

## **1 The Transportation Planning Process 1**

1.1 Why Are Highways So Important? 1

1.2 The Administration of Highway Schemes 1

1.3 Sources of Funding 2

1.4 Highway Planning 3

1.4.1 Introduction 3

1.4.2 Travel Data 4

1.4.3 Highway Planning Strategies 6

1.4.3.1 Land-Use Transportation Approach 6

1.4.3.2 The Demand Management Approach 6

1.4.3.3 The Car-Centred Approach 7

1.4.3.4 The Public Transport-Centred Approach 7

1.4.4 Transportation Studies 7

1.4.4.1 Transportation Survey 7

1.4.4.2 Production and Use of Mathematical Models 8

1.5 The Decision-Making Process in Highway and Transport Planning 8

1.5.1 Introduction 8

1.5.2 Economic Assessment 10

1.5.3 Environmental Assessment 11

1.5.4 Public Consultation 12

1.6 Summary 13

References 13

## **2 Forecasting Future Traffic Flows 15**

2.1 Basic Principles of Traffic Demand Analysis 15

2.2 Demand Modelling	16
2.3 Land-Use Models	18
2.4 Trip Generation	18
2.4.1 TRICS ® Database	23
2.5 Trip Distribution	24
2.5.1 Introduction	24
2.5.2 The Gravity Model	25
2.5.3 Growth Factor Models	30
2.5.4 The Furness Method	31
2.6 Modal Split	36
2.7 Traffic Assignment	41
2.8 A Full Example of the Four-Stage Transportation Modelling Process	46
2.8.1 Trip Production	46
2.8.2 Trip Distribution	47
2.8.3 Modal Split	50
2.8.4 Trip Assignment	52
2.9 'Decide and Provide' Versus 'Predict and Provide'	53
2.10 Concluding Comments	54
Additional Problems	54
References	57
<b>3 Scheme Appraisal for Highway Projects</b>	<b>59</b>
3.1 Introduction	59
3.2 Economic Appraisal of Highway Schemes	60
3.3 Cba	61

3.3.1	Introduction	61
3.3.2	Identifying the Main Project Options	61
3.3.3	Identifying all Relevant Costs and Benefits	62
3.3.3.1	Reductions in VOCs	63
3.3.3.2	Savings in Time	63
3.3.3.3	Reduction in the Frequency of Accidents	64
3.3.4	Economic Life, Residual Value, and the Discount Rate	64
3.3.5	Use of Economic Indicators to Assess Basic Economic Viability	65
3.3.6	Highway CBA Worked Example	67
3.3.6.1	Introduction	67
3.3.6.2	Computation of Discounted Benefits and Costs	68
3.3.6.3	Npv	70
3.3.6.4	Benefit-Cost Ratio	70
3.3.6.5	Irr	70
3.3.6.6	Summary	70
3.3.7	Coba	70
3.3.8	Advantages and Disadvantages of CBA	71
3.4	Payback Analysis	73
3.5	Environmental Appraisal of Highway Schemes	75
3.6	The New Approach to Appraisal	80
3.6.1	Environment	81
3.6.1.1	Noise	81
3.6.1.2	Local Air Quality	81
3.6.1.3	Landscape	82

3.6.1.4 Biodiversity	82
3.6.1.5 Heritage	82
3.6.1.6 Water	82
3.6.1.7 Safety	83
3.6.1.8 Economy	83
3.6.1.9 Journey Times and VOCs	83
3.6.1.10 Costs	83
3.6.1.11 Reliability	83
3.6.1.12 Regeneration	83
3.6.1.13 Accessibility	84
3.6.1.14 Pedestrians, Cyclists, and Equestrians	84
3.6.1.15 Access to Public Transport	85
3.6.1.16 Community Severance	85
3.6.1.17 Integration	85
3.7 NATA Refresh	86
3.7.1 Changes to the AST	86
3.7.2 Enhanced Presentation of Monetary Impacts	87
3.7.3 More Detailed Relationship Between Benefit-Cost Ratio and Value for Money	87
3.8 Transport Analysis Guidance: The Transport Appraisal Process	87
3.9 Project Management Guidelines	89
3.10 Common Appraisal Framework for Transport Projects and Programmes	90
3.11 Summary	91
References	91
<b>4 Basic Elements of Highway Traffic Analysis</b>	<b>93</b>

