

Robert Gordon

# Intelligent Transportation Systems

Functional Design for Effective Traffic  
Management

*Second Edition*



Springer

# Intelligent Transportation Systems



Robert Gordon

# Intelligent Transportation Systems

Functional Design for Effective  
Traffic Management

Second Edition



Springer

Robert Gordon  
Plainview, NY, USA

Additional material to this book can be downloaded from <http://www.springer.com/us/book/9783319147673>

ISBN 978-3-319-14767-3                      ISBN 978-3-319-14768-0 (eBook)  
DOI 10.1007/978-3-319-14768-0

Library of Congress Control Number: 2015936046

Springer Cham Heidelberg New York Dordrecht London  
© Springer International Publishing Switzerland 2010, 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media  
([www.springer.com](http://www.springer.com))

# Preface

Functional design, as described in this book, is the selection of ITS management strategies and the field equipment deployments required to implement them. In most cases, functional design stops short of the selection of detailed technologies. Starting with the development of detailed objectives, functional design relates management strategies to project objectives, identifies alternative strategies for further consideration, and evaluates these strategies. It then determines whether one or more strategies can cost effectively satisfy the objectives and recommends the most appropriate alternative.

Although considerable effort has been expended by the Federal Highway Administration and others to develop high-level systems engineering processes, in practice, ITS designers have often used a “bottom up” approach. Designers often select devices and device locations without a strong connection to project objectives or to methodologies that assess the feasibility of the project and the proposed design. This book provides guidance for adapting these systems engineering processes to freeway ITS project functional requirements. It provides the basis for selecting the types of ITS components and the management strategies employed. A number of handbooks and other resources are available to provide guidance for the detailed selection of field equipment and operations to manage the equipment. This book assumes that the reader is familiar with the functions of ITS devices such as dynamic message signs, highway advisory radio, traffic detectors, and CCTV applications.

This edition is essentially an updated version of *Intelligent Freeway Transportation Systems: Functional Design*. The text discusses the increased emphasis on coordination among transportation management centers and the more intensive management techniques provided by emerging active traffic management strategies. ITS evaluation techniques are described in more detail, and examples of the communication of the results of these evaluations to decision makers and to the public are described. Several types of transportation corridors are described, and examples of corridor management strategies are included. Some material was updated and obsolete material was removed.

The book emphasizes the use of fundamental transportation planning and traffic engineering principles to develop functional designs. It is assumed that the reader is

somewhat familiar with this area. The book largely reflects the author's experience in adapting these principles to ITS design. For example, the book provides models to suggest appropriate locations for such ITS devices as CCTV cameras and dynamic message signs and describes methodologies for estimating the benefits of proposed functional designs. The models enable the designer to estimate the performance differences among alternatives and estimate benefits for functional design purposes. Approximations are introduced to expedite the use of these models by practitioners. While the author has found these models to be useful, readers are encouraged to modify and enhance them to better suit their needs. The web site <http://www.springer.com/us/book/9783319147673> provides worksheets that facilitate the use of some of the models. The worksheets are provided in an unprotected format to enable users to modify them as required.

I give particular thanks to my wife, Norma, who provided support and encouragement to complete the effort.

Plainview, NY, USA

Robert Gordon

# Contents

<b>1</b>	<b>Introduction</b> .....	1
1.1	Purpose of Book.....	1
1.2	Development of ITS Design Practices .....	2
1.3	Summary of Contents and Organization .....	3
	References.....	6
<b>2</b>	<b>Cost Effective Design Processes</b> .....	7
2.1	Systems Engineering.....	7
2.1.1	Systems Engineering Requirements for Federal Aid Projects.....	7
2.1.2	Systems Engineering as a Life-Cycle Process .....	8
2.1.3	ITS Project Development.....	12
2.2	Goals, Objectives and Requirements .....	12
2.3	Evaluation Methodologies .....	18
	References.....	18
<b>3</b>	<b>Functional ITS Design Issues</b> .....	19
3.1	Relationship of ITS Design to General Transportation Planning Principles.....	19
3.1.1	General Traffic Flow Relationships .....	19
3.1.2	Shock Waves .....	21
3.1.3	Classification of Congestion .....	21
3.1.4	Diversion for Non-Recurrent Congestion .....	22
3.1.5	Recurrent Congestion.....	26
3.2	Performance and Benefit Assessment .....	27
3.2.1	Performance Measures to Facilitate System Design.....	28
3.2.2	Performance Measures and ITS Planning.....	31
3.3	Alternatives for Functional Design .....	33
3.3.1	Design Constraints .....	34
3.3.2	Relationship of ITS Management Concepts to Objectives.....	35
	References.....	39



