

TRAFFIC ENGINEERING AND ROAD SAFETY

PRADIP K. SARKAR | UDIT JAIN



» Pearson

Traffic Engineering and Road Safety

Pradip K. Sarkar

Former Professor and Head
Department of Transport Planning
School of Planning and Architecture
New Delhi
Institution of National Importance
Ministry of Human Resource Department
Government of India

Former Director
Transportation
Asian Institute of Transport Development
New Delhi

Udit Jain

Assistant Professor
Department of Civil Engineering
Visvesvaraya National Institute of Technology (VNIT), Nagpur
(An Institute of National Importance, MoE, Govt. of India)
Nagpur, Maharashtra

Pearson

Although the author and publisher have made every effort to ensure that the information in this book was correct at the time of editing and printing, the author and publisher do not assume and hereby disclaim any liability to any party for any loss or damage arising out of the use of this book caused by errors or omissions, whether such errors or omissions result from negligence, accident or any other cause. Further, names, pictures, images, characters, businesses, places, events and incidents are either the products of the author's imagination or used in a fictitious manner. Any resemblance to actual persons, living or dead or actual events is purely coincidental and do not intend to hurt sentiments of any individual, community, sect or religion.

In case of binding mistake, misprints or missing pages etc., the publisher's entire liability and your exclusive remedy is replacement of this book within reasonable time of purchase by similar edition/ reprint of the book.

Advanced Specialist—Product: R. Dheepika

Advanced Specialist—Production: C. Purushothaman

Copyright © 2026 Pearson India Education Services Pvt. Ltd

All rights reserved. This book is sold subject to the condition that it shall not, by way of trade or otherwise, be lent, resold, hired out, or otherwise circulated without the publisher's prior written consent in any form of binding or cover other than that in which it is published and without a similar condition including this condition being imposed on the subsequent purchaser and without limiting the rights under copyright reserved above, no part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording or otherwise), without the prior written permission of both the copyright owner and the publisher of this book.

ISBN 978-93-560-6636-6

First Impression

Published by Pearson India Education Services Pvt. Ltd, CIN: U72200TN2005PTC057128.

Head Office: 1st Floor, Berger Tower, Plot No. C-001A/2, Sector 16B, Noida - 201 301, Uttar Pradesh, India.

Registered Office: 6th Floor, Tower A, Unit A and B, International Tech Park, CapitaLand, 200 Feet Radial Road, Zamin Pallavaram, Old Pallavaram, Chennai - 600 117, Tamil Nadu, India.

Website: in.pearson.com, Email: companysecretary.india@pearson.com

Digitally printed in India by Trinity Academy for Corporate Training Ltd, New Delhi in the year of 2026.

Contents

Foreword	xxvii
Preface	xxxi
About the Authors	xxxv
Chapter 1 Introduction to Traffic Engineering and Road Safety	1
1.1 Introduction	1
1.2 Evolving Process of Traffic Engineering	2
1.3 Role and Importance of a Traffic Engineer	3
1.4 Functions of Traffic Engineering and Road Safety	3
1.4.1 Collection of Primary and Secondary Data, Analysis and Inference of Data	3
1.4.2 Traffic and Transportation Planning	4
1.4.3 Design of Traffic Facilities	4
1.4.4 Traffic Regulation, Operation and Control	4
1.5 Organization of Traffic Engineering	5
1.6 Need for Road Safety Studies	6
1.7 Organization and Functions of Road Safety Wing	6
1.7.1 National Road Safety Council	7
1.8 Responsibilities of Road Safety Officials and Their Duties	8
1.9 Emergence of Road Safety Rules and Technology at the Global Level	9
Summary	10
References	10
Chapter 2 Traffic Surveys	11
2.1 Introduction	11
2.2 Traffic Data	12
2.2.1 Primary Data	12
2.2.2 Data from Other Secondary Sources	13
2.3 Traffic Surveys	13

2.4	Road Inventory Survey	14
2.5	Classified Traffic Volume Survey	14
2.6	Traffic Flow Data at Intersections	17
2.7	Origin and Destination (O-D) Survey	18
2.8	Household Travel Survey	19
2.8.1	Conduct of Household Travel Survey, Data Coding, Punching/Feeding and Editing	21
2.9	Speed and Delay Survey	22
2.9.1	Methods for Conducting Speed and Delay Studies	23
2.9.2	Moving Car Observer Method	23
2.9.3	Floating Car Method	26
2.9.4	Average Speed Method	27
2.9.5	Maximum Car Method	27
2.9.6	Elevated Observer Method	27
2.9.7	License Plate Method	27
2.9.8	Photographic Method	27
2.9.9	Interview Method	27
2.10	Speed Studies	28
2.10.1	Spot Speed Studies	28
2.10.2	Methods of Measurement	31
2.11	Intersection Delay Studies	34
2.11.1	Types of Delay	34
2.11.2	Delay Diagram	36
2.11.3	Webster's Delay Models	38
2.12	Parking Survey	43
2.12.1	Parking Accumulation	44
2.12.2	Parking Volume	44
2.12.3	Parking Load	45
2.12.4	Average Parking Duration	45
2.12.5	Parking Turnover	45
2.12.6	Parking Index	45
2.13	Pedestrian Survey	46
2.14	Bus Transport Survey	46
2.15	Intermediate Public Transport Survey	46
2.16	Establishment Survey	47
2.17	Goods Survey	47
	<i>Summary</i>	49
	<i>Review Questions</i>	49
	<i>References</i>	50
Chapter 3	Traffic Forecast	53
3.1	Introduction	53
3.2	Current Status in Traffic Forecasting	54

