

# Contents

<b>1 An Overview of the <i>Highway Capacity Manual</i> and Its History .....</b>	<b>1</b>
1.1 The Emerging Need for National Standards .....	1
1.1.1 Early Toll Roads [1-3].....	1
1.1.2 The National Road [4-6] .....	3
1.1.3 The Good Roads Movement [8, 9].....	3
1.1.4 The National Trails Movement .....	4
1.2 Developing a National Program for Highways .....	4
1.3 The Automobile Emerges and the Need for a National Highway System.....	5
1.4 The Formation of the Highway Capacity and Quality of Service Committee .....	6
1.5 The First Edition: The 1950 Highway Capacity Manual .....	9
1.6 The Second Edition: The 1965 Highway Capacity Manual .....	10
1.7 The Third Edition: The 1985 Highway Capacity Manual .....	13
1.8 Updates to the 1985 Highway Capacity Manual .....	17
1.9 The Fourth Edition: The 2000 Highway Capacity Manual .....	19
1.10 The Fifth Edition: The 2010 Highway Capacity Manual .....	20
1.10.1 Organization of the 2010 HCM.....	21
1.10.2 Into the Future .....	23
References .....	25
<b>2 The Fundamental Concept of Capacity .....</b>	<b>27</b>
2.1 The Early Years.....	29
2.2 The 1950 Highway Capacity Manual.....	30
2.3 The 1965 Highway Capacity Manual.....	33
2.4 The 1985 Highway Capacity Manual.....	36
2.5 The Interim Updates: 1994 and 1997 .....	38
2.6 The 2000 Highway Capacity Manual.....	40
2.7 The 2010 Highway Capacity Manual .....	41
2.7.1 The “Capacity Drop” and Related Issues .....	41
2.7.2 A Task Force Is Formed.....	42
2.7.3 The 2010 Definition of Capacity.....	43

2.8	What's in the Future? .....	43
2.8.1	The Capacity of What?.....	44
2.8.2	What Time Interval?.....	44
2.8.3	The "Capacity Drop" Issue.....	45
2.8.4	Oh, Those Random Variables .....	45
	References .....	46
<b>3</b>	<b>The Fundamental Concept of Level of Service .....</b>	<b>49</b>
3.1	In the Beginning: The 1950 <i>Highway Capacity Manual</i> .....	50
3.2	Level of Service Concept Introduced: The 1965 <i>Highway Capacity Manual</i> .....	50
3.3	Some Key Changes in the Level of Service Concept: The 1985 <i>Highway Capacity Manual</i> .....	58
3.4	A Brave New World Is Entered: The 2000 <i>Highway Capacity Manual</i> .....	61
3.5	The Introduction of User Perceptions: The 2010 <i>Highway Capacity Manual</i> .....	63
3.6	A New Challenge: Incorporating Reliability and Other Factors .....	68
3.7	Level of Service – Some Structural and Theoretical Issues .....	69
3.7.1	Who Are We Talking To? .....	69
3.7.2	The Issue of Aggregation .....	71
3.7.3	What Information Does LOS Represent?.....	71
3.7.4	The Step-Function Nature of Level of Service.....	72
3.7.5	Level of Service F and Failure .....	72
3.7.6	The Problem of Relativity .....	73
3.8	Uncertainty in Level of Service Predictions.....	73
3.9	What Is the Future of Level of Service? .....	74
	References .....	75
<b>4</b>	<b>Passenger Car Equivalents and Other Adjustment Factors.....</b>	<b>77</b>
4.1	What Are We Adjusting? .....	77
4.2	Defining Equivalence .....	78
4.3	Non-standard Elements Considered in Capacity Methodologies ....	81
4.4	Representing the General Geometric Environment of a Facility....	82
4.5	Adjusting for Lane Width and Lateral Clearance.....	83
4.5.1	The 1950 HCM .....	83
4.5.2	The 1965 HCM .....	84
4.5.3	The 1985 HCM .....	86
4.5.4	The 1994 Update .....	87
4.5.5	The 1997 Update .....	89
4.5.6	The 2000 HCM .....	90
4.5.7	The 2010 HCM .....	91