- 4 Non-Recurrent Congestion: Improvement of Time to Clear Incidents**..... 41
  - 4.1 Definition of an Incident for ITS Design Purposes..... 41
    - 4.1.1 Effect of Incidents on Capacity..... 42
    - 4.1.2 Secondary Accidents..... 42
    - 4.1.3 Work Zone Accidents..... 43
  - 4.2 Models of the Effects of Freeway Incidents..... 43
    - 4.2.1 Frequency and Severity of Incidents..... 46
    - 4.2.2 Data Collection for Development of Incident Model..... 47
  - 4.3 Relationship of Reduction in Delay to Reduction in Incident Clearance Time..... 49
  - 4.4 Interaction of Capacity Restrictions and Traffic Conditions..... 51
    - 4.4.1 Cohort Model..... 51
    - 4.4.2 Time Saved Per Incident..... 54
    - 4.4.3 Classification of Incidents..... 55
    - 4.4.4 Incident Management Approaches..... 56
    - 4.4.5 Distribution of Traffic for Incident Conditions..... 56
    - 4.4.6 Geographic Levels of Diversion..... 60
  - 4.5 Functional Requirements for Improving Incident Response and Relationship of Improvement Techniques..... 68
    - 4.5.1 Improving Incident Detection and Verification..... 69
    - 4.5.2 Improving Incident Response, Clearance and Recovery Through ITS..... 79
  - 4.6 Measuring Incident Management Effectiveness..... 84
    - 4.6.1 Degree of Attainment for Recommended Management Functions, Operations and Technologies..... 84
    - 4.6.2 General Measures..... 85
    - 4.6.3 Model for Evaluating Incident Management Effectiveness..... 86
  - References..... 89
- 5 Non-recurrent Congestion: Incident Information to Motorists**..... 91
  - 5.1 Motorist Diversion..... 92
    - 5.1.1 Motorist Messaging Techniques..... 92
    - 5.1.2 Operational Diversion Policies and Strategies..... 95
    - 5.1.3 Strategic Network Management..... 97
    - 5.1.4 Diversion Strategies..... 100
    - 5.1.5 Reduction in Freeway Delay Resulting From Diversion..... 103
    - 5.1.6 Effect of Diversion on Arterial Traffic..... 105
    - 5.1.7 Reduction in Corridor Delay Resulting from Diversion for Incidents..... 107
  - 5.2 Design Considerations for DMS Locations..... 108
    - 5.2.1 Basic Considerations for DMS Functional Placement..... 108
    - 5.2.2 Simple Models to Assist in DMS Functional Placement..... 108