4.1	Introduction	93
4.2	Surveying Road Traffic	93
4.2.1	Introduction	93
4.2.2	Vehicle Surveys	94
4.2.2.1	Introduction	94
4.2.2.2	Manual Counts	94
4.2.2.3	Automatic Counts	94
4.2.3	Speed Surveys	95
4.2.4	Delay/Queuing Surveys	96
4.2.5	Area-Wide Surveys	96
4.2.5.1	Introduction	96
4.2.5.2	Roadside Interview Surveys	97
4.2.5.3	Self-Completion Forms	97
4.2.5.4	Registration Plate Surveys	97
4.3	Journey Speed and Travel Time Surveys	98
4.3.1	Introduction	98
4.3.2	The Moving Observer Method	98
4.4	Speed, Flow, and Density of a Stream of Traffic	103
4.4.1	Speed–Density Relationship	103
4.4.2	Flow–Density Relationship	104
4.4.3	Speed–Flow Relationship	105
4.5	Headway Distributions in Highway Traffic Flow	109
4.5.1	Introduction	109
4.5.2	Negative Exponential Headway Distribution	110

4.5.3 Limitations of the Poisson System for Modelling Headway 114

4.6 Queuing Analysis 114

4.6.1 Introduction 114

4.6.2 The D/D/1 Queuing Model 114

4.6.3 The M/D/1 Queuing Model 118

4.6.4 The M/M/1 Queuing Model 119

4.6.5 The M/M/N Queuing Model 120

Additional Problems 123

References 128

## **5 Determining the Capacity of a Highway 129**

5.1 Introduction 129

5.2 The 'Level of Service' Approach Using the Transportation Research Board 129

5.2.1 Introduction 129

5.2.2 Some Definitions 131

5.2.3 Maximum Service Flow Rates for Multilane Highways 131

5.2.4 Maximum Service Flow Rates for Two-Lane Highways 137

5.2.5 Sizing a Road Using the Highway Capacity Manual Approach 140

5.3 The 2010 Highway Capacity Manual – Analysis of Capacity and Level of Service for Multi-Lane and Two-Lane Highways 143

5.3.1 Introduction 143

5.3.2 Capacity and Level of Service of Multilane Highways (2010 Highway Capacity Manual) 143

5.3.2.1 Flow Characteristics Under Base Conditions 143

5.3.2.2 Capacity of Multilane Highway Segments 144

5.3.2.3 Level of Service (LOS) for Multilane Highway Segments 144

5.3.2.4 Required Data for the LOS Computation 144

5.3.2.5	Computing LOS for a Multilane Highway	145
5.3.3	Capacity and Level of Service of Two-Lane Highways	150
5.3.3.1	Flow Characteristics Under Base Conditions	150
5.3.3.2	Capacity and Level of Service	150
5.3.3.3	Required Input Data and Default Values	151
5.3.3.4	Demand Volumes and Flow Rates	152
5.3.3.5	Computing LOS and Capacity for a Two-Lane Highway	152
5.3.3.6	Determining Level of Service for Class 1 Two-Lane Highways	154
5.3.3.7	Determining the Level of Service for Class 2 Two-Lane Highways	161
5.3.3.8	Determining the Level of service for Class 3 Two-Lane Highways	166
5.4	The 2016 Highway Capacity Manual – Analysis of Capacity and Level of Service for Multi-Lane Highways	167
5.4.1	Introduction	167
5.4.2	Capacity and Level of Service of Multilane Highways (2016 Highway Capacity Manual)	167
5.4.2.1	Speed Versus Flow	167
5.4.2.2	Baseline Conditions and Capacity	167
5.4.2.3	Determining Free-Flow Speed	168
5.4.2.4	Determination of Incident Flow Rate	168
5.4.2.5	Calculation of Density and Determination of Level of Service	168
5.5	The UK Approach for Rural Roads	170
5.5.1	Introduction	170
5.5.2	Estimation of AADT for a Rural Road in Its Year of Opening	171
5.6	The UK Approach to Urban Roads	173
5.6.1	Introduction	173
5.6.2	Forecast Flows on Urban Roads	174