4.5.8	Summary and Comments .....	91
4.6	Passenger Car Equivalents: The Impacts of Heavy Vehicles on Traffic Operations .....	92
4.6.1	The 1950 HCM .....	93
4.6.2	The 1965 HCM .....	94
4.6.2.1	Two-Lane Highways: The Walker Method.....	94
4.6.2.2	Multilane Highways (and Freeways) .....	99
4.6.3	The 1985 HCM .....	102
4.6.3.1	Two-Lane Rural Highways .....	102
4.6.3.2	Multilane Highways and Freeways .....	105
4.6.4	The 2000 Highway Capacity Manual.....	109
4.6.4.1	Two-Lane, Two-Way Highways.....	109
4.6.4.2	Multilane Highways and Freeways .....	110
4.6.5	The 2010 Highway Capacity Manual.....	112
4.7	Adjustment Factors for Signalized Intersections.....	112
4.8	Adjustments: Theory vs. Practice.....	113
	References .....	116
<b>5</b>	<b>Overview of Uninterrupted Flow Methodologies of the <i>Highway Capacity Manual</i> .....</b>	<b>119</b>
5.1	Freeway Facilities and Components.....	120
5.2	Basic Freeway Segments.....	121
5.3	Freeway Weaving Segments .....	122
5.4	Freeway Merge and Diverge Segments.....	122
5.5	Freeways as Facilities .....	123
5.5.1	The Time-Space Domain for Freeway Facility Analysis .....	124
5.5.2	Levels of Service for Freeway Facilities .....	126
5.5.3	Capacity Adjustments .....	127
5.5.3.1	Adjustment for Short-Term Work Zones .....	127
5.5.3.2	Adjustments Due to Long-Term Construction Zones .....	127
5.5.3.3	Adjustments Due to Inclement Weather .....	127
5.5.3.4	Adjustments Due to Incidents .....	128
5.5.4	Analysis of Oversaturated Conditions .....	129
5.6	Multilane Highways .....	129
5.7	Two-Lane Highways .....	130
	References .....	131
<b>6</b>	<b>Speed-Flow-Density Relationships: The Fundamental Basis of Uninterrupted Flow Analysis .....</b>	<b>133</b>
6.1	Ideal or Base Conditions .....	133
6.2	The Appetite for Data and the Need for Professional Judgment .....	134
6.3	The Early Days: Bruce D. Greenshields and Others .....	134

6.4	Greenshield's Breakthrough Study of 1934 .....	141
6.5	The 1950 Highway Capacity Manual.....	145
6.6	Exciting Times: The Late 1950's and Early 1960's .....	147
6.6.1	Harold Greenberg's Logarithmic Speed-Density Curves .....	147
6.6.2	Robin Underwood's Exponential Speed-Density Curves .....	149
6.6.3	Leslie Edie's Discontinuous Curves.....	152
6.6.4	The Lost Study of Raymond Ellis .....	153
6.6.5	Drake, Shofer, and May, Jr.: Comparing the Alternatives .....	154
6.7	The 1965 Highway Capacity Manual.....	158
6.8	The 1985 Highway Capacity Manual.....	162
6.9	The Updates .....	166
6.9.1	1994: A New Multilane Highway Procedure .....	166
6.9.2	1994: Updating Freeway Procedures.....	168
6.9.3	1997: A New Methodology for Freeway Analysis.....	172
6.10	The 2000 <i>Highway Capacity Manual</i> .....	173
6.11	Developing Speed-Flow Curves for the 2010 HCM .....	173
6.11.1	The Original Effort and Recommendations.....	174
6.11.1.1	The Issue of Capacity .....	177
6.11.1.2	Shaping the Speed-Flow Curves .....	177
6.11.2	Controversies Concerning the Recommended Curves .....	179
6.11.2.1	Freeways vs. Multilane Highways .....	179
6.11.2.2	The Form and Substance of the Speed-Flow Curves .....	182
6.11.3	Back to the Drawing Board.....	184
6.11.3.1	Three-Segment Linear Curves .....	185
6.11.3.2	Werner Brilon's Continuous Equation .....	185
6.11.3.3	Equations in the General Form of the 2000 HCM .....	186
6.11.3.4	The Classic Parabola .....	186
6.11.3.5	The Anchoring Process .....	187
6.11.3.6	Determining the Value of BP1 .....	189
6.11.3.7	The Regression Analysis and Final Curves.....	192
6.11.3.8	Revised Recommended Curves.....	197
6.12	Comparisons, Conclusions, and Recommendations for Future Researchers .....	198
	References .....	201
<b>7</b>	<b>Basic Freeway and Multilane Highway Segments.....</b>	<b>205</b>
7.1	A General Model Format .....	205
7.2	The 1950 Highway Capacity Manual.....	206