- 5.3 Quality of Motorist Information..... 114
- 5.4 ITS and Technology Applications in Emergency Evacuations ..... 114
  - 5.4.1 Introduction ..... 114
  - 5.4.2 ITS and Technology Applications ..... 115
- References ..... 117
- 6 Recurrent Congestion: Information to Motorists ..... 119**
  - 6.1 Nature of Recurrent Congestion..... 119
  - 6.2 Motorist Information During Recurrent Congestion..... 119
  - 6.3 Variations During Periods of Recurrent Congestion..... 120
  - 6.4 Diversion During Recurrent Congestion..... 122
  - Reference..... 123
- 7 Ramp Metering ..... 125**
  - 7.1 Introduction ..... 125
  - 7.2 Background ..... 126
    - 7.2.1 Early Metering Projects..... 126
    - 7.2.2 Ramp Meter Installation Requirements ..... 127
  - 7.3 Flow Characteristics and Freeway Capacity ..... 128
    - 7.3.1 Flow Characteristics for Near-Capacity Conditions ..... 128
    - 7.3.2 Effective Capacity Improvement Through Ramp Metering..... 132
    - 7.3.3 Freeway Service Improvement Through Ramp Metering... 133
  - 7.4 Ramp Metering Strategies..... 136
    - 7.4.1 Overview of Metering Strategies ..... 136
    - 7.4.2 Pretimed Restrictive Ramp Metering..... 138
    - 7.4.3 Local Traffic Responsive Restrictive Ramp Metering ..... 139
    - 7.4.4 System-Wide Traffic Responsive Restrictive Ramp Metering..... 145
    - 7.4.5 Design Issues..... 145
  - 7.5 Ramp Metering and the Motorist ..... 151
    - 7.5.1 Motorist Benefits and Disbenefits Resulting from Ramp Metering..... 151
    - 7.5.2 Public Acceptance of Ramp Metering..... 152
  - 7.6 Benefits Model for Ramp Metering ..... 153
  - References ..... 154
- 8 Transportation Management Centers ..... 157**
  - 8.1 Transportation Management Center Functions ..... 157
    - 8.1.1 Support of Emergency Management Services ..... 157
    - 8.1.2 Provision of Information to Motorists..... 158
    - 8.1.3 Operation of Ramp Meters ..... 158
    - 8.1.4 Operation of Service Patrols ..... 159
    - 8.1.5 Coordination of Traffic Signal Operation with Freeway and Corridor Requirements ..... 160
    - 8.1.6 Provision of Weather Information Related to Roadway Conditions ..... 160

- 8.2 Example of Transportation Management Center  
in Major Urban Location..... 161
- 8.3 Interconnection and Coordination of TMCs ..... 163
  - 8.3.1 Regional Coordination..... 164
  - 8.3.2 Statewide Coordination ..... 168
- References..... 175
- 9 Evaluation of System Design and Operation..... 177**
  - 9.1 Evaluation of Design Alternatives and Project Feasibility ..... 177
    - 9.1.1 Benefit and Cost Analysis..... 177
    - 9.1.2 Alternatives Evaluation and Project Feasibility ..... 180
  - 9.2 Project Evaluation ..... 181
    - 9.2.1 Role and Function of Evaluation ..... 181
    - 9.2.2 Functions and Measures to Consider for Evaluation..... 183
    - 9.2.3 Data Structures for Evaluation..... 184
    - 9.2.4 Description of Measures ..... 187
  - References..... 191
- 10 Active Traffic Management (ATM) ..... 193**
  - 10.1 Definition and Concept ..... 193
  - 10.2 Speed Harmonization..... 195
  - 10.3 Temporary Shoulder Use..... 196
  - 10.4 Queue Warning..... 199
  - 10.5 Dynamic Merge Control ..... 201
  - 10.6 Dynamic Lane Markings..... 202
  - 10.7 Implementation Considerations ..... 202
  - 10.8 Planning for Active Traffic Management..... 204
  - References..... 204
- 11 Corridor Management..... 207**
  - 11.1 Coordinated Freeway and Arterial Operation ..... 207
    - 11.1.1 Management Strategies..... 208
    - 11.1.2 Operational Plans and Procedures  
for Coordinating Freeways and Arterials..... 208
  - 11.2 Integrated Corridor Management ..... 210
  - 11.3 Special Corridors..... 214
    - 11.3.1 Types of Special Corridors ..... 214
    - 11.3.2 Example of Special Corridor ..... 214
  - References..... 219
- 12 Website Support..... 221**
  - 12.1 Introduction ..... 221
  - 12.2 System Delay per Incident ..... 221
  - 12.3 Relative Effectiveness of CCTV Coverage..... 222
  - 12.4 Incident Management Effectiveness Potential ..... 222
  - 12.5 Delay Reduced on Freeway Due to Queue Reduction  
Resulting from Diversion..... 222