4	3.3	Traffic Flow Forecasting Techniques	55
4	3.3.1	Sampling Technique Used	55
7	3.4	Type of Sampling	56
8	3.5	Time Trend Analysis	58
9	3.5.1	Time Series Modeling	59
1	3.5.2	Examples of Curve Fitting Using the Principle of Least Square	60
2	3.5.3	Freehand Curve Method	61
3	3.5.4	Growth Rate Method or Projection Method	65
3	3.5.5	Principle of Least Square	68
6	3.5.6	Examples of Non-Linear Curve Fitting Method	69
7	3.5.7	Steps for Regression Analysis	70
7	3.5.8	Multiple Regressions	71
7	3.6	Elasticity of Traffic Demand	71
7	3.6.1	Discrete Method	72
7	3.6.2	Regression Method	73
7	3.6.3	Example of Traffic Forecast Based on Elasticity of Traffic Demand	73
8	3.7	Markov Chain	77
8	3.7.1	Definition of State-Related Data	79
1	3.7.2	Transition Probability Matrix of State	79
4	3.7.3	Initial Probability Matrix	80
4	3.7.4	Transitional State Probabilities	80
6	3.7.5	Traffic Growth	82
8	3.7.6	Traffic Forecast Based on Traffic Assignment	82
13	Annexure 1		83
14	Annexure 2		84
15	Summary		86
15	References		87
15	Questions		87
15	Chapter 4	Geometric Design of Roads	89
16	4.1	Introduction	89
16	4.2	Design Types and Standards	89
17	4.3	Classification of Roads	90
17	4.3.1	Allocation of Land for Road for Road Cross Sections	90
49	4.4	Topography	103
49	4.5	Design Speed	104
50	4.6	Concept of Design Vehicle	105
53	4.7	Vehicle Turning Characteristics	107
53	4.8	Sight Distance	107
54	4.8.1	Stopping Sight Distance	108

4.8.2	Overtaking Sight Distance	109
4.8.3	Intermediate Sight Distance	113
4.9	Horizontal Alignment	116
4.9.1	Super Elevation	119
4.9.2	Minimum Radius of Horizontal Curves	121
4.10	Transition Curves	124
4.10.1	Widening at Curves	128
4.11	Vertical Alignment	132
4.11.1	Ruling Gradient	132
4.11.2	Limiting Gradient	133
4.11.3	Exceptional Gradient	133
4.11.4	Minimum Gradient	133
4.11.5	Grade Compensation at Curves	134
4.12	Combination of Vertical and Horizontal Alignment	140
4.13	Application of Software in Highway Design and Engineering	142
4.14	Lateral and Vertical Clearances	142
4.15	Provision of Bus Stops	143
	Summary	145
	Questions	145
	References	146
Chapter 5	Geometric Design of Intersections	147
5.1	General	147
5.2	Types of Conflicting Manoeuvres	148
5.3	Types of At-Grade Intersection Layouts	149
5.3.1	Unchannelized and Unflared Intersections	151
5.3.2	Flared Intersections	152
5.3.3	Channelized Intersections	153
5.4	Factors Influencing Design	154
5.5	Safety	154
5.6	Points of Conflict	154
5.7	Area of Conflict	156
5.8	Control of Speed and Corner Radii	156
5.9	Traffic Control and Geometric Design	157
5.10	Capacity	158
5.11	Location of Intersection	158
5.12	Spacing of Intersections	158
5.13	Redesign of Alignment	158
5.14	Integration Between Horizontal and Vertical Curve at Intersection	159
5.15	Intersection Sight Distance	160

