results
guidelines were adapted to urban networks, being proposed that the average GEH statistic should be less than 2, with individual values less than 5 for the best 85% traffic counts comparisons. For this work it was desirable to use the complete set of traffic flows in the network, being found through several tests that specifying an average GEH less than 2.5 for the complete set of arc and turn movements is fairly equivalent to the previous criteria relative to the partial set.

3 Development of the reference model

3.1 The Coimbra road network

As typical in cities with medieval origin, the main activities take place in the central part where the road structure has a very limited capacity. When the model was constructed, although a clear road hierarchy didn’t exist, there was a ring road offering enough capacity and smooth flow conditions. This ring road was concluded with the construction of the Rainha Santa Bridge, and high expectations existed regarding the importance of this infrastructure to decrease congestion levels. The model was developed during the construction period of the bridge, with purely academic purposes. It aimed to predict main flow changes in the city after the bridge opening, and to identify possible problems – new congestion points or trough traffic in residential areas.

3.2 Study Area and Model Structure

The Coimbra model was based on the SATURN software package [10]. SATURN was developed by the University of Leeds, and can be considered a “mesoscopic” model, as it allows the coding of the network in two levels of detail: the assignment mode, where the travel time is calculated using of “speed-flow” curves and it is assumed that no delays occur on nodes; and the simulation mode, where the turn movements delays are calculated in great detail through the use of specific sub-models.

The study area (see Figure 2) has about 85 km², comprising the most part of the Coimbra municipality. An outer part with 69 km² with a sparse network was coded in the assignment mode, and the inner part, with 16 km², where congestion can occur and the distance between junctions is relatively small, was coded in the simulation mode. In the outer area the network was coded using bi-linear speed flows, in accordance to the guidelines of the UK Department of Transports [11]. In the city center network, delays occur mostly in the junctions. This has implied an extensive work of collecting and coding lane-use data and traffic light plans, and also the estimation of saturation flows and critical gaps.

3.3 Origin – Destination Matrix

The result of a complex and expensive process of constructing the Coimbra OD matrix based on inquiries and counts was used in this work as part of a global mobility study sponsored by the Coimbra municipality. The OD matrix is comprised of 182 zones, providing desegregated information by travel time, motivation of the journey, and by vehicle class. The model was developed with the aim of predicting circulation conditions in the morning peak (8:00 – 9:00). For this period, the resulting matrix has 24343 trips.

3.4 Calibration and Validation

The third part of the work was the calibration of the model – finding the optimal values of some parameters in order to minimize the differences between estimates and
observations of traffic flows and travel times. However, as was recognized that some important variables were measured with insufficient accuracy, only small corrections were made in this stage. This way, the only global change was made to the relationship \( \text{PPM}/\text{PPK} \) (pence per minute / pence per kilometer), that describes how drivers valuate lengthier routes to save time, with an optimal value of 1.0.

The model validation process comprised of traffic flows and travel times comparisons following the DMRB recommendations [1]:

**Traffic flows.** The validation was conducted over 75 links and 62 turns. It was obtained an average GEH\(_M\) of 7.4 for the best 85% best comparisons (target: GEH\(_M\) < 5).

**Travel times.** This test was done driving over five different routes, in the period 8:00 – 9:00 of typical week days, covering the most part of the urban area. The results indicate a poor quality of the model, with differences in some routes above 1 minute and 15% in the travel times.

The conclusion was that, nevertheless the effort applied in model building (approximately four man-months, excluding the OD matrix), the model doesn’t respect the validation guidelines defined for this type of models. However, taking in account the purely academic ends the model was designed for, the result was considered acceptable.

4 Application: assessment of the impact of quantification errors in the model results

The generic framework previously presented allows simulating and accessing the impacts of a wide variety of errors and, thus, responding to several questions that may be prompted to the model users. In this chapter are presented four analyses resulting of the application of the methodology to the COIMBRA-SAT model.

4.1 Single occurrence errors - global demand factor

This first analysis addresses the influence of errors in the global parameters of the models, such as the ones that control the driver behaviour. Specifically for this study, one was trying to find out how simple errors of under or overestimation of the OD matrix can jeopardize the applicability of a model. Within SATURN, that effect may be simulated by changing the GONZO parameter (e.g. GONZO =1.1 means that the reference O/D matrix will be majored by 10%). To do this, 10 variation of the base-model were run, corresponding to errors between -50% and +50%, in 10% increments (in real problems one shouldn’t expect errors above 10 or 15% - this range was selected only to facilitate the reading of the results) – see Figure 3.

4.2 Multiple occurrence errors – saturation flows of turn movements

The objective of this kind of analyses was to understand the effect of errors in variables with multiple occurrences, each one associated with a specific network element (e.g. individual gap acceptance values, link speeds or saturation flows). In this study, it was selected the “saturation flow” of turn movements since its quantification implies a huge coding effort (in the Coimbra’s network it was necessary to quantify this variable for 1487 turns).

A scenario was simulated where all saturation flows were estimated by sampling of field observations. To do this, for each turn movement a population of saturation flows was built, centered in its medium (coded) value (\( \bar{S} \)) and normally distributed according to a given variability in terms of coefficient of variation (\( CV = \sigma / \bar{S} \), where \( \sigma \) is the standard deviation). For each tested CV (15 total), a value was randomly draw from the corresponding distribution and the SATURN model was run. Since each drawn produced a different set of saturation flows, the process was repeated 20 times for each CV, resulting in a total of 300 runs (see Figure 4).
4.3 Multiple occurrence variables – combination of random and systematic errors

The objective of this analysis was to access the sensitivity of the model to errors that may arise when sub-models are used to estimate multiple occurrence variables. It was assumed that this can lead to systematic errors (SE) with a random component of severity constant all over the network.

The methodology used to simulate the random component of the errors is the same that was described in the previous analysis. This way, for a selected systematic error (SE - percent deviation) and coefficient of variation (CV), each of the saturation flows values was replaced by another randomly drawn from a normal distributed population whose average results of the reference coded value adjusted by the systematic error. This process was run at three levels: first, with the same CV, a number of times enough to make clear the importance of the random component (10 runs); then, for the same systematic error, with different magnitudes of the random component: CV = [0; 0.05; 0.10; 0.15]; finally, with different systematic errors: SE = [-0.30 to 0.30 in 0.02 steps] (see Figure 5).

From the graph the following conclusions can be drawn:

The sub estimation capacity errors tend to have a higher impact. This is related with the introduction of errors in non-congested turns: the increase in capacity doesn’t change the time required to make the maneuver. However, if the error goes in the way of movement saturation, then the travel time increases fast, especially if the queue reaches the upstream junction causing blocking-back.

4.4 Impact of quantification errors under different simulation environment

In the previous analyses it was evaluated the sensitivity of the COIMBRA-SAT model to errors in single and multiple occurrence variables, assuming the inexistence of other kind of errors. However, the conclusions were drawn for some particular conditions, and it is a pertinent question to know how the model behaves under different base conditions, like different demand levels, road structures or even different driver behaviors.

As an example of this kind of analyses, the impact of random errors in the saturation flows was accessed, under different driver attitudes regarding the route choice model, namely the relative valorization of the link travel time against link length (in SATURN this behavior is modeled trough the combination of parameters PPM/PPK presented before. The impact of the errors was accessed...
for 10 relations PPM/PPK, and in each of these 20 different combinations of saturation flows where drawn, with CV = 0.15, representing a total of 200 runs (see Figure 6).

Finally, it should be interesting to access the level of specificity of the results, by applying the methodology, in the present case used with the SATURN package, to other networks and even other kinds of models, namely to traffic microscopic models.

### References


