Preface

Overview, Objectives, and Main Contributions

Overview

In the present context of restraint in the construction of new infrastructures due to territorial, environmental, and economical restrictions, and given the big bang of mobility in the last decades in all sectors, the transportation system management acquires a fundamental role as an optimizer of the available resources. This requires the application of new policies addressed to achieve two main objectives: sustainability and competitiveness.

Mobility management is the big issue. The information technologies and communications are the tools. It is therefore needed a management system that links these objectives with these available tools. This management system should be based on quantitative traffic information in real time. Travel time and its reliability stand out as key factors in traffic management systems, as they are the best indicators of the level of service in a road link and perhaps the most important variable for measuring congestion. In addition, travel time is the best and most appreciated traffic information for road users as it plays a fundamental role in the traveler planning process (travel or not travel, best time to travel, route and mode choice…). At the same time, highway travel time measurement and quantitative forecasting in congested conditions pose a striking methodological challenge.

The most elementary method to measure a highway travel time is by identifying the vehicle at the entrance and exit of the target section and computing the elapsed time between identifications (i.e., direct measurement). However, the necessary automatic vehicle identification (AVI) is not a trivial task. As it will be described in this book, it needs somehow advanced technology. All of these technologies require the extensive installation of new hardware in the vast highway network, which cannot be achieved overnight, and possibly, it is not profitable in the whole network.

To date, these systems have only seen limited demonstration, and the extensive deployment is not expected beyond the hot spots of the network.

Loop detectors still represent the main source of traffic data in all highways worldwide. And it is expected to remain like this in the medium term (May et al. 2004). Note that loop detectors are not adequate for link measurements (e.g., travel times) but are capable of a comprehensive measurement of the punctual data (e.g., traffic counts: the original objective), which is not less valuable and for which the AVI technologies are not so well suited. Given the predominance and preexistence of this surveillance context, lots of traffic agencies worldwide have decided to develop travel time information systems based on a simple and intuitive methodology: They estimate indirectly link travel times from the spatial generalization of the loop punctual measurement of average speed.

As it will be detailed in the next chapters, in both the direct measurement and the indirect estimation of highway travel times difficulties arise. In addition, different measurement processes lead to conceptually different results (see Chap. 2 devoted to travel time definitions), an issue which is frequently overlooked. Note that a directly measured travel time is a trajectory-based measurement in space-time where the vehicle needs to have finished his trip in order to obtain the measurement. In contrast, indirect estimations usually are instantaneously obtained and do not respond to the trajectory of any particular vehicle. If that was not enough, the main objective of a real-time highway travel time information system should be to provide the driver with the information of the travel time his trip will undertake once entering the highway. This means that a real-time information system needs in reality future information, where the horizon of the forecast is equal to the trip travel time.

This situation, with multiple surveillance equipments, inhomogeneous data with different variables being measured, different travel time estimation algorithms with different accuracies, different spatial coverage, and different temporal implications, is the ideal environment for data fusion schemes, where the objective is to use jointly the information provided by different sources in order to infer a more accurate and more robust estimation of the target variable (i.e., the travel time).

Objectives

The main objective of the present monograph is to present a methodology capable of providing the driver entering a highway with accurate information of his expected travel time. Note that this information involves two components: the measurement of the current travel times and the estimation of the evolution of the traffic conditions during the time taken for the trip. An additional requirement is that the travel time estimation must be obtained by making the best usage possible of the available and multiple highway data sources, neither increasing the highway density of surveillance nor changing the typology of the measurement equipment.

Therefore, the objective is to add value to the traffic data which are currently being measured.