09	5.16	Data Requirement for Design of Intersection	161
13	5.17	Design of Various Types of Uncontrolled and Uncontrolled	
16		Intersections At-Grade	162
19	5.17.1	Uncontrolled Junction	162
21	5.17.2	Uncontrolled Channelized Intersection	164
24	5.17.3	Priority Junction	166
28	5.17.4	Design of Roundabouts	168
32	5.17.5	Mini-Roundabout	173
32	5.18	Various Categories of Roundabout	179
33	5.18.1	Steps for Designing of Roundabout	183
33	5.18.2	Capacity of Roundabout Based on the Indo Highway	
33		Capacity Manual	183
34	5.19	Design of Road Geometrics at Signalized Intersection	189
40	5.19.1	Design Speed	191
42	5.19.2	Auxiliary Lanes	191
42	5.19.3	Right Turning Lanes	192
43	5.19.4	Deceleration Lanes	193
45	5.19.5	Seagull Island	194
45	5.19.6	Opposed Right Turns	195
46	5.19.7	Central Island Median Design	195
	5.19.8	Left Turn Lanes	196
7	5.19.9	Pavement Tapers	197
7	5.19.10	Sight Distance at Signalized Intersection	197
8	5.20	Grade Separated Intersections and Interchanges	198
9	5.20.1	Warrants for Grade-Separated Intersections	
1		and Interchanges	198
2	5.20.2	Classification of Intersection	199
3		<i>Summary</i>	206
4		<i>Questions</i>	207
4		<i>References</i>	208
4	Chapter 6	Traffic Flow Characteristics	209
6	6.1	Introduction	209
6	6.2	Terminologies	209
7	6.3	Macroscopic Traffic Flow Parameters	210
8	6.3.1	Traffic Flow (Q)	210
8	6.3.2	Traffic Density (K)	212
8	6.3.3	Traffic Speed (U)	213
3	6.4	Macroscopic Traffic Flow Models	214
	6.4.1	Greenshields Model	214
	6.4.2	Greenberg's Logarithmic Speed-Density Model	217

6.4.3	Underwood's Exponential Speed-Density Model	217
6.4.4	Multi-Regime Speed-Density Models	218
6.5	Types of Speed	219
6.5.1	Time Mean Speed	219
6.5.2	Space Mean Speed	219
6.5.3	Journey Speed	219
6.5.4	Running Speed	220
6.5.5	Spot Speed Data Analysis and Fitting of Normal Distribution to Speed Data	220
	<i>Summary</i>	223
	<i>Problems</i>	224
	<i>References</i>	224
Chapter 7	The Queuing Theory and its Application to Traffic Engineering Situations	227
7.1	Introduction	227
7.1.1	Significance of Queuing Theory in Traffic Engineering	227
7.2	Queuing System	228
7.2.1	Notations	229
7.2.2	Queuing Patterns	229
7.3	Queuing Analysis	231
7.3.1	Analysis of Varying Service Rate Pattern	231
7.3.2	Analysis of Varying Arrival Rate Pattern	245
7.4	Introduction to Shockwaves	251
7.4.1	Classification of Shockwaves	251
	<i>Summary</i>	253
	<i>Questions</i>	253
	<i>References</i>	255
	<i>Appendix-1</i>	256
Chapter 8	Capacity of Roads	257
8.1	Introduction	257
8.2	Concepts and Types of Highway/Road Capacity (US-HCM (2010))	258
8.2.1	Basic Capacity	258
8.2.2	Possible Capacity	258
8.2.3	Practical/Design Capacity	259
8.3	IRC:64 (1990)	261
8.4	IRC:106 (1990)	262
8.5	Indo-HCM (2017)	262
8.5.1	Single-Lane, Intermediate Lane and Two-Lane Roads	262

7	8.5.2	Multilane Divided Interurban Highways	273
8	8.5.3	Interurban and Urban Expressways	280
9	8.5.4	Urban Roads	287
9		<i>Summary</i>	293
9		<i>Questions</i>	294
9		<i>References</i>	295
0			
	Chapter 9	Pedestrian Facilities	297
0	9.1	General	297
3	9.2	Types of Pedestrian Crossing Facilities	297
4	9.2.1	Surface Level Crossings	297
4	9.2.2	Grade Separated Crossing	298
	9.2.3	Based on Electronic Device Usage	298
7	9.3	Safety Provisions for Pedestrian Facilities	301
7	9.4	Critical Gap	306
7	9.5	Crossing Warrants	307
7	9.5.1	Psychological Gap Size	309
8	9.6	Walkability Index	310
9		<i>Summary</i>	312
9		<i>Questions</i>	312
11		<i>References</i>	315
11			
5	Chapter 10	Parking Theory and Surveys	317
11	10.1	Introduction	317
11	10.2	Types of Parking	317
3	10.2.1	On Street Parking	317
3	10.2.2	Off Street Parking	319
5	10.3	Parking Requirements	320
6	10.4	Effect of Improper Parking	321
7	10.5	Parking Terminologies	321
7	10.6	Parking Surveys	323
7	10.6.1	In-Out Survey	323
8	10.6.2	License Plate Method of Survey	325
8		<i>Summary</i>	327
8		<i>Problems</i>	327
8		<i>References</i>	329
8			
9	Chapter 11	Traffic Control Devices	331
11	11.1	Introduction	331
12	11.1.1	Principles of Traffic Signs	331
12	11.1.2	Classification of Signs	332

