

PREFACE

1	I INTRODUCTION AND BACKGROUND			
	1.1	The Transportation System 1		
		1.1.1 Definition and Scope, 1		
		1.1.2 Fixed Facilities, 1		
		1.1.3 Flow Entities and Technology, 2		
		1.1.4 Control System, 2		
		1.1.5 Transportation Demand, 2		
		1.1.6 Quantification versus Valuation, 3		
	1.2	Transportation System Classification 4		
		1.2.1 Classification Schemes, 4		
1.2.2 Private and Public Transportation, 5		1.2.2 Private and Public Transportation, 5		
	1.3 The Role of Government 5			
		1.3.1 Governmental Participation, 5		
		1.3.2 Instruments of Governmental Involvement, 6		
		1.3.3 Arguments for and against Governmental Intervention, 6		
	1.4	Tools and Applications 8		
		I.4.1 Background, 8		
		1.4.2 Mathematical Models, 8		
		1.4.3 Components of Mathematical Models, 10		
		1.4.4 Transportation Models, 11		
	1.5	Summary 12		
	References 12			

v

VI			
a 1:	Desia	n and Operation	13
2		ADWAY DESIGN	13
~			
	2.1	Introduction 14	
	2.2	Equations of Motion 14	
		2.2.1 Rectilinear Motion, 14	
		2.2.2 Braking Distance, 19	
		2.2.3 Curvilinear Motion, 22	
		2.2.4 Relative Motion, 26	
	2.3	Human Factors 29	
		2.3.1 Perception-Reaction, 29	
		2,3.2 Dilemma Zones, 32	
		2.3.3 Visual Acuity, 39	
		2.3.4 Lateral Displacement, 41	
	2.4	Geometric Design of Highways 43	
		2.4.1 Background, 43	
		2.4.2 Functional Classification of Highways, 43	
		2.4.3 Cross-Section Design, 45	
		2.4.4 Horizontal Alignment, 46	
		2.4.5 Determination of Design Radius, 50	
		2.4.6 Superelevation Design, 51	
		2.4.7 Vertical Alignment, 54	
		2.4.8 Stopping and Passing Sight Distance, 58	
		2.4.9 Geometrics of Sight Distance, 60	
		2.4.10 Discussion of Alignment Design, 62	
		2.4.11 Delineation of Vehicular Paths, 65	
		2.4.12 Design Vehicles, 65	
		2.4.13 Channelization of At-Grade Intersections, 67	
		2.4.14 Modern Roundabouts, 75	
		2.4.15 Traffic-Calming Devices, 78	
	2.5	Pavement Structures 82	
		2.5.1 Background, 82	
		2.5.2 Pavement Materials and Types, 83	
		2.5.3 Pavement Structure, 85	
		2.5.4 Pavement Design, 88	
		2.5.5 Design Methods, 89	
		2.5.6 Life-Cycle Economic Analysis, 89	
		2.5.7 Pavement Management Systems, 90	
		2.5.8 High Performance Concrete, Superpave, and LTPP, 91	
	2.6	Summary 93	
		Exercises 94	