5.7 Expansion of 12- and 16-Hour Traffic Counts into AADT Flows 177

5.8 Concluding Comments 178

Additional Problems 179

References 181

## **6 The Design of Highway Intersections 183**

6.1 Introduction 183

6.2 Deriving DRFs from Baseline Traffic Figures 184

6.2.1 Existing Junctions 184

6.2.2 New Junctions 184

6.2.3 Short-Term Variations in Flow 184

6.2.4 Conversion of AADT to Highest Hourly Flows 185

6.3 Major/Minor Priority Intersections 185

6.3.1 Introduction 185

6.3.2 Equations for Determining Capacities and Delays 189

6.3.3 Geometric Layout Details 196

6.3.3.1 Horizontal Alignment 196

6.3.3.2 Vertical Alignment 196

6.3.3.3 Visibility 196

6.3.3.4 Dedicated Lane on the Major Road for Right-Turning Vehicles 196

6.4 Roundabout Intersections 197

6.4.1 Introduction 197

6.4.2 Types of a Roundabout 199

6.4.2.1 Mini-Roundabout 199

6.4.2.2 Normal Roundabout 200

6.4.2.3	Double Roundabout	200
6.4.2.4	Other Forms	201
6.4.3	Traffic Capacity at Roundabouts	203
6.4.3.1	Drf	205
6.4.4	Geometric Details	209
6.4.4.1	Entry Width	209
6.4.4.2	Entry Angle	209
6.4.4.3	Entry Radius	209
6.4.4.4	Entry Deflection/Entry Path Radius	210
6.4.4.5	Icd	210
6.4.4.6	Circulatory Carriageway	210
6.4.4.7	Main Central Island	210
6.5	Basics of Traffic Signal Control: Optimisation and Delays	210
6.5.1	Introduction	210
6.5.2	Phasing at a Signalised Intersection	212
6.5.3	Saturation Flow	212
6.5.4	Effective Green Time	217
6.5.5	Optimum Cycle Time	217
6.5.6	Average Vehicle Delays at the Approach to a Signalised Intersection	220
6.5.7	Average Queue Lengths at the Approach to a Signalised Intersection	222
6.5.8	Signal Linkage	223
6.6	Concluding Remarks	228
	Additional Problems	228
	References	230