11.1.3	Guidelines for Manufacturing Sign Boards	336
11.1.4	Guidelines for Installation of Signs	340
11.2	Road Markings	341
11.2.1	Materials and Features	341
11.2.2	Performance and Colour Patterns of Road Markings	343
11.2.3	Classification of Road Markings	343
11.3	Delineators	353
11.3.1	Roadway Indicators	354
11.3.2	Median Marker	357
11.3.3	Hazard Markers	357
11.3.4	Object Markers	358
11.4	Other Control Measures	358
11.4.1	Chicanes	358
11.4.2	Curb Extension	359
11.4.3	Rumble Strips	360
11.4.4	Transverse Bar Markings (TBMs)	361
11.4.5	Speed Hump and Speed Bumps	362
11.4.6	Speed Humps	363
11.4.7	Raised Crossings	363
	<i>Summary</i>	364
	<i>Questions</i>	364
	<i>References</i>	364
	<i>Annexure – A</i>	365
	<i>Annexure – B</i>	382
Chapter 12	ITS based Traffic Information System	393
12.1	Introduction	393
12.2	Data Process and Dissemination of Information	394
12.2.1	Manage Events/Incidents	395
12.2.2	Archived Data Management	395
12.3	Data Dictionary Standards	396
12.4	Traffic Information from Other Sources	398
12.4.1	Closed-Circuit Television	398
12.4.2	Variable Message Signs	399
12.4.3	Interactive Kiosks	400
12.4.4	Automated Trip Itineraries	401
12.4.5	In-vehicle Information System	401
12.4.6	Bus Information System	402
12.4.7	Information on Intelligent Speed Adaptation	403
12.4.8	Vehicular Ad-hoc Network or VANET	403
12.5	Graphical Data Dictionary (GDD)	404

	<i>Summary</i>	406
	<i>Questions</i>	407
	<i>References</i>	407
Chapter 13	Traffic Signals and Delay at Intersections	409
13.1	Introduction	409
13.2	Traffic Signal	409
13.3	Objective of Installing Traffic Signals	409
13.4	Signal Sequence	410
13.4.1	British System	410
13.4.2	American System	410
13.4.3	Indian System	410
13.4.4	Pedestrian Signal	410
13.5	Signal Face	411
13.6	Establishment of Signal Faces	412
13.7	Classification of Traffic Signals	412
13.8	Terms Related to Signal Design	413
13.8.1	US Highway Capacity Manual Method (HCM 2010)	413
13.8.2	IRC: 93-1985 Method	416
13.9	Delay at Intersections	418
13.9.1	Estimation of Vehicular Delay	419
13.10	Classification of Traffic Signal Co-Ordination System	423
13.11	Design of Signal	425
13.11.1	Optimum Signal Cycle Length	425
13.11.2	Pretimed Signal Design	426
13.12	Warrants for Installing Traffic Signals	441
13.13	Important Software for Traffic Engineering	442
13.13.1	TRANSYT/TRANSYT 16	442
13.13.2	SATURN	443
13.13.3	SIDRA	444
13.13.4	HCS2016[16]	445
13.13.5	ARCADY	445
	<i>Summary</i>	446
	<i>Review Questions</i>	446
	<i>References</i>	446
Chapter 14	Advanced Traffic Management System Using Intelligent Transportation Systems	449
14.1	Introduction	449
14.1.1	Purpose of TSM	450
14.1.2	Objectives of TSM	450

14.1.3	Techniques of TSM	451
14.1.4	Traffic Control Devices	452
14.1.5	Traffic Segregation Techniques	452
14.1.6	Demand Management Techniques	453
14.1.7	Public Transport as Priority Techniques	453
14.1.8	Self-Enforcing Techniques	454
14.1.9	Police–Public Interaction Techniques	454
14.1.10	Evolving of TSM in to Advance TSM Using ITS	454
14.2	Development of Advanced Traffic Management System Through Various Phases	457
14.3	Traffic Management Centre	459
14.4	Communication System in ATMS	461
14.4.1	Information Gathering	463
14.4.2	Information Processing	463
14.4.3	Service Delivery	464
14.5	Advanced Traffic Management System	465
14.5.1	Advanced Traveller Information System	465
14.5.2	Advanced Vehicle Control Systems	466
14.5.3	Advanced Public Transport System	466
14.5.4	Commercial Vehicle Operation	466
14.5.5	Emergency Management	467
14.5.6	Incident Management	468
14.5.7	Urban Road Safety	468
14.6	Sensors/Equipments for Transportation System	469
14.7	Applications of Sensors in Traffic Management	472
14.8	How to Manage and Process Huge Data in the TMC	473
14.9	Data Warehousing, Mining, Fusion and Analysis	475
14.9.1	Data Warehousing and Mining	475
14.9.2	Big Data Analysis	476
14.9.3	Data Processing and Fusion	477
14.10	ITS Standards	479
14.11	Case Studies	480
14.11.1	Case Study: Kochi	480
14.11.2	Case Study: Seoul	481
	<i>Summary</i>	482
	<i>Questions</i>	482
	<i>References</i>	483
Chapter 15 Traffic Psychology		485
15.1	Introduction	485
15.2	Traffic Psychology as Related to Road User Behaviour	486