References 97

3	TRAI	FFIC STREAM FLOW MODELS	100
	3.1	Introduction 100	
	3.2	Vehicular Stream Models 100	
		3.2.1 Vehicular Following, 1003.2.2 Safety Considerations, 102	
	3.3	Stream Variables 104	
		 3.3.1 Spacing and Concentration, 104 3.3.2 Headway and Flow, 104 3.3.3 Average or Mean Speed, 104 3.3.4 Time-Distance Diagrams of Flow, 106 	
	3.4	Vehicular Stream Equations and Diagrams 109	
		 3.4.1 The Fundamental Equation of a Vehicular Stream, 109 3.4.2 The Case of Uniform Flow, 109 3.4.3 The Case of Highway Traffic Flow, 114 	
	3.5	Stream Measurements: The Moving-Observer Method 117	
		3.5.1 Background, 117 3.5.2 The Moving-Observer Method, 118	
	3.6	Shock Waves in Traffic 123	
		3.6.1 Background, 123 3.6.2 The Shock Wave Equation, 125	
	3.7	Summary 129	
		Exercises 129	
		References 131	
4	CAPA	ACITY AND LEVEL OF SERVICE ANALYSIS	133
	4.1	Introduction 133	
	4.2	Pedestrian and Bicycle Facilities 134	
		 4.2.1 Background, 134 4.2.2 Pedestrian-Flow Models, 134 4.2.3 Pedestrian Level of Service, 136 4.2.4 Bicycle Level of Service, 136 	
	4.3	Transit Systems: Uninterrupted Flow 138	
		 4.3.1 Background, 138 4.3.2 Uninterrupted Speed-Flow Relationships, 139 4.3.3 Fleet Size, 141 4.3.4 Transit Network Fleet Size, 142 	

viii Contents

4.4	Transit Systems: Interrupted Flow 144
	 4.4.1 Background, 144 4.4.2 Transit Stations, 145 4.4.3 Single-Platform Capacity, 145 4.4.4 Other Designs, 147
4.5	Highways: Uninterrupted Flow 147
	 4.5.1 Background, 147 4.5.2 Level of Service, 148 4.5.3 Freeway-Base Conditions, 150 4.5.4 Freeway Capacity and Level of Service, 152 4.5.5 Freeway Congestion Quantification, 155 4.5.6 Capacity Restrictions, 156
4.6	Highways: Interrupted Flow 157
	 4.6.1 Background, 157 4.6.2 Types of Signals, 157 4.6.3 Signal Detectors and Controllers, 158 4.6.4 Signal Timings, 167 4.6.5 Time-Distance Diagram of Interrupted Flow, 175 4.6.6 Pretimed Signal Coordination, 176 4.6.7 Actuated Signal Coordination, 179
4.7	Capacity of Signalized Intersections 179
	 4.7.1 Background, 179 4.7.2 Capacity and Performance Analysis, 180 4.7.3 Planning Analysis, 188 4.7.4 Case Studies, 189 4.7.4.1 Simple Signalized Intersection, 190 4.7.4.2 Complex Signalized Intersection, 193 4.7.4.3 Planning a Signalized Intersection, 197 4.7.5 Arterial Street LOS and Congestion
4.8	Quantification, 200 Traffic Data Collection Methods 203
4.9	Capacity Analysis of Unsignalized Intersections 207
	4.9.1 Background, 207 4.9.2 Two-Way Stop-Controlled Intersections, 208 4.9.3 All-Way Stop-Controlled Intersections, 212 4.9.4 Roundabouts, 216 4.9.5 Signalization Warrants, 218
4.10	Summary 219
	Exercises 220
	References 229

Part 2:	Trans	portation Systems	231
5	TRA	NSPORTATION MODES	232
	5.1	Introduction 232	
	5.2	Modes 233	
		 5.2.1 Motor Carriers, 235 5.2.2 Railroads, 237 5.2.3 Pipelines, 239 5.2.4 Water Transportation, 240 5.2.5 Air Carriers, 243 5.2.6 Express Package Carriers, 247 	
	5.3	Intercity Passenger Travel 249	
		5.3.1 Major Modes, 2495.3.2 Choice of Mode, 2505.3.3 Emerging Intercity Modes, 253	
	5.4	Summary and Comparisons among Modes and Countries 255	
		Exercises 257	
		References 261	
6	iibe	AN AND INTELLIGENT TRANSPORTATION SYSTEMS	263
	6.1	Introduction 263	203
	6.2	Development of Cities and Transportation Modes 263	
	6.3	Urban Transportation Modes 268	
		 6.3.1 Roadway Modes, 268 6.3.2 Fixed Guideway Modes, 269 6.3.3 Demand-Responsive, Dual Mode, and Other Modes, 271 	
	6.4	Urban Transportation Issues 272	
		6.4.1 General, 272 6.4.2 Traffic Congestion, 273 6.4.2.1 Supply Strategies, 277 6.4.2.2 Demand Strategies, 279	
	6.5	Intelligent Transportation Systems 281	
		6.5.1 User Services, 2836.5.2 Architecture Components and Standards, 2886.5.3 ITS in Europe and Japan, 292	