## **7 Geometric Alignment and Design 233**

### 7.1 Basic Physical Elements of a Highway 233

#### 7.1.1 Main Carriageway 233

#### 7.1.2 Central Reservation 233

#### 7.1.3 Hard Shoulders/Hard Strips/Verges 234

### 7.2 Design Speed and Stopping and Overtaking Sight Distances 237

#### 7.2.1 Introduction 237

#### 7.2.2 Urban Roads 238

#### 7.2.3 Rural Roads 239

##### 7.2.3.1 Statutory Constraint 239

##### 7.2.3.2 Layout Constraint 239

##### 7.2.3.3 Alignment Constraint 240

##### 7.2.3.4 New/Upgraded Rural Roads 242

### 7.3 Geometric Parameters Dependent on Design Speed 244

### 7.4 Sight Distances 244

#### 7.4.1 Introduction 244

#### 7.4.2 Stopping Sight Distance 245

#### 7.4.3 Overtaking Sight Distance 246

### 7.5 Horizontal Alignment 248

#### 7.5.1 General 248

#### 7.5.2 Deriving the Minimum Radius Equation 248

#### 7.5.3 Horizontal Curves and Sight Distances 251

##### 7.5.3.1 Alternative Method for Computing Ms 253

#### 7.5.4 Transitions 254

7.5.4.1 Shift 255

7.6 Vertical Alignment 258

7.6.1 General 258

7.6.2 K Values 259

7.6.3 Visibility and Comfort Criteria 260

7.6.4 Parabolic Formula 260

7.6.5 Crossfalls 263

7.6.6 Vertical Crest Curve Design and Sight Distance Requirements 264

7.6.6.1 Derivation of Crest Curve Formulae 265

7.6.7 Vertical Sag Curve Design and Sight Distance Requirements 269

7.6.7.1 Driver Comfort 269

7.6.7.2 Clearance from Structures 269

7.6.7.3 Sag Curves in Night-Time Conditions 270

Additional Problems 271

References 274

## **8 Highway Pavement Materials 275**

8.1 Introduction 275

8.2 Pavement Components: Terminology 275

8.3 Soils at Subformation Level 279

8.4 Materials in Foundations 279

8.5 Materials in Flexible Pavements 280

8.5.1 Bitumen 280

8.5.2 Asphalt Concrete (Coated Macadams) 281

8.5.3 Hot Rolled Asphalt 282

8.5.4	Aggregates	282
8.5.5	Designation of Asphalt Materials Used in Flexible Pavements	282
8.6	Concrete in Rigid Pavements	284
8.7	Surfacing Materials	285
8.7.1	Surface Dressing and Modified Binders	285
8.7.1.1	Cutback Bitumen	285
8.7.1.2	Bituminous Emulsions	285
8.7.1.3	Chippings	286
8.8	Stiffness Modulus	286
8.9	Measurement and Testing of Material and Pavement Properties	289
8.9.1	CBR Test	289
8.9.2	Determination of CBR Using Plasticity Index	292
8.9.2.1	Liquid Limit	292
8.9.2.2	Plastic Limit	292
8.9.2.3	Plasticity Index	292
8.9.2.4	Using I P and Soil Type to Derive CBR	292
8.9.3	Using CBR to Estimate Stiffness Modulus	293
8.9.4	Falling Weight Deflectometer (FWD)	293
8.9.5	Light Weight Deflectometer (LWD)	297
8.9.6	Dynamic Cone Penetrometer (DCP)	298
8.9.7	Penetration Test for Bitumen	298
8.9.8	Softening Point of Bitumen	299
8.9.9	Polished Stone Value (PSV)	300
8.9.10	Aggregate Abrasion Value (AAV)	300