Two main research directions appear when facing the issue of real-time monitoring of the traffic evolution. The first and most intuitive way of quantitatively knowing what is happening in a highway stretch is by measuring. In practice, this is not an easy task. The measurement equipments are limited. They may not be able to measure the most important variables. The amount of measurements may not be representative of the average traffic stream. Their spatial coverage may be limited. The necessary temporal aggregations to reduce the amount of data being transmitted may bias the measurement and add some delay to the information. The existence of outliers adds additional complexity. And finally, a non-negligible amount of measurement units may usually be out of order. The alternative consists in modeling. Highway traffic consists in the interaction of a huge number of drivers: human beings with different ages, different races, different religious creeds, different gender, different political preferences, different way of life options and different psychological stabilities (Vanderbilt 2008). Nevertheless (and perhaps surprisingly), on the average, they all behave similarly when they face similar conditions. This means that, given the characteristics of the drivers' population, the characteristics of the highway environment they are facing, and the mobility demand (i.e., the number and characteristics of the trips), it should be possible to know how these vehicles are going to interact and therefore to obtain all the resulting variables of their trips (e.g. their travel times). The forecasting capabilities of this approach are appealing. Again, this is not an easy task. It is difficult to know (which means measure) the characteristics of the drivers' population. And it is difficult to accurately model the behavioral laws that steer the relation between the infrastructure and drivers and also between drivers among themselves. In fact, some of these behavioral laws are still unknown (Daganzo 2002). It is even difficult to know the mobility demand. In conclusion, there are a lot of unknowns.

The dilemma is then to select one option. Lately, modeling has experienced an enormous popularity increase. It seems that modeling is now easier than has ever been before. And the results are better (at least faster—in real time—and more visual). This is due to the quick development of computers and the enhancement of its visual capabilities, which has given rise to traffic simulators (in particular microsimulators, where the performance of each vehicle can be seen in 3D). Although these enhancements brought up by the digital era, the baseline difficulties remain the same. One must realize that most of these difficulties are solved by case-specific overcalibrations, which blur the forecasting capabilities of the model. Fortunately, researchers all over the world are working hard in overcoming these problems, and in the future, this may come to a happy end. In contrast, traffic monitoring seemed to have fallen out of favor some years ago. This was mainly due to the huge costs of enhancing the traffic surveillance systems given the enormous inertia of the vast highway network. The surveillance equipment rapidly became outdated, with high maintenance cost and a high rate of malfunctioning. This entire situation discouraged practitioners and researchers from devoting their interests in traffic monitoring. This is now changing with the appearance of high-tech low-cost traffic detectors. Technological reliability will surely be enhanced, and acquisition and maintenance costs will be cut down. However, the conceptual difficulties in the measurements will also remain the same. In addition, all the surveillance system will not be replaced overnight, and different equipment will need to coexist.

Both research directions, measuring and modeling, are appealing. Both have a huge potential. In spite of the modeling "attacks" and the temporary monitoring decline, measuring will not be substituted by modeling. Traffic monitoring will be always necessary. Maybe the axiom should be "measure all you can; model the rest." This is what this book is devoted to: providing methodologies to accurately measure highway travel times. In general, methodologies are not technologically captive, as it is more related to the concept of the measurement than to the technological equipment used.

In particular, the example of application of the proposed methodologies in the book is presented in the specific case of a closed toll highway, where the direct travel time measurement is given by the information contained in the toll tickets (real of virtual by means of electronic toll collection systems), which record the exact time and location where each vehicle enters and leaves the highway. The indirect estimation is obtained from the flow, speed, and occupancy measurements of inductive loop detectors. Although this specific environment of application, the proposed methodologies will be easily generalized to other context where both a direct measurement and an indirect estimation are available.

When facing the travel estimation problem in this closed toll highway environment, with these commonly available sources of data, three main questions arise:

- How travel time can be measured from toll ticket data?
- How travel time can be measured from loop detector data?
- Given these two travel time estimations from different data sources with their intrinsic characteristics, can we combine them to obtain better information?

These questions are going to be answered in the present book.

Structure and Main Contributions

After this overview of the monograph, which gives an introduction to its contents and provides linking arguments between its different parts, the rest of the book is structured as a compendium of seven self-contained chapters. Each one deals with some part of the global research question. This may facilitate the partial reading and diffusion of its contents.