x Contents

		6.5.4 Mature ITS Applications, 295 6.5.4.1 Detectors, 295 6.5.4.2 Traffic Signal Systems, 298 6.5.4.3 Freeway Management, 301 6.5.4.4 Electronic Road Pricing and Automatic Vehicle Classification, 307 6.5.5 Safety and Liability, 310
	6.6	Summary 311
		Exercises 312
		References 314
7	TRAI	NSPORTATION PLANNING 318
	7.1	Introduction 318
	7.2	Historical Development in the United States 320
		 7.2.1 Colonial Era, 320 7.2.2 Turnpikes and Canals, 320 7.2.3 Railroads, 321 7.2.4 Rural Highways, 323 7.2.5 Urban and Regional Transportation Planning, 325
	7.3	Development of a Formal Planning Process 327
		 7.3.1 Housing Policies, 327 7.3.2 The 3C Process, 328 7.3.3 Social Concerns, 329 7.3.4 National Environmental Legislation, 330 7.3.5 Toward Planning Coordination, 331 7.3.6 Intermodal Surface Transportation Efficiency Act of 1991, 333 7.3.7 Transportation Equity Act for the Twenty-First Century, 334
	7.4	Planning Studies and Methods 335
		 7.4.1 Background, 335 7.4.2 Antecedents to Planning Studies, 335 7.4.3 Planning for Future Needs, 336 7.4.4 Large-Scale Urban Travel Surveys, 336 7.4.5 Travel-Demand Forecasts, 336
	7.5	Other Planning Issues 339
		 7.5.1 Background, 339 7.5.2 Transportation and Land Use, 339 7.5.3 Operational Land-Use Models, 341 7.5.4 Project, System, and Operational Planning, 343 7.5.5 Planning at the Statewide Level, 344
		,

	7.6	Summary 344	
		Exercises 345	
		References 346	
8	TRA	VEL-DEMAND FORECASTING	348
	8.1	Introduction 348	
	8.2	Trip Generation 350	
		 8.2.1 Background, 350 8.2.2 Trip Purpose, 351 8.2.3 Zone-based versus Household-Based Models, 351 8.2.4 Productions and Attractions, 353 8.2.5 Regression Models, 354 8.2.6 Trip-Rate Analysis, 355 8.2.7 Cross-Classification Models, 356 8.2.8 The FHWA-Simplified Trip-Production Procedure, 358 8.2.9 Summary, 361 	
	8.3	Trip Distribution 361 8.3.1 Background, 361 8.3.2 The Gravity Model, 362 8.3.3 Calibration of the Gravity Model, 369 8.3.4 Limitations of the Gravity Model, 376 8.3.5 The Fratar Model, 377 8.3.6 Limitations of the Fratar Model, 380 8.3.7 Summary, 381	
	8.4	Mode Choice 381 8.4.1 Background, 381 8.4.2 Utility and Disutility Functions, 382 8.4.3 The Multinomial Logit (MNL) Model, 385 8.4.4 The Incremental (or Pivot-Point) Logit Model, 388 8.4.5 Independence of Irrelevant Alternatives (IIA) Property, 389 8.4.6 The Nested Logit Model, 390 8.4.7 Estimation of Logit Models, 398 8.4.8 Summary, 399	
	8.5	Trip Assignment 400 8.5.1 Background, 400 8.5.2 Person-Trips and Vehicle-Trips, 401 8.5.3 Diurnal (Time-of-Day) Patterns of Demand, 401 8.5.4 Trip Direction, 402 8.5.5 Historical Context, 402 8.5.6 Highway Network Description, 404	

