Springer Complexity

Springer Complexity is a publication program, cutting across all traditional disciplines of sciences as well as engineering, economics, medicine, psychology and computer sciences, which is aimed at researchers, students and practitioners working in the field of complex systems. Complex Systems are systems that comprise many interacting parts with the ability to generate a new quality of macroscopic collective behavior through self-organization, e.g., the spontaneous formation of temporal, spatial or functional structures. This recognition, that the collective behavior of the whole system cannot be simply inferred from the understanding of the behavior of the individual components, has led to various new concepts and sophisticated tools of complexity. The main concepts and tools – with sometimes overlapping contents and methodologies – are the theories of self-organization, complex systems, synergetics, dynamical systems, turbulence, catastrophes, instabilities, nonlinearity, stochastic processes, chaos, neural networks, cellular automata, adaptive systems, and genetic algorithms.

The topics treated within Springer Complexity are as diverse as lasers or fluids in physics, machine cutting phenomena of workpieces or electric circuits with feedback in engineering, growth of crystals or pattern formation in chemistry, morphogenesis in biology, brain function in neurology, behavior of stock exchange rates in economics, or the formation of public opinion in sociology. All these seemingly quite different kinds of structure formation have a number of important features and underlying structures in common. These deep structural similarities can be exploited to transfer analytical methods and understanding from one field to another. The Springer Complexity program therefore seeks to foster cross-fertilization between the disciplines and a dialogue between theoreticians and experimentalists for a deeper understanding of the general structure and behavior of complex systems.

The program consists of individual books, books series such as "Springer Series in Synergetics", "Institute of Nonlinear Science", "Physics of Neural Networks", and "Understanding Complex Systems", as well as various journals.

Understanding Complex Systems

Series Editor

J.A. Scott Kelso
Florida Atlantic University
Center for Complex Systems
Glades Road 777
Boca Raton, FL 33431-0991, USA

Understanding Complex Systems

Future scientific and technological developments in many fields will necessarily depend upon coming to grips with complex systems. Such systems are complex in both their composition (typically many different kinds of components interacting with each other and their environments on multiple levels) and in the rich diversity of behavior of which they are capable. The Springer Series in Understanding Complex Systems series (UCS) promotes new strategies and paradigms for understanding and realizing applications of complex systems research in a wide variety of fields and endeavors. UCS is explicitly transdisciplinary. It has three main goals: First, to elaborate the concepts, methods and tools of self-organizing dynamical systems at all levels of description and in all scientific fields, especially newly emerging areas within the Life, Social, Behavioral, Economic, Neuro- and Cognitive Sciences (and derivatives thereof); second, to encourage novel applications of these ideas in various fields of Engineering and Computation such as robotics, nanotechnology and informatics, third, to provide a single forum within which commonalities and differences in the workings of complex systems may be discerned, hence leading to deeper insight and understanding. UCS will publish monographs and selected edited contributions from specialized conferences and workshops aimed at communicating new findings to a large multidisciplinary audience.

B. S. Kerner

The Physics of Traffic

Empirical Freeway Pattern Features, Engineering Applications, and Theory

Springer

Boris S. Kerner
DaimlerChrysler AG
70546 Stuttgart
Germany

ISBN 978-3-642-05850-9 ISBN 978-3-540-40986-1 (eBook)
DOI 10.1007/978-3-540-40986-1

springeronline.com

Originally published by Springer-Verlag Berlin Heidelberg New York in 2004.

Softcover reprint of the hardcover 1st edition 2004

Print data prepared by TechBooks
Cover design: Erich Kirchner, Heidelberg
Printed on acid-free paper 54/3141/XO - 5 4 3 2 1 0

Preface

This monograph is devoted to a new approach to an old field of scientific investigation, freeway traffic research. Freeway traffic is an extremely complex *spatiotemporal* nonlinear dynamic process. For this reason, it is not surprising that *empirical* traffic pattern features have only recently been sufficiently understood. Such empirical features are in serious conflict with almost all earlier theoretical and model results. Consequently, the author introduced a new traffic flow theory called "three-phase traffic theory," which can explain these empirical spatiotemporal traffic patterns. The main focus of this book is a consideration of *empirical spatiotemporal* traffic pattern features, their engineering applications, and explanations based on the three-phase traffic theory.

The book consists of four parts. In Part I, empirical studies of traffic flow patterns, earlier traffic flow theories, and mathematical models are briefly reviewed. Three-phase traffic theory is considered as well. This theory is a qualitative theory. Main ideas and results of the three-phase traffic flow theory will be introduced and explained without complex mathematical models. This should be suitable for a very broad audience of practical engineers, physicists, and other readers who may not necessarily be specialists in traffic flow problems, and who may not necessarily have worked in the field of spatiotemporal pattern formation.

In Part II, empirical spatiotemporal traffic pattern features are considered. A microscopic three-phase traffic theory of these patterns and results of an application of the pattern features to engineering applications are presented in Part III and Part IV, respectively.