Chapter 1, entitled *Highway Travel Time Information Systems: A Review*, has the objective of providing a global view of the issues treated in the book and of the results obtained. Some baseline concepts are also introduced. Specifically, the issues addressed include the analysis of the importance of travel time information in mobility management, the qualitative description of direct and indirect methods for travel time estimation, the definition of data fusion concepts and their relationship with travel time forecasting, the effects of travel time information dissemination strategies on drivers, and a discussion on some issues regarding the value of travel time information as a traveler-oriented reliability measure. Finally, some overall conclusions and issues for further research are outlined.

Chapter 2 is an instrumental part of the book, where travel time definitions are analytically presented. Also, a trajectory reconstruction algorithm necessary in order to navigate between different travel time definitions is proposed. The concepts presented in this chapter are aimed to create a conceptual framework useful in comparing travel times obtained from different methodologies. This should be considered as baseline knowledge when going through the whole book.

Chapter 3 is devoted to indirect travel time estimation from loop detector data. Specifically, it addresses the main drawback in obtaining travel times from punctually measured average speed: the spatial generalization of the measurements. Several methods are proposed in the literature ranging from the simplest constant interpolation to mathematically complex truncated quadratic ones. The research tendency seems lately to follow the direction of continuously increasing the mathematical complexity of the methods overlooking traffic dynamics. This issue is addressed in this Chap. 3, entitled *Accuracy of Travel Time Estimation Methods Based on Punctual Speed Interpolations*. This chapter claims that all speed interpolation methods that do not consider traffic dynamics and queue evolution do not contribute to more accurate travel time estimations. Lacking a better approach, the simplest midpoint interpolation is recommended.

While Chap. 3 highlights the main problems of travel time estimation methods based on punctual speed measurements and proves that the inaccuracies resulting from limited measurement spots are unavoidable without the consideration of traffic dynamics, Chap. 4 claims that this improved accuracy may not be necessary for real-time information systems and in some cases may even be detrimental. This contradicts the common perception that freeway travel time information systems, whose objective is to provide real-time information, must be supported by very accurate travel time measurements. This perception leads traffic agencies to be more prone to using fancy new technologies for directly measuring travel times than to make the most of already installed loop detectors. Chapter 4, entitled *Design of Spot Speed Methods for Real-Time Provision of Traffic Information*, shows how this can be a myopic approach, as more accurate travel time measurement may lead to worse performance of a real-time information system. In addition to this claim, this chapter provides useful guidelines for practitioners for setting the main parameters of the system, and also some practice ready enhancements to commonly used spot speed travel time estimation methods. In the authors' opinion, this is a significant contribution and especially relevant and interesting for the practitioner community. It can also provide a global framework that may help researchers to not forget the final objective.

Chapter 5 deals with direct travel time measurement. Entitled *Highway Travel Time Measurement from Toll Ticket Data*, it provides a method capable of obtaining main trunk average travel times (e.g., in between junctions) from specific origin–destination individual vehicle travel times, which include the "entrance time" and the "exit time" (i.e., the time required to travel along the on-/off-ramp and to pay the fee at the toll plaza. This method allows reducing the intrinsic delay in the information of directly measured travel times, which is essential for a real-time application of the information system.

Having obtained travel time estimations from the different available data sources (i.e., direct and indirect), Chap. 6 entitled *Short-Term Prediction of Highway Travel Time Using Multiple Data Sources* proposes a data fusion scheme, partially based on the probabilistic Bayes' theory, whose objective is to use the potentials of each source of data to overcome the limitations of the others in order to obtain a more accurate and robust travel time estimation. In addition, the proposed method uses the different temporal alignments of travel time estimations to infer a tendency and improve the forecasting capabilities of real-time measurements. The source estimation methods used in this last chapter are the ones presented in the previous chapters.