xii Contents

		8.5.7 Link Flows and Interzonal Flows, 408	
		8.5.8 Route Choice Behavior, 409	
		8.5.9 Minimum Path Algorithms, 409	
		8.5.10 A Minimum Tree-Seeking Procedure, 410	
		8.5.11 Free/All-or-Nothing Traffic Assignment, 414	
		8.5.12 Free/Multipath Traffic Assignment, 414	
		8.5.13 Capacity-Restrained Traffic Assignment, 416	
		8.5.14 Transit Assignment, 420	
		8.5.15 Summary, 421	
	8.6	Transport Behavior of Individuals and Households 422	
		8.6.1 Background, 422	
		8.6.2 Conceptual Models, 422	
		8.6.3 Demand Models with Behavioral Content, 425	
		8.6.4 Trip-, Journey-, and Tour-Based Models, 431	
	8.7	Other Demand-Forecasting Models 433	
		8.7.1 Background, 433	
		8.7.2 Demand-Model Consistency, 433	
		8.7.3 Simultaneous or Direct Demand Formulations, 433	
		8.7.4 Combined Modeling Strategies, 435	
		8.7.5 Models of Demand Elasticity, 436	
	8.8	Summary 441	
		Exercises 442	
		References 450	
Part 3:	Trans	portation Impacts	455
9	9 TRA	AFFIC IMPACT AND PARKING STUDIES	456
	9.1	Introduction 456	
	9.2	Traffic Impact Studies 456	
		9.2.1 Background, 456	
		9.2.2 Basic Characteristics, 457	
		9.2.3 Overview of Steps, 458	
		9.2.4 Major Components of Traffic Impact Studies, 459	
		9.2.5 Site and Network Improvement Alternatives, 468	
		9.2.6 Comprehensive Example, 469	
	9.3	Parking Studies 479	
		9.3.1 Background, 479	
		9.3.2 Types of Parking, 480	
		9.3.3 Types of Parking Studies, 481	
		9.3.4 Parking Measurements and Analysis, 486	
		9.3.5 Design, Operation, and Other Considerations, 489	

Contents xiii

	9.4	Summary 491	
		Exercises 492	
		References 497	
10	AIR (DUALITY, NOISE, AND ENERGY IMPACTS	498
	10.1	Introduction 498	
	10.2	Air Pollution 499	
		 10.2.1 Background, 499 10.2.2 Problem Dimensions, 500 10.2.3 Emission Levels, 501 10.2.4 Air Pollution Dispersion, 504 10.2.5 The Box Model, 504 	
	10.3	Noise Generation 506	
		 10.3.1 Background, 506 10.3.2 Noise Measurement, 507 10.3.3 Noise Propagation and Mitigation Strategies, 509 10.3.4 Noise Measures, 509 10.3.5 Mathematical Models of Transportation Noise, 512 	
	10.4	Energy Consumption 515	
		 10.4.1 Background, 515 10.4.2 National Response to the Energy Embargo, 516 10.4.3 Transportation-User Reactions, 516 10.4.4 Energy-Related Transportation Actions, 517 10.4.5 Vehicle-Propulsion Energy, 518 10.4.6 Indirect Energy Consumption, 523 	
	10.5	Summary 523	
		Exercises 524	
		References 527	
11	EVAL	UATION AND CHOICE	529
	11.1	Introduction 529	
	11.2	Feasibility and Impact Enumeration 530	
		 11.2.1 Measures of Feasibility, 530 11.2.2 Impact Trade-Offs, 531 11.2.3 Generalized Impact Matrices, 531 	
	11.3	Engineering Economic Analysis 532	
		11.3.1 Background, 532 11.3.2 Project Evaluation, 532	

xiv Contents

11.3.3 Independent and Mutually Exclusive Alternatives, 538
11.3.4 Evaluation of Mutually Exclusive Alternatives, 540
11.3.5 Identification and Valuation of Benefits and Costs, 541