<b>Contents</b>	<b>XIII</b>
7.3 The 1965 Highway Capacity Manual.....	209
7.4 The 1985 Highway Capacity Manual.....	213
7.4.1 Setting Level of Service Criteria .....	213
7.4.2 What Is the Appropriate Defining Measure for LOS?.....	214
7.4.3 Base Speed-Flow Curves .....	215
7.4.4 Basic Freeway Segment Methodology .....	217
7.4.5 Multilane Highway Methodology .....	220
7.5 The 2000 Highway Capacity Manual.....	221
7.5.1 Level of Service Definitions.....	222
7.5.2 Capacity Under Ideal or Base Conditions .....	223
7.5.3 Estimating Free-Flow Speed .....	224
7.5.4 General Methodology.....	226
7.6 The 2010 Highway Capacity Manual.....	228
7.6.1 Predicting Free-Flow Speed for Basic Freeway Segments .....	229
7.6.2 Revised Values of MSF for Basic Freeway Segments .....	229
7.7 Sample Problems.....	230
References .....	230
<b>Appendix: Sample Problems in Basic Freeway Segment and Multilane Highway Analysis.....</b>	<b>231</b>
Problem 7A.1 – Design of a Rural Freeway Segment.....	231
Problem 7A.2 - Analysis of an Existing Urban Freeway .....	237
Problem 7A.3 – A Suburban Multilane Highway .....	243
<b>8 Analysis of Weaving Segments.....</b>	<b>249</b>
8.1 Weaving Segments: Definition and Terminology .....	249
8.2 Historic Problems in Dealing with Weaving Segments .....	252
8.2.1 Weaving on Non-freeway Facilities .....	252
8.2.2 Weaving between Ramps .....	252
8.2.3 Out of the Realm of Weaving.....	253
8.3 Weaving Analysis in the 1950 HCM .....	254
8.4 Weaving Analysis in the 1965 HCM .....	258
8.4.1 The Leisch/Normann Method: Chapter 7 of the 1965 HCM.....	259
8.4.2 The Hess and Moskowitz/Newman Methods: Chapter 8 of the 1965 HCM.....	262
8.4.3 Inconsistencies in the 1965 HCM .....	263
8.5 New Approaches Involving Configuration and Other New Concepts.....	263
8.5.1 NCHRP 3-15: First Steps towards the 1985 HCM.....	264
8.5.1.1 The NCHRP 3-15 Data Base.....	264
8.5.2 NCHRP 3-15: Approach and General Results .....	265

