# PREFACE

For years, I have been thinking about writing an introductory book on traffic flow theory. The main purpose is to help readers who are new to this subject and who do not have much knowledge of mathematics and traffic flow. To serve this purpose, I have tried to make the contents self-contained and assume minimal knowledge of mathematics and traffic flow.

This book is derived from my lecture notes for CEE520 Traffic Flow Theory and Simulation I (formerly offered as CEE590T Traffic Flow Theory on an experimental basis before it was assigned a permanent course number) at the University of Massachusetts Amherst. Hence, the chapters are more like lectures, with focused topics, each of which fits in a class meeting. The book takes a unified perspective on traffic flow modeling and consists of five parts which are coherently connected. Each part is briefly described as follows.

Part I focuses on traffic flow characteristics. It starts with intelligent transportation systems and traffic sensing technologies to illustrate how to quantify traffic flow and collect such data. This is followed by three chapters with in-depth discussion of traffic flow characteristics, on the basis of which their relationships are developed and a few equilibrium traffic flow models are introduced.

Part II is about traffic flow modeling at the *macroscopic* level. The goal is to solve for temporal-spatial evolution of traffic flow characteristics given initial and boundary conditions. The first few chapters provide a jump start on mathematical modeling, especially partial differential equations. With such knowledge, the domain knowledge of traffic flow is integrated into mathematical modeling, resulting in a first-order quasi-linear partial differential equation problem known as the Lighthill, Whitham, and Richards (LWR) model in the traffic flow community. Solutions to the problem are introduced, including a graphical technique that uses the method of characteristics and numerical techniques that involves a few discretization schemes.

Part III is devoted to traffic flow modeling at the *microscopic* level. The emphasis is on drivers' car-following behavior involving operational control in the longitudinal direction. A series of car-following models with differing modeling philosophies and complexity are introduced. To provide an opportunity to cross-compare the relative performance of these models, a common ground is set up so that these models can demonstrate themselves. Such a process is called benchmarking, and the common ground consists of two scenarios, one microscopic and the other macroscopic. The microscopic scenario is a hypothetical driving process aimed at testing these models under various driving regimes (such as free flow and car following); the macroscopic scenario is a set of empirical data focusing on examining the macroscopic properties of these models (e.g., how their implied fundamental diagrams compare with the observed diagrams).

Part IV extends traffic flow modeling to the *picoscopic* level. A modeling framework called a driver-vehicle-environment closed-loop system is introduced to capture the ultrafine level of detail of traffic flow. Such a framework involves a driver model, a vehicle model, and the driving environment. The driver model collects and processes information from its vehicle and the driving environment and makes control decisions on motion in longitudinal and lateral directions. The vehicle model executes its driver's control decision and moves dynamically on the road. The driver-vehicle unit constitutes one of the entities in the environment whose dynamic change affects driver control in the next step. As an example of this modeling framework, a simple engine model and further a dynamic interactive vehicle model are proposed, and a field theory is formulated to model the driver.

All things come together in Part V. With the field theory as the basis, a unified perspective can be cast on traffic flow theory. The macroscopic models and microscopic models introduced thus far can be related to each other, all linked directly or indirectly to the field theory. Hence, a unified diagram is constructed to highlight such relations. In addition, benchmarking is done to cross-compare the performance of some of the macroscopic models and microscopic models in the diagram. Further, a multiscale modeling approach is presented which involves traffic flow modeling at four levels of detail—namely, macroscopic, mesoscopic, microscopic, and picoscopic. The emphasis of multiscale modeling is to ensure modeling consistency—that is, how less detailed models are derived from more detailed models and, conversely, how more detailed models are aggregated to less detailed models. The proposed approach may establish the theoretical foundation for traffic modeling and simulation at multiple scales seamlessly within a single system.

This book is ideal for use by entry-level graduate students in transportation engineering as a textbook for a traffic flow theory course. In addition, civil engineering juniors and seniors may find some in-depth information about traffic flow fundamentals in this book. Further, applied mathematics majors may find concrete examples of mathematical modeling with specific domain knowledge. Advanced readers are referred to other traffic flow theory books for in-depth coverage; a few of them are as follows:

- G.F. Newell, Theory of Highway Traffic Flow, 1945-1965, Course Notes UCB-ITS-CN-95-1, 1996.
- A.D. May, Traffic Flow Fundamentals, Prentice-Hall, New York, 1989.
- C.F. Daganzo, Fundamentals of Transportation and Traffic Operations, Pergamon-Elsevier, Oxford, UK, 1997.
- N. Gartner, C.J. Messer, A.K. Rathi, Revised Monograph on Traffic Flow Theory: A State-of-the-Art Report, TRB, 2001.
- D.L. Gerlough, M.J. Huber, Traffic Flow Theory—A Monograph, TRB Special Report 165, 1975.
- D.L. Gerlough, D.G. Capelle, An Introduction to Traffic Flow Theory, HRB Special Report 79, 1964.
- D.R. Drew, Traffic Flow Theory and Control, McGraw-Hill, New York, 1968.
- W. Leutzbach, Introduction to the Theory of Traffic Flow, Springer-Verlag, New York, 1988.
- M. Treiber, A. Kesting, Traffic Flow Dynamics, Springer, New York, 2013.
- L. Elefteriadou, An Introduction to Traffic Flow Theory, Springer, New York, 2014.
- B.S. Kerner, Introduction to Modern Traffic Flow Theory and Control, Springer, New York, 2009.

I thank Professor John D. Leonard at Georgia Institute of Technology and Professor Billy M. Williams at North Carolina State University, who introduced me to this field and sparked my interest in traffic flow theory. Thanks also go to former students in my traffic flow theory classes—their insightful discussion and kind encouragement made this work possible.

Finally, I acknowledge my limitations. Though I have tried hard to ensure the quality and accuracy of information, I can make mistakes. Therefore, readers should use this book with discretion.

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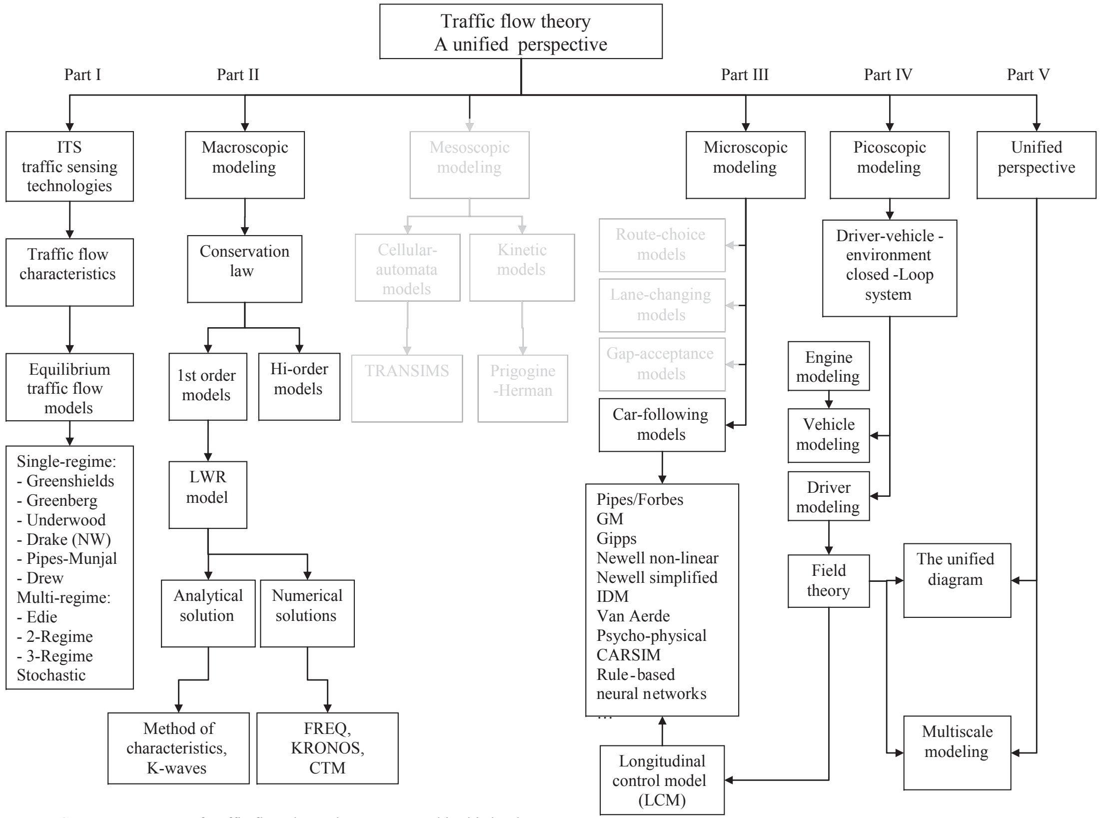


Note: Gray areas are part of traffic flow theory but not covered in this book.