11.3.6 Limitations of Economic Evaluation, 542

Effectiveness Analysis 543

11.4.1 Background, 543
11.4.2 Cost-Effectiveness, 543
11.4.3 Rank-Ordering Techniques, 545
11.4.4 Scoring Techniques, 550

11.4

		11.4.5 Group Consensus, 553	
	11.5	Summary 553	
		Exercises 554	
		References 555	
art 4: S	upport	ing Elements	557
12	ELEM	IENTS OF ENGINEERING ECONOMY	558
	12.1	Money and Its Time Value 558	
	12.2	Interest and Discount 559	
	12.3	Simple and Compound Interest 560	
	12.4	Nominal and Effective Interest Rates 562	
	12.5	Discrete and Continuous Compounding 562	
	12.6	Cash Flows 563	
	12.7	Equal Series of Payments 565	
	12.8	Superposition of Cash Flows 567	
		Exercises 569	
13	PROE	BABILITY AND STATISTICS	571
	13.1	Introduction 571	
	13.2	Elements of Probability Theory 572	
		 13.2.1 Background, 572 13.2.2 Definition of Probability, 572 13.2.3 Conditional Probability and Independence, 574 13.2.4 Discrete Distributions, 575 13.2.5 Some Common Discrete Distributions, 578 	

		13.2.6 Continuous Random Variables, 58313.2.7 Some Common Continuous Distributions, 584
	13.3	Experimental Data and Model Parameters 588
	13.4	Linear and Nonlinear Regression 589
		13.4.1 Simple Linear Regression, 589 13.4.2 Correlation, 594 13.4.3 Multiple Linear Regression, 596 13.4.4 Direct Nonlinear Regression, 596 13.4.5 Linear Regression with Transformed Variables, 598 13.4.6 Selection of Explanatory Variables, 599
	13.5	Hypothesis Testing and Model Evaluation 601
		13.5.1 Single-Parameter Test, 602 13.5.2 Test of a Linear Model, 603 13.5.3 Test of Equality of Segmented Linear Models, 604 13.5.4 Comprehensive Judgement of a Linear Model, 605
	13.6	Summary 607
		Exercises 607
		References 610
14	QUEU	ING AND SIMULATION 611
	14.1	Introduction 611
	14.2	Queuing Models 612
		 14.2.1 Background, 612 14.2.2 Single-Server FIFO Systems, 613 14.2.3 Multiserver FIFO Systems, 614
	14.3	Computer Simulation 616
		 14.3.1 Background, 616 14.3.2 Monte Carlo Simulation, 616 14.3.3 Simulation of the Outcomes of a Continuous Random Variable, 619 14.3.4 Generation of Random Numbers, 620 14.3.5 The Simulation Model, 621
	14.4	Summary 624
		Exercises 624
		References 625

xvi	Contents
741	COMONE

15	TRAN	SPORTATION SOFTWARE	626
	15.1	Introduction 626	
	15.2	Geographic Information Systems (GIS) 627	
		15.2.1 GIS Fundamentals, 627 15.2.2 GIS Products, 630 15.2.3 GIS and GPS, 631	
	15.3	Traffic Simulation Software 632	
		 15.3.1 Traffic Simulation Model Characteristics, 632 15.3.2 Classification, 632 15.3.3 Traffic Simulation Models, 634 15.3.3.1 Urban Street Networks, 634 15.3.3.2 Freeways and Freeway Corridors, 640 15.3.3.3 Mixed Networks, 642 15.3.4 Model Selection, Output Variability, and Other Limitations, 644 	
	15.4	Capacity Software: HCS, SIDRA, and Others 646	
	15.5	Planning Software: EMME/2, QRS II, TRANPLAN, MINUTP, TP+, TRANSCAD, TRANSIMS 646	
		References 560	
API	PENDIX	(A 1982 GUIDELINES FOR THE PREPARATION OF ENVIRONMENTAL DOCUMENTS	653
IND	EX		679