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On the evaluation of a public transportation network quality: Criteria validation methodology

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ABSTRACT

A public transportation network serves in adequate way a population if it evolves in time following the existent social reality. Changes made in order to improve service must be analyzed and evaluated. The introduction of modern technology to validate the fare card allowed a quick access to important, although incomplete, data. Databases with only the getting in validation information can be used to construct an origin–destination (OD) matrix, allowing a service quality analysis. Here it is presented a basic methodology to rigorously validate service quality criteria considering what might be interesting for the user. The quality analysis philosophy is the following. First, based on automatically gathered data, one reconstructs the origin–destination (OD) matrix, which contains information concerning the number of passengers traveling between zones of a certain region. The OD matrix is used to calculate some criteria characterizing the transportation network quality, such as traveling times, waiting times at a stop or transport occupation. The reconstructed OD matrix always contains errors, which cause errors in the criteria values. How significant are these errors? This question can be answered using our criteria validating methodology, which is based on statistical analysis. It has been implemented at the urban bus transport system of Porto, STCP, allowing the evaluation of the transportation network quality under a number of criteria and guaranteeing rigorous results.

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1. Introduction

A public transportation network is a complex service system with the social objective of adequately responding to the dislocation needs of the population of a certain region. In particular, in the case of a large urban area which has suffered in recent years great changes in terms of residential zones, many times quite distant from the working and leisure places, it is important that public transportation quickly responds to the changes, trying to provide a better service.

Studying public transportation network involves the possibility of measuring its quality in terms of several quantities such as traveling times, number of line changes in a trip, waiting times at stops, vehicle occupation, and so on. It is also important to have an instrument allowing the study of eventual service alterations such as route changes, lines' elimination and creation of new ones, augmenting/diminishing of the number of vehicles.

A rigorous methodology was developed to validate criteria allowing to analyze the performing quality of an urban public transportation network with an emphasis on the user viewpoint. It has been implemented at the urban bus transport system of Porto, STCP (Sociedade de Transportes Colectivos do Porto, Portugal).

The quality analysis philosophy is basically the following. First, one reconstructs the origin–destination (OD) matrix. This matrix contains information concerning the number of passengers traveling between zones of a certain region (Faria, Vieira, Sorratini, & Macedo, 2004; Macedo, Sorratini, Faria, & Carvalho, 2004). A similar OD matrix appears in studies on the cargo quantity moved inside a certain region (Ortúzar & Willumsen, 2004). Then the OD matrix is used to calculate some criteria characterizing the transportation network quality, such as traveling times, waiting times at a stop, and number of line changes in a trip, transport occupation. Finally, the most important moment of the evaluation is the criteria validation. The OD matrix reconstruction always contains errors, which cause errors in the evaluation criteria values. How significant are the errors? This question can be answered using our criteria validating methodology, which is based on statistical analysis and allows one to estimate the criteria robustness. With the help of this

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methodology anyone evaluating a transportation network can accept or reject criteria and guarantee some rigor in the evaluation.

It is difficult and expensive to obtain the OD matrix directly either by measure or by surveys. However, using indirect means, it is possible to get a good approximation of it. In particular, the problem of the OD matrix evaluation for traffic flows has been quite studied (Abrahamsson, 1998; Eisenman & List, 2004; Gunnar, Johansson, & Telkamp, 2004; Kwon & Varaiya, 2005; Dixon & Rilett, 2005). Also, a more recent study (Zhao, Rahbee, & Wilson, 2007) describes how automatic data collection systems can be used to estimate passenger OD matrix in the context of a rail network.

The matrix reconstruction method depends on the information retrieved and several approaches to obtaining it have been developed (Abrahamsson, 1998; Codina & Barceló, 2004; Codina, Garcia, & Marín, 2006; Doublas & Benitez, 2005; Gaudry, 2000; Ortúzar & Willumsen, 2004; Sherali, Narayanan, & Sivanandan, 2003; Spiess, 1990). In this work the OD matrix is reconstructed using data from ticket validation by passengers getting in at any stop of the STCP network. This information, of more than one hundred thousand ticket validations, pertaining to specific time periods (peak hours, other hours of the day, working days, week-ends, summer, winter), can easily be obtained in an automatic way. A rechargeable fare card, identified with a number, is used to validate a trip when a passenger enters a vehicle making it an entry-only system. The system allows to identify the sequence of lines taken by a passenger, but it does not give precise information about the final destination. Although the ticket number permits to trace patterns of behavior of a certain passenger, the gathered information does not return a full OD matrix, which must be approximated using reasonable hypothesis. For example, many of "regular" passengers validate their card twice a day, in the morning when they go to work, and in the evening when they return home. This gives a possibility to know also the destination in many cases and is used in the modeling of possible alighting.