8.9.11 Patch Test 300

Additional Problems 301

References 302

Design Manual for Roads and Bridges 302

Standards 302

Other Government Publications 303

Other References 303

## **9 Design and Construction of Highway Pavements 305**

9.1 Introduction and Design Approach 305

9.2 Sustainability and Good Road Design 306

9.3 Whole-Life Cost Analysis 307

9.4 Traffic Loading 307

9.4.1.1 Commercial Vehicle Flow (F) 309

9.4.1.2 Growth Factor (G) 309

9.4.1.3 Wear Factor (W) 310

9.4.1.4 Design Period (Y) 310

9.4.1.5 Percentage of Vehicles in the Heaviest Loaded Lane (P) 311

9.5 Foundation Design 314

9.5.1 Introduction 314

9.5.2 Restricted Foundation Design Method 316

9.5.3 Performance Design Method 319

9.5.3.1 Design Charts for Foundation Layer Thickness: Performance Design 321

9.5.3.2 Testing Foundation Surface Modulus on Demonstration Area and During Construction 322

9.5.4 Drainage and Frost 323

9.6 Pavement Design 324

9.6.1 Design of Flexible Pavements 325

9.6.2 Design of Rigid Pavements 328

9.6.2.1 Continuously Reinforced Concrete 328

9.6.2.2 Roller Compacted Concrete 331

9.6.2.3 Jointed Concrete Pavements 332

9.7 Construction of Flexible Pavements 334

9.7.1 Construction of Bituminous Road Surfacing 334

9.7.1.1 Transporting and Placing 335

9.7.1.2 Compaction of the Bituminous mix 336

9.7.1.3 Application of Coated Chippings to Smooth Surfacing 336

9.8 Construction of Rigid Pavements 336

9.8.1 Concrete Slab and Joint Details 336

9.8.1.1 Joints in Concrete Pavements 337

9.8.2 Reinforcement 339

Additional Problems 339

References 340

Design Manual for Roads and Bridges 340

Standards 341

Other Government Publications 341

Other References 342

## **10 Pavement Maintenance 343**

10.1 Introduction 343

10.2 Pavement Deterioration 343

10.3 Compiling Information on the Pavement's Condition 345

10.3.1 Introduction 345

10.3.2 Traffic-Speed Surveys of Surface and Structural Condition 346

10.3.3 Traffic-Speed Surveys of Skidding Resistance 348

10.3.3.1 Skidding Resistance 348

10.3.3.2 Measurement of Skidding Resistance 349

10.3.4 Visual Condition Surveys 350

10.3.5 Cores 351

10.3.6 Dynamic Cone Penetrometer 351

10.3.7 Deflectograph 351

10.3.8 Ground-Penetrating Radar (GPR) 353

10.3.9 Falling Weight Deflectometer (FWD) 354

10.3.10 Other Investigation Techniques 354

10.4 Forms of Maintenance 354

10.4.1 Flexible Pavements 355

10.4.2 Rigid Pavements 357

References 359

**11 The Highway Engineer and the Development Process 361**

11.1 Introduction 361

11.2 Transport Assessments 362

11.2.1 Introduction 362

11.2.2 Identifying the Need for an Assessment 362

11.2.3 Preparing a TA 363

11.2.3.1 Description of On-Site Existing Baseline Conditions 364

11.2.3.2	Definition of the Proposed Development	365
11.2.3.3	Setting the Assessment Years for Which Capacity Analyses Are Carried Out	365
11.2.3.4	Setting the Analysis Periods for Which Capacity Analyses Are Carried Out	365
11.2.3.5	Estimation of Trips Generated by the Proposal	366
11.2.4	Final Comment	367
11.3	Travel Plans	367
11.3.1	Introduction	367
11.3.2	Thresholds	367
11.3.3	When Is a Travel Plan Required?	368
11.3.4	What Information Should Be Included Within a Travel Plan?	369
11.3.4.1	Appointment of a Travel Plan Coordinator	369
11.3.4.2	Initial Monitoring Process	369
11.3.4.3	Setting Targets for Modal Split	370
11.3.4.4	Monitoring How Things Have Changed	370
11.3.5	Mobility Management Plans in Ireland	371
11.4	Road Safety Audits	372
11.4.1	Principles Underlying the Road Safety Audit Process	372
11.4.2	Definition of Road Safety Audit	373
11.4.3	Stages Within Road Safety Audits	374
11.4.4	Road Safety Audit Response Report	375
11.4.5	Checklists for Use Within the RSA Process	376
11.4.6	Risk Analysis	378
11.4.7	Conclusions	381
	References	381

## **12 Defining Sustainability in Transportation Engineering 383**

12.1 Introduction 383

12.2 Social Sustainability 383

12.3 Environmental Sustainability 383

12.4 Economic Sustainability 384

12.5 The Four Pillars of Sustainable Transport Planning 384

12.5.1 Put Appropriate Governance in Place 385

12.5.2 Provide Efficient Long-Term Finance 385

12.5.3 Make Strategic Investments in Major Infrastructure 385

12.5.4 Support Investments Through Local Design 386

12.5.5 Concluding Comments 386

12.6 How Will Urban Areas Adapt to the Need for Increased Sustainability? 386

12.7 The Role of the Street in Sustainable Transport Planning 387

12.7.1 Street Classification System 387

12.7.2 Designing an Individual Street 387

12.7.2.1 Introduction 387

12.7.2.2 A Rational Approach to Speed in Urban Areas 389

12.7.3 The Pedestrian Environment 390

12.7.3.1 General Design Principles of Footpaths 390

12.7.4 Design for Cycling 392

12.7.4.1 Cycling Design Criteria 392

12.7.4.2 Design Guidelines 393

12.7.5 Carriageway Widths on Urban Roads and Streets 396

12.7.6 Surfaces 396

12.7.7 Junction Design in an Urban Setting	398
12.7.8 Forward Visibility/Visibility Splays	399
12.8 Public Transport	400
12.8.1 Bus and Rail Services in Cities	400
12.8.2 Design of Street Network to Accommodate Bus Services	401
12.9 Using Performance Indicators to Ensure a More Balanced Transport Policy	402
12.9.1 The Traditional Approach	402
12.9.2 Using LOS to Measure the Quality of Pedestrian Facilities	402
12.9.2.1 Introduction	402
12.9.2.2 Formulae for Estimation of Link-Based Pedestrian LOS	404
12.9.2.3 Free-Flow Walking Speed	405
12.9.2.4 Average Pedestrian Space	405
12.9.2.5 Pedestrian LOS Score ( $I_p$ , link)	405
12.9.2.6 Determining Link-Based Pedestrian LOS	406
12.9.3 Using LOS to Measure the Quality of Cycling Facilities	408
12.9.3.1 Formulae for Estimation of Link-Based Bicycle LOS	408
12.9.3.2 Determining Link-Based Bicycle LOS	410
12.9.4 Measuring the Quality of Public Transport Using LOS	412
12.9.4.1 Acceleration-Deceleration Delay	414
12.9.4.2 Delay Due to Serving Passengers	414
12.9.4.3 Re-entry Delay ( $d_{re}$ )	414
12.10 A Sustainable Parking Policy	419
12.10.1 Introduction	419
12.10.2 Seminal Work of Donald Shoup in the United States	419

12.10.3 The Pioneering ABC Location Policy in the Netherlands 420

12.10.4 Possible Future Sustainable Parking Strategies 421

References 422

Index 423