- 12.6 Probability that the Motorist Encounters DMS Prior to Incident (P34)..... 222
- 12.7 Queue Storage Requirement for Ramp Meter..... 223
- Reference..... 223
- 13 ITS and the Connected Vehicle..... 225**
  - 13.1 The Connected Vehicle ..... 225
  - 13.2 Connected Vehicle Data Links ..... 226
  - 13.3 Cellular/Internet Based Services ..... 227
  - 13.4 In-Vehicle Displays ..... 229
  - 13.5 The Traffic Management Dilemma ..... 230
  - 13.6 USDOT Connected Vehicle Program..... 230
  - References..... 235
- Appendix A: Travel Time, Delay and Travel Time Reliability Measures..... 237**
- Appendix B: Relative Effectiveness of CCTV Coverage ..... 249**
- Appendix C: Example of Benefits for Incident Management ..... 253**
- Appendix D: Message Display Software for Southern State Parkway..... 257**
- Appendix E: Washington State Fuzzy Logic Ramp Metering Algorithm ..... 261**
- Appendix F: Benefits Model for Motorist Assistance Patrols..... 265**
- Appendix G: National Incident Management System and Incident Classification..... 267**
- Appendix H: Special Corridor Traffic Decision Support and Demand Management System Concept..... 271**
- Index..... 277**



# List of Symbols, Abbreviations, and Acronyms

The following table defines the symbols, abbreviation, and acronyms that are most commonly used in the book. Parameters and variables used in the equations are defined in the discussion of the equations. Definitions for the appendices are provided in the appendix.

Acronym	Definition
AADT	Annual average daily traffic
ACCR	Accident rate
ACR	Accident rate for section
ADD	Average vehicle delay (diversion)
ADM	Active demand management
ADMS	Archived data monitoring system
ADMS	Arterial dynamic message sign
ADND	Average vehicle delay (no diversion)
ADOT	Arizona Department of Transportation
ADUS	Archived Data Use Service
AID	Automatic incident detection
ALINEA	A local ramp metering algorithm
ANPRM	Advanced notice of proposed rulemaking
APM	Active parking management
AR	Accidents reduced
ARI	Accident rate in interchange area
ARNI	Accident rate in non-interchange area
ARTEMIS	Advanced Regional Traffic Interactive Management and Information System
ATDM	Active traffic and demand management
ATM	Active traffic management
ATSMR	Average time per mile per vehicle saved by metering

(continued)

(continued)

Acronym	Definition
B <sub>l</sub>	Timely detection probability for a range of scenarios for different detector spacing
B <sub>j</sub>	Total mainline traffic in section J
BSM	Basic safety message
C	Capacity
C2C	Center-to-center
CAD	Computer aided dispatch
CALTRANS	California Department of Transportation
CCTV	Closed circuit television
CD	Capacity deficit
CDS	Total corridor delay reduction
CFA	Coordinated freeways and arterials
CFR	Code of Federal Regulations
CMS	Changeable message sign (also known as dynamic message sign)
CO	Carbon monoxide
CONOPS	Concept of operations
crf	Capital recovery factor
CS	Capacity along arterial with signal
CVF	Commercial vehicle fraction
CVRIA	Connected Vehicle Reference Implementation Architecture
DAR	Additional delay incurred by pre-diversion traffic on diversion route
DC	Delay from TC to T
DD	Delay prior to TC
DF	Public diversion fraction for no major arterial congestion
D <sub>t</sub>	Delay from the start of the incident up to incident clearance
DIF	Delay for non-diverted freeway traffic
DOT	Department of Transportation
DMS	Dynamic message sign
D <sub>Q</sub>	Delay from incident clearance to queue dissipation
DQC	Delay after incident clearance
DSRC	Direct short range communication
DSS	Decision support system
D <sub>T</sub>	Total delay
DTA	Dynamic traffic assignment
E511	Emergency telephone response service provided by PSAP
ER	Emission rate
FE	Excess fuel consumption
FHWA	Federal Highway Administration
FRM	Fraction of roadway segment influenced by metering
FRR	Fraction of ramps in roadway segment that contain ramp meters
G	Gini coefficient
GE	Excess fuel consumption rate

(continued)