15.2.1	Interaction with the Traffic Environment in the Perspective of a Driver	486
15.3	Cognitive Ability in Safe Driving	488
15.3.1	Laboratory Setting for Driver Diagnostics	490
15.3.2	Test for Visual Parameters	490
15.4	Visual Assessment of Drivers	491
15.5	Sensorimotor Assessment for Drivers	492
15.5.1	Vienna Testing System	492
15.5.2	Assessment of Drivers with Indigenous Car Driving Simulator	496
15.6	Application of Artificial Intelligence Techniques for Driver Diagnostics and Evaluation	496
15.7	Recommendation	497
	<i>Summary</i>	498
	<i>Questions</i>	498
	<i>References</i>	499
Chapter 16	Traffic Calming Measures—A Review	501
16.1	Introduction	501
16.2	Experiences in Traffic Calming in Europe and USA	502
16.2.1	Dutch Approach to Traffic Calming	502
16.2.2	Denmark and Norway Approach to Traffic Calming	503
16.2.3	German Approach to Traffic Calming	503
16.2.4	Lessons from the European Countries and USA	503
16.3	Need for Traffic Calming Measures	505
16.4	Best Practices for Implementation in Traffic Calming Measures	506
16.4.1	Residential Area	506
16.4.2	Hilly Roads	506
16.4.3	At Collector and Arterial Roads in Urban Areas	508
16.4.4	Safety at School Zones	510
16.4.5	Rural Roads	513
16.5	Measures of Effectiveness	515
16.6	Traffic Calming Measures in Indian Context	515
16.6.1	Aalborg University, Denmark, Department of Development and Planning and IIT, Delhi	516
16.6.2	Traffic Calming Measures on National and State Highways	516
16.6.3	The Study by IIT, Delhi	516
16.6.4	Traffic Calming Measures on National and State Highways Passing Through Towns and Villages	517
16.6.5	Guidelines for Traffic Calming Measures in Urban and Rural Areas	518

16.7	Possible, Design Measures for Traffic Calming	519
	<i>Summary</i>	520
	<i>Questions</i>	521
	<i>References</i>	522
Chapter 17	Road Accident	525
17.1	Introduction	525
17.2	What is Safety Science?	526
17.3	Road Accidents	527
17.3.1	Accidents by Road Categories and Features	528
17.3.2	Accidents by Road Features	529
17.3.3	Road Accidents in Urban and Rural Areas	530
17.4	Road Accident Data Collection	531
17.5	Data Collection and Recording System in Developed Countries	534
17.5.1	CARE	534
17.5.2	IRTAD (Aggregate Database)	535
17.5.3	The International Transport Forum	535
17.6	Limitations of Data Collection	536
17.7	Road Accident Investigation	537
17.7.1	Collision Diagram	539
17.7.2	Preparation of a Collision Diagram	540
17.7.3	Crash Pattern	541
17.8	Various Activities Involved in the Conduct of Crash Investigation	541
17.8.1	Short Comings in Indian Investigation	544
17.9	Crash Investigation Programme	545
17.10	Crash Data Analysis	548
17.10.1	Methods of Data Analysis	548
17.10.2	Negative Binomial Regression Model	548
17.11	Definitions and Identification of Black Spot	549
17.11.1	Methods for Identification of Blackspots	551
17.12	Concept of Star Rating for Assessing the Level of Safety Risk	557
	<i>Summary</i>	558
	<i>Questions</i>	558
	<i>References</i>	559
Chapter 18	Road Safety Audits	573
18.1	Introduction	573
18.2	Definition, Concepts and Process	575
18.3	Aims and Benefits of RSA	576
18.4	Procedures and Conduct of Road Safety Audits	577
18.5	Role and Responsibility of Road Safety Auditor or Team	581

519	18.6 Project Assessment and Report Submission	583
520	18.7 Principles of Safer Road Design	585
521	18.8 Checklists	586
522	Summary	588
	Questions	588
525	References	589
525	Chapter 19 Enhancing Road Safety Using Five Pillars	591
526		
527	19.1 Introduction	591
528	19.2 Five Pillars of Road Safety	593
529	19.3 Road Safety Scenario in India	596
530	19.4 Initiatives By the Government of India	597
531	19.5 Policy Statements	597
534	19.6 An Overview of the Motor Vehicle (Amendment)	599
534	19.6.1 Background	599
535	19.6.2 High Penalty	600
535	19.7 Key Areas of Concerns on Worsening Road Safety Situation	
536	in India	602
537	19.7.1 Reducing Pedestrians' Accidents	603
539	19.7.2 Strategies for Improving Black Spots on Highways	603
540	19.7.3 Improving Road Safety Through Community	
541	Participation	604
541	19.7.4 Reducing Accidents Due to Drunk and Driving	604
544	19.7.5 Developing Methods and Practices for Post-Crash	
545	Management Through Trauma	605
548	19.7.6 Effective Steps Towards Two-Wheeler Motorized Safety	606
548	19.7.7 Effect of Fatigue on the Occurrence of Accidents	
548	for Truck Drivers	607
549	19.7.8 Evolving Effective Enforcement Mechanism	607
551	19.7.9 Ensuring Road Safety for School Children	608
557	19.7.10 Low-Cost ITS for Road Safety	608
558	19.7.11 Traffic Calming	609
558	19.7.12 Design of Safe Vehicles	609
559	19.7.13 Strategies for Action Plans Using Engineering and	
	Non-Engineering Measures	609
573	19.7.14 Inclusive Design of Safe Roads	610
573	19.7.15 Developing Institutional Mechanism	610
575	19.8 Concept of Development of Forgiving Roads	611
576	19.9 Road Safety Education, Enforcement and Post-Care Emergency	615
577	19.9.1 Introduction	615
581	19.9.2 Awareness Building Campaign Development	615