I am very grateful to Herman Haken for the opportunity to write this book. I am also very grateful to my colleagues at DaimlerChrysler AG, Peter Häußermann, Harald Brunini, Ralf Guido Herrtwich, and Matthias Schulze for their support. I thank my colleagues and friends Hani Mahmassani, Dietrich Wolf, and Michael Schreckenberg for their support in the first publications of my three-phase traffic theory. I would also like to thank the coauthors of our joint publications, Peter Konhäuser, Martin Schilke, Hubert Rehborn, Sergey Klenov, Dietrich Wolf, Matthias Herrmann, Malte Rödiger, Heribert Kirschfink, Mario Aleksić, and Andreas Haug for their very fruitful cooperation. In particular, I thank Sergey Klenov, Hubert Rehborn, Mario Aleksić, Ines Maiwald-Hiller, Andreas Haug, and James Banks for their suggestions and help in the preparation of this book. I would like to thank the Hessen (Germany) Ministry of Roads and Traffic for help in the preparation of the empirical data. I acknowledge funding by the German Ministry of Education (BMBF) within projects SANDY and DAISY. I would like to thank Pravin Varaiya and his colleagues for access to traffic data of the PeMS (Freeway Performance Measurement System) database in the USA. I also thank my wife, Tatiana Kerner, for her help and understanding.

Stuttgart, *Boris Kerner*
August 2004

Contents

Acronyms and Conventions

SP	synchronized flow pattern
MSP	moving SP
WSP	widening SP
LSP	localized SP
ASP	alternating SP
GP	general pattern
DGP	dissolving GP
AGP	alternating GP
EP	expanded congested pattern
FCD	floating car data
TCC	traffic control center
UTA	model for traffic prediction in city networks
ASDA	model for automatic tracking of moving jams
FOTO	model for automatic identification of traffic phases and tracking of synchronized flow
CA model	cellular automata traffic flow model
ALINEA	model for automatic feedback on-ramp metering
ANCONA	model for automatic on-ramp control of congested patterns at freeway bottleneck
ACC	automatic cruise control
x	spatial coordinate in direction of traffic flow
t	time
q	flow rate
ρ	vehicle density
v	vehicle speed
d	vehicle length
v_{g}	velocity of downstream front of wide moving jam
$q_{\mathrm{out}}^{(\mathrm{J})}$	flow rate in traffic flow formed by wide moving jam outflow
q_{out}	flow rate in free flow formed by wide moving jam outflow
ρ_{min}	density in free flow formed by wide moving jam outflow

$v_{\max}$	average speed in free flow formed by wide moving jam outflow
$\rho_{\max}$	density within wide moving jam (jam density)
$v_{\min}$	average speed within wide moving jam
L_{J}	width (in longitudinal direction) of wide moving jam
F→S transition	phase transition from free flow to synchronized flow
F→J transition	phase transition from free flow to wide moving jam
S→J transition	phase transition from synchronized flow to wide moving jam
S→F transition	phase transition from synchronized flow to free flow
J→S transition	phase transition from wide moving jam to synchronized flow
J→F transition	phase transition from wide moving jam to free flow
F→S→J transitions	F→S transition followed by S→J transition
P_{FS}	probability for F→S transition on hypothetical homogeneous road for given observation time T_{ob} and given road length
$P_{\mathrm{FS}}^{(\mathrm{B})}$	probability for F→S transition at freeway bottleneck for given observation time T_{ob}
$q_{\mathrm{C}}^{(\mathrm{B})}$	freeway capacity in free flow at freeway bottleneck
$q_{\max}^{(\mathrm{free\ B})}$	maximum freeway capacity in free flow at freeway bottleneck relative to $P_{\mathrm{FS}}^{(\mathrm{B})} = 1$
$q_{\mathrm{th}}^{(\mathrm{B})}$	minimum freeway capacity in free flow at freeway bottleneck
$q_{\mathrm{FS}}^{(\mathrm{B})}$	pre-discharge flow rate
$q_{\mathrm{out}}^{(\mathrm{bottle})}$	discharge flow rate from congested pattern at freeway bottleneck
$q^{(\mathrm{pinch})}$	average flow rate in pinch region of GP or EP
$q_{\lim}^{(\mathrm{pinch})}$	limiting (minimum) flow rate in pinch region of GP or EP
L_{syn}	width of synchronized flow region (in longitudinal direction) in congested pattern
q_{on}	flow rate to on-ramp
q_{in}	flow rate in free flow on main road upstream of on-ramp bottleneck
q_{sum}	flow rate downstream under free flow condition at on-ramp bottleneck
η	pecentage of vehicles which want to leave main road via off-ramp
$\rho_{\max}^{(\mathrm{free,\ emp})}$	maximum density relative to empirical limit point for free flow
$q_{\max}^{(\mathrm{free,\ emp})}$	maximum flow rate relative to empirical limit point for free flow

$\rho_{\max}^{(\mathrm{free})}$	maximum density relative to hypothetical limit point for free flow on homogeneous road
$q_{\max}^{(\mathrm{free})}$	maximum flow rate relative to hypothetical limit point for free flow on homogeneous road
T_{av}	averaging time interval for traffic variables
T_{ob}	time interval for observing traffic flow
$T_{\mathrm{J}}^{(\mathrm{wide})}$	mean time between downstream fronts of wide moving jams
τ_{J}	mean duration of wide moving jams
T_{J}	mean time between narrow moving jams