In planning a transportation network it is natural to use the idea that the movement is done through shortest time paths. There are many papers on the subject (Bielli, Boulmakoul, & Mouncif, 2006; Dial, 2006, for example). Under this hypothesis several operational quality criteria can be evaluated.

In this work we consider some specific information retrieved from the STCP ticket databases to reconstruct the OD matrix and very simple evaluation criteria. However, the same analysis can be fulfilled for a more involved model.

It should be noted that the interaction between different transportation networks (bus and metro, for example) does not affect the proposed methodology of quality evaluation criteria validation.

The paper is organized in the following way: Section 2 contains an informal discussion of some problems in the quality evaluation of a transportation network using indirect information and in Section 3 a formal model for such a network is presented. In Section 4 a reconstruction algorithm for the OD matrix is introduced. The validation criteria are considered in Section 5. Section 6 is dedicated to the general criteria validation methodology. The computational results are presented in Section 7. The last section contains the conclusions.

2. Informal outline of the problem

The problem addressed here is the following. Given some information concerning the movement of the transportation network passengers, for example the number of passengers getting in/out at any stop, we have to reconstruct the OD matrix and to evaluate some criteria characterizing the network quality. Moreover it is necessary to study the robustness of the criteria with respect to the OD matrix estimation error in order to preview possible network quality evaluation errors. To illustrate the main aspects of the problem we present a model example. It should be noted that there are several types of information, but here we are considering only one of them.

Take an oriented line and suppose that at stops 1 and 2 two people were registered in and at stops 3 and 4 two people were registered out. We do not know at which stop the people getting out at stops 3 and 4, got in. Using this information, it is impossible to uniquely determine the OD matrix. All possible trips fitting the given getting in/out information correspond, respectively, to the following OD matrices:

$$\begin{bmatrix} 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} 0 & 0 & 0 & 2 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

where an element (i,j) gives the number of passengers traveling from stop i to stop j. One can then conclude that it is not possible to reconstruct the OD matrix without ambiguity, even in a very simple situation.

Let the travel time between two consecutive stops be equal to 1. Then the mean traveling time for the three possible trips is always equal to 2.

Clearly more detailed information is contained in the graph of the function describing the number of persons traveling during a given time. Although the mean times are equal, the graphs are totally different (see Fig. 1).

For example, if we get the first matrix as the result of the OD matrix reconstruction in the model problem, then the function describing the number of persons traveling during a given time is shown in Fig. 1(a). The 'real' OD matrix may be the second one and the 'real' function describing the number of persons traveling during a given time is that one shown in Fig. 1(b). The distance between the two graphs is significant. Thus the functions describing the number of persons traveling during a given time significantly depend on the OD matrix reconstruction quality, but the mean travel times are more robust.

The analysis of all possible situations allows us to determine the transportation network quality evaluation criteria reliability. In

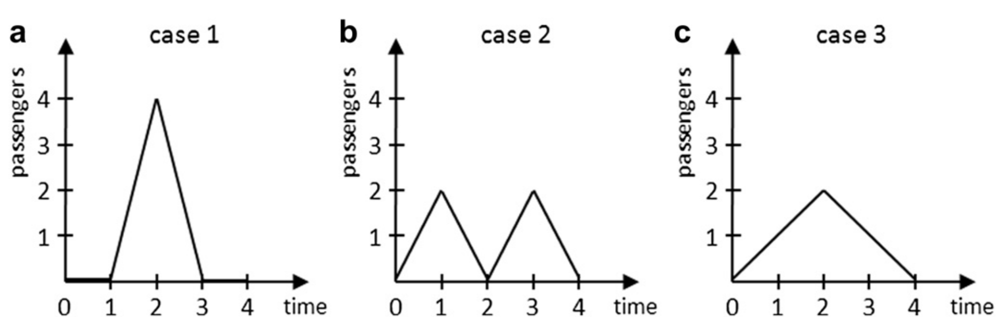

Fig. 1. Number of passengers as a function of the traveling time in the three cases.

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