19.9.3	Audio Visual Information and Education Communications	616
19.9.4	Road Safety Awareness Campaign Implementation: Key Steps	617
19.9.5	Road Safety Education	618
19.9.6	Enforcement	619
19.9.7	Post-Crash Emergency Care	620
	<i>Summary</i>	622
	<i>Questions</i>	622
	<i>References</i>	622
Chapter 20	Use of AI for Road Safety	625
20.1	What is Artificial Intelligence?	625
20.2	When Did the AI's Surge Begin?	627
20.3	AI's Impact Everywhere	629
20.3.1	Impact of AI on Privacy	630
20.3.2	Scandal on Facebook	631
20.3.3	Face Recognition Scandal	632
20.3.4	Fake Face	632
20.3.5	Mass Surveillance	632
20.3.6	Impact of Artificial Intelligence on Human Rights	633
20.4	AI in Road Safety	634
20.4.1	The Five Es of Road Safety	635
20.4.2	Literature Review	635
20.4.3	Applications of AI in Vehicles	635
20.4.4	AI's Challenges in Improving Road Safety	640
20.5	How AI Helps in Traffic Management	641
20.5.1	AI in Modern-Day Traffic Control Solutions	642
20.5.2	Use of Technology in Traffic Management	643
20.6	Is AI the Future?	646
20.7	AI Road Safety in India	647
20.7.1	Scope of AI Use	648
20.7.2	ADAS – Pilot Project in Nagpur	648
20.7.3	The Urgency to Improve Road Safety in India	648
	<i>Summary</i>	649
	<i>Questions</i>	650
	<i>References</i>	650
Chapter 21	Road Traffic and Air Pollution (Road Traffic Impact on Environment)	651
21.1	Introduction	651
21.2	Growth of Vehicles in Different Cities in India	652

21.3	Air Pollution	653
21.4	Issues and Challenges Facing the Urban Road Transport Sector	654
21.5	Road Transport and Indian Cities	655
21.6	Environmental Challenges	655
21.6.1	Congestion	655
21.6.2	Air Pollution	656
21.6.3	Climate Change	656
21.7	Quantum of Air Pollution in Indian Cities	657
21.8	Impact of Congestion on Emissions	659
21.9	Health Impacts of Air Pollution	660
21.10	Air Quality Management	662
	<i>Summary</i>	664
	<i>Review Questions</i>	665
	<i>References</i>	665
Chapter 22	Traffic Noise and Its Impact	667
22.1	Introduction	667
22.1.1	Comparison of Noise Standards for Various Categories of Zones in India (MoEF Notification)	667
22.1.2	International Comparison of Noise Standard	668
22.1.3	Basics of Noise	670
22.2	Impact of Traffic Noise on Human Health	674
22.3	Adverse Effects of Noise on Health	675
22.3.1	Noise Annoyance	675
22.3.2	Noise and Sleep Disturbance	675
22.3.3	Noise and Cardiovascular Diseases	676
22.3.4	Noise and Hearing Loss	676
22.3.5	Psychological Effects	676
22.4	An Example to Conduct Traffic Noise Study	677
22.4.1	Methodology for Determining Annoyance	678
22.4.2	Traffic Volume Survey	680
22.4.3	Noise Measurement Survey	681
22.4.4	Impact of Traffic Noise on Health in Delhi	683
22.4.5	Noise Annoyance Index (NAI)	684
22.4.6	Traffic Noise Annoyance Model for Day Time	686
22.4.7	Noise Annoyance Models for Night Time	688
22.4.8	Determination of Noise Acceptability Limits	689
	<i>Summary</i>	691
	<i>Questions</i>	691
	<i>References</i>	691

Chapter 23 Street Lighting	693
23.1 Background	693
23.2 Scope	694
23.3 Definitions	694
23.4 Quality Criteria of Road Lighting	695
23.4.1 Luminance	696
23.4.2 Illuminance	696
23.4.3 Uniformity	696
23.4.4 Glare	696
23.4.5 Visual Guidance	697
23.4.6 Other Important Factors	698
23.5 Key Design Guidelines	698
23.5.1 Definition of Terms Related to Lighting Installation	698
23.5.2 Classification of Roads with Lighting Perspective	699
23.5.3 Recommended Values for Illumination	702
23.5.4 Maintenance Factors for Luminaires in Urban and Rural Locations	703
23.5.5 Calculation of Performance	703
23.5.6 General Design Recommendations	704
23.5.7 Luminaries Selection (Flood Light/Streetlight)	705
23.5.8 Illumination Level for Various Types of Pavements	708
23.6 Characteristics of Light Fixture	708
23.6.1 Mounting Height of Fixtures	708
23.6.2 Classification of Fixtures	708
23.7 Aesthetic and Durability	712
23.7.1 Lamp	713
23.7.2 Ballast	713
23.7.3 Luminaire	713
23.7.4 Landscape Lighting	714
23.8 Intersections	719
23.8.1 Intersections	719
23.8.2 Roundabouts	723
23.9 Provision for Lighting for Pedestrians	724
23.10 Provision of Lighting at Bus Stops	726
23.10.1 Lighting Technique for Bus Stops	727
23.10.2 Luminaire Selection for Bus Stops Using Solar Lamps	727
23.10.3 Lighting Design for Bus Stops Using Solar System	728
23.11 Lighting of Highways Passing Through Urban Areas	729
23.11.1 Lighting Technique for Urban Areas	729
23.11.2 Luminaire Selection (Refer to Fig. 23.33)	733
23.11.3 Lighting Design	734
23.12 Toll Plaza Lighting	735