Chapter 7, entitled *Value of Highway Information Systems*, is the last chapter of the monograph. Its main objective is to assess the real benefits of information systems, widely implemented worldwide. Contributions of the chapter can be grouped into two aspects. First is the results, quantifying the value of travel time information in different scenarios. These include one or two available routes, peak or off-peak traffic, different types of trips, and massive or limited dissemination of strategies. The richness of this set of scenarios overcomes the limitations of other research efforts of the same nature. Second is the methodology, proposing a departure time selection model based on a simplification of the expected utility theory, with some restrictions to account for already planned decisions and habits, and a cost model accounting for the unreliability of the trip. This is based on Small's classic model with some modifications to include stress and the possibility of rescheduling activities as a result of information. The empirical data presented for the application of the method (measured in a Spanish highway) may also be a valuable contribution. All these arguments make this chapter interesting for both researchers and practitioners.

Summarizing, the objective of the book is to provide solutions to a global engineering problem. Each one of the chapters provides answer to a partial question, which follows from the original research problem. The unity of the topic treated is therefore granted.

In addition, in any engineering monograph, the practical application of the proposed methodology to a pilot test site is desired. In this particular case, data from a privileged site were available. The AP-7 highway runs along the whole Spanish Mediterranean coast, from Algeciras to the French border at La Jonquera. On the northeastern stretch of the highway, from La Roca, near Barcelona, to La Jonquera, a closed tolling scheme is in use. Toll ticket data were available to the author. Moreover, in some sections of the highway near Barcelona (in particular from La Roca to Maçanet—see Fig. 1), additional monitoring by means of loop detector data was installed every 5 km approximately. Only a requirement is missing for this stretch being a perfect test site: a congestion episode. Unfortunately, for the highway users (but fortunately for the development of the present book), every Sunday

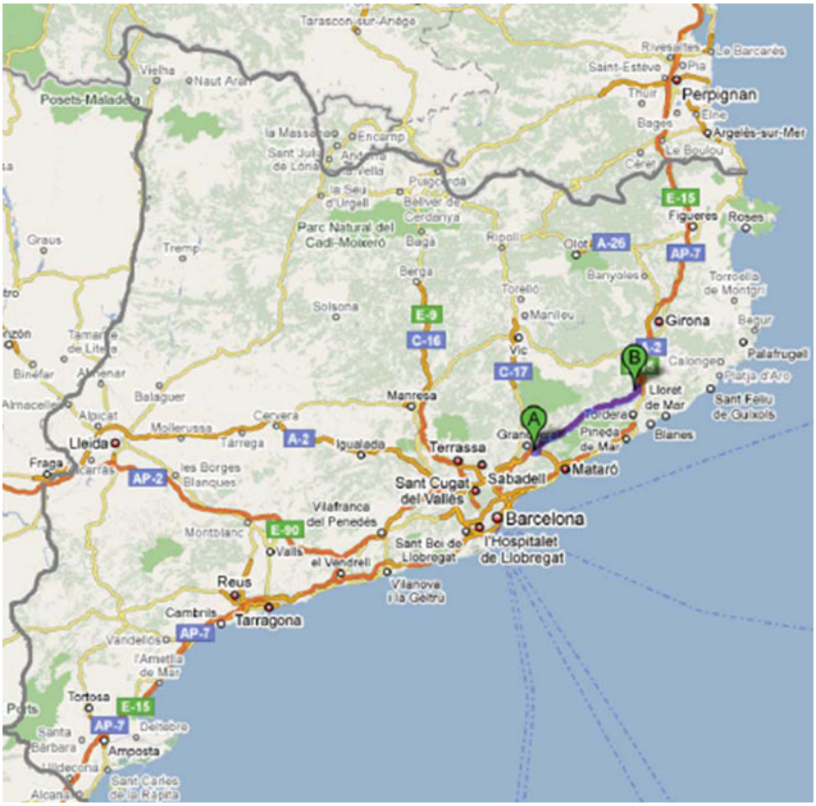

Fig. 1 Test site location. *Source* Google Maps

(among other days) of the summer season (particularly long in the Mediterranean climate), congestion grows in the southbound direction of the highway, due to the high traffic demand toward Barcelona of drivers which have spend a day or the weekend on the coast. Hopefully, the contents in this book may help to alleviate this congestion, or at least it will provide information to diminish the drivers' suffering. This was the privileged test site used in all the research presented here.

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