93	23.12.1 Lighting Technique for Toll Plaza	735
93	23.12.2 Luminaries Selection for Toll Plaza Lighting	736
94	23.12.3 Installation Strategy for Toll Plaza Lighting	738
94	23.12.4 Lighting Design for Toll Plaza Lighting	740
95	23.13 Road Tunnel and Underpasses Lighting	740
96	23.13.1 Distinction Between Long and Short Tunnels	741
96	23.13.2 Tunnel-Related Zones	742
96	23.13.3 Tunnel Lighting-Related Terms	744
96	23.13.4 Lighting of the Tunnel Walls and Ceiling	747
97	23.13.5 Uniformity of Luminance	747
98	23.13.6 Glare Restriction	747
98	23.13.7 Night-Time Lighting of Tunnels	748
98	23.14 Flyover and Bridges Lighting	748
99	23.14.1 Lighting Techniques for Flyovers	749
702	23.15 Cycle Track	752
703	23.15.1 Lighting Technique for Cycle Tracks	752
703	23.15.2 Luminaire Selection for Cycle Tracks	753
704	23.15.3 Lighting Design for Cycle Tracks	754
705	23.16 Lighting for Parking Areas	754
708	23.16.1 Lighting Technique for Parking Areas	755
708	23.16.2 Luminaire Selection for Parking Areas	755
708	23.16.3 Lighting Design for Parking Areas	756
708	23.17 Lighting for Subways	756
712	23.17.1 Lighting Technique for Subways	756
713	23.17.2 Luminaire Selection for Subways	756
713	23.17.3 Lighting Design for Subways	757
713	23.18 Energy Efficient Lighting	758
713	23.19 Types of Lamp Technologies	759
714	23.20 Intelligent Street Lighting Systems	762
719	23.20.1 Technical Specifications for Smart Street Lighting	764
719	23.21 Operation and Maintenance	764
723	23.21.1 Breakdown Maintenance	765
724	23.21.2 Preventive Maintenance	765
726	23.21.3 Special Maintenance for Solar Street Lights System	766
727	Summary	766
727	References	767
728	Questions	767
729	Chapter 24 Traffic Impact Studies	769
729	24.1 Introduction	769
733	24.2 Why is TIS Needed?	771
734	24.3 Classification of Transport Impact Assessment	771
735		

24.4	Problems in Dealing with TIS	772
24.5	Methodology	773
24.6	Site Analysis	774
24.7	Trip Generation	775
24.7.1	Trip Type	776
24.7.2	Bicycle and Pedestrian Analysis	776
24.7.3	Transit Analysis	777
24.7.4	Truck Trip Generation	778
24.7.5	Safety	779
24.8	Traffic Assignment and Study Area	779
24.9	Traffic Impact Analysis	780
24.10	Mitigation	781
24.11	An Example of TIS with Implementation of BRT	782
24.12	A Case Study: Qatar	782
24.12.1	Background	783
24.12.2	Study Objectives	784
24.12.3	Project Description	785
24.12.4	Design Parameters Considered for TIS	786
24.12.5	Evaluation of Road Network After Traffic Assignment	787
24.12.6	Mitigation Measures	789
24.13	Conclusion and Recommendation	790
	Summary	790
	Questions	791
	References	791
Chapter 25	Applications of Statistics in Traffic Engineering and Road Safety	793
25.1	Introduction	793
25.2	What are the Types of Analytics?	794
25.2.1	Descriptive Analytics	794
25.2.2	Diagnostic Analytics	795
25.2.3	Predictive Analytics	795
25.2.4	Prescriptive Analytics	795
25.3	Central Tendency	795
25.3.1	Mean	796
25.3.2	Median	796
25.3.3	Mode	797
25.3.4	Skewness and Kurtosis	798
25.4	Variability	799
25.4.1	Variance	799
25.4.2	Standard Deviation	799

772	25.5	Probability	799
773	25.5.1	Basic Probability Rules	800
774	25.5.2	All Probability Formulas	802
775	25.6	Probability Functions	802
776	25.6.1	Discrete Probability Functions	802
776	25.6.2	Continuous Probability Distributions	804
777	25.7	Relationship Between Variables	808
778	25.7.1	Correlation	808
778	25.7.2	Scatter Diagram	808
779	25.7.3	Covariance	809
779	25.8	Hypothesis Testing and Statistical Significance	809
780	25.8.1	Null and Alternative Hypothesis	809
781	25.8.2	Interpretation of P-Value	810
782	25.9	Regression	814
782	25.9.1	Linear Regression	815
783	25.9.2	Multiple Linear Regression	815
784	25.9.3	Steps for the Linear Regression	816
785		Summary	816
786		Questions	817
787		References	817
789			
790		<i>Annexures</i>	819
790		<i>Index</i>	835
791		<i>Credits</i>	853
793			
793			
794			
794			
794			
795			
795			
795			
795			
796			
796			
797			
798			
799			
799			

modern
engineer-
would
encing
pter-1
orately

s have
erical.
uently

pter 8
traffic
pacity
ssion.
esign

n the

being
e felt
m in

gnals
ware

pre-
d its
ging

ately
icial
nav-
the
the
ter-
it is
e of
res-
tely
ng-
ner

in the chapter 18. Further to this chapter, Five Pillars of road safety is demonstrated in the chapter 19. As subject of road safety requires engineering and non-engineering approaches by studying socio-economic fabric of the society, an attempt has been initiated in the chapter 20 to work with the use of "Artificial Intelligence on Road Safety."

Traffic and Noise cannot be separated against each other and continues to draw attention to the traffic engineer, the chapter 21 presents Traffic Noise dealing with the definition, concepts, standards etc. along with various case studies with traffic noise prediction models. Along with this, air polluted due effect of increased traffic that cannot be ignored causing not only harming human health but also responsible for deteriorating environment is also being addressed in the chapter 22. Traffic safety and efficiency during the night time is of paramount importance which has been dealt at great length in Chapter 23 on Street Lighting that includes from the fundamental concepts, to the types of lighting and design consideration for various types road network and intersections.

Currently, traffic engineers are increasingly confronted with the challenges to demonstrate the details of Traffic Impact Assessment during the time of transport proposal being finalized. The preparation of Traffic Impact Statement in the developed countries has been a mandatory. Therefore, the chapter 24 outlines the procedure to carry out TIS along with citing a project including the various parameters used for evaluation for the impact of traffic assessment.

Finally, the book is conclusive with the applications of statistics in Traffic Engineering and Road Safety where a great deal of statistics is often applied in order to make any traffic engineering more scientific and rational. The Chapter 25 discusses the applications of statistics supported with various techniques and methods in a summarized form.

Traffic Engineering and Road Safety Science are the evolving process always exploring the possibilities towards perfection and optimal way of enhancing the efficiency and safety of traffic operation towards exceling sustainable society . From the perspective of the safe and efficient transport network, this book has been designed to address most of the challenging problems of road transportation. Keeping this view, there are a number of chapters written to accomplish the tasks of meeting the challenges of road transport system. While addressing the various issues and problems of traffic and road safety. here's a lowdown of some professionals as mentioned below who lent their support and cooperation by contributing the five chapters.

- i. Dr. Arpita Saha, Assistant Professor, VNIT, Nagpur: Chapter on Traffic Signal and Delays at Intersection
- ii. Dr. Neelima Chakraborty, Principal Scientist, CRRI, New Delhi: Chapter on Traffic Psychology
- iii. Dr. Akhilesh Srivastav, Former GM, NHAI: Chapter on Use of Artificial Intelligence in Road Safety
- iv. Prof. Aqeel Ahmed, Director & Head, Civil Engineering Department, Integral University, Lucknow: Chapter on Traffic Noise
- v. Dr. S. Velumurgan, Chief Principal Scientist, CRRI, New Delhi: Chapter on Street Lighting

22.1 INTRODUCTION

Noise is defined as unwanted or excessive sound, which is an undesirable by-product of our modern way of life. It can be annoying, can interfere with sleep, work or recreation and in extremes, it may cause physical and psychological damage. While noise emanates from many different sources, transportation noise is perhaps the most pervasive and difficult source to avoid in society today.

Urbanization is increasing at a very fast rate in our country. Road length and its conditions are also improving which is encouraging traffic day by day. This has led to traffic congestion on roads and noise pollution. The transportation sector is one of the major contributors to noise in an urban area, accounting for as much as 55% of the total noise on arterials (*Bhattacharya C.C. (2002)*). Road traffic noise is the most irritating pollution which has a major concern on communities living in the vicinity of highway corridors. Several studies have shown that some of the most pervasive sources of noise in our environment today are those associated with transportation. Traffic noise tends to be a dominant noise source in our urban as well as rural environment.

In older days, vehicular growth was a blessing, but nowadays, it is destroying the environment. Its effect can be seen not only in India but also all over the world. Various countries have evolved norms for traffic noise; very few efforts have been made in this field in India.

22.1.1 Comparison of Noise Standards for Various Categories of Zones in India (MoEF Notification)

The noise standards adopted by the Government of India are in tune with the norms suggested by World Health Organization (WHO). Noise norms with respect to various categories of areas/zones as per *Ministry of Environment and Forest (MoEF) Notification (2000)* are presented in **Table 22.1**.