8.5.3	The NCHRP 3-15 Methodology.....	267
8.5.4	Revising the NCHRP 3-15 Method.....	271
8.5.5	The Leisch Method.....	276
8.5.6	The Reilly Method .....	280
8.6	Weaving Analysis in the 1985 HCM .....	282
8.7	Weaving Analysis in the 2000 HCM .....	288
8.8	Evolution of $N_{w,MAX}$ .....	292
8.9	Weaving Analysis in the 2010 HCM .....	293
8.9.1	A Data Base for the 2010 HCM Methodology.....	294
8.9.2	Length of a Weaving Segment Redefined.....	295
8.9.3	Lane-Changing Behaviour in a Weaving Segment .....	296
8.9.4	Predicting Speed.....	299
8.9.5	Levels of Service .....	301
8.9.6	Capacity of a Weaving Segment .....	301
8.9.7	Maximum Length of a Weaving Segment.....	302
8.9.8	Some Final Thoughts on the 2010 HCM Method .....	303
8.10	Multiple Weaving Segments .....	303
8.11	Base Conditions for Weaving Analysis.....	304
8.12	Sample Problems.....	304
	References .....	304
	<b>Appendix: Sample Problems in Weaving Segment Analysis.....</b>	<b>306</b>
	Problem 8A.1 – A Ramp-Weave Segment .....	306
	Problem 8A.2 – A Major Weaving Segment.....	323
<b>9</b>	<b>Analysis of Merge and Diverge Segments .....</b>	<b>339</b>
9.1	The 1950 Highway Capacity Manual.....	339
9.2	The 1965 Highway Capacity Manual.....	342
9.2.1	Levels of Service .....	343
9.2.2	Determining the Key Variable: Lane 1 Volume Immediately Upstream of the Ramp Junction .....	345
9.2.2.1	The Level of Service A – C Methodology for Determining Lane 1 Volume.....	345
9.2.2.2	The Weaving Checkpoint Volume – LOS A-C Methodology .....	347
9.2.2.3	The Level of Service D-E Methodology for Determining Lane 1 Volume.....	349
9.2.2.4	Weaving Checkpoint for the LOS D-E Methodology .....	350
9.2.3	Applying Adjustment Factors .....	351
9.3	The 1985 Highway Capacity Manual.....	353
9.3.1	Determining Lane 1 Volume.....	353
9.3.2	Converting to Flow Rates and Base Conditions .....	354

9.3.3	Computing Checkpoint Flow Rates and Checkpoint Criteria .....	354
9.4	A New Procedure for the 1994 and 1997 Updates .....	355
9.4.1	Capacity and Level of Service Criteria for Ramp Junctions.....	357
9.4.2	Determining the Flow in Lanes 1 and 2 Immediately Upstream of a Ramp Junction .....	359
9.4.3	Predicting Density and Speed in the Ramp Influence Area.....	362
9.4.4	Special Cases.....	363
9.5	The 2000 Highway Capacity Manual.....	363
9.5.1	Changes in Capacity and Interpretation .....	364
9.5.2	Selecting an Equation for $v_{12}$ on 6-Lane Freeways .....	364
9.5.3	Predicting Speed across All Freeway Lanes.....	366
9.6	The 2010 Highway Capacity Manual.....	367
9.6.1	The Reasonableness Check .....	367
9.6.1.1	Reasonableness Check and Adjustment for 6-Lane Freeways .....	368
9.6.1.2	Reasonableness Check and Adjustment for 8-Lane Freeways .....	368
9.6.1.3	After Adjustments Are Made .....	368
9.6.2	Changing Equation 5, Table 9.9 .....	368
9.7	An Observation .....	369
9.8	Sample Problems.....	369
	References .....	369
<b>Appendix:</b>	<b>Sample Problems in Merging and Diverging Segment Analysis .....</b>	<b>370</b>
Problem 9A.1:	– On-Ramp, Off-Ramp Sequence on a 6-Lane Freeway .....	370
Problem 9A.2:	– An On-Ramp on an 8-Lane Freeway .....	382
Problem 9A.3	– A Segment with Auxiliary Lane .....	388
<b>10</b>	<b>Analysis of Two-Lane, Two-Way Highways .....</b>	<b>393</b>
10.1	The 1950 Highway Capacity Manual .....	393
10.2	The 1965 Highway Capacity Manual.....	395
10.3	The 1985 Highway Capacity Manual .....	398
10.3.1	Methodology for General Terrain Segments .....	399
10.3.2	Methodology for Significant Grades .....	401
10.3.3	Design Treatments .....	404
10.4	The 2000 Highway Capacity Manual.....	405
10.4.1	Adjusting Demand Flow Rates .....	407
10.4.2	Grade Adjustment Factor ( $f_G$ ).....	408

10.4.3	Adjustment Factor for Heavy Vehicles .....	409
10.4.4	Predicting the Average Travel Speed .....	412
10.4.5	Predicting the Percent Time Spent Following.....	415
10.4.6	Impacts of Passing Lanes and Truck Climbing Lanes .....	415
10.4.7	A Problem with the Methodology .....	418
10.5	The 2010 Highway Capacity Manual.....	419
10.5.1	NCHRP 20-7, Task 160 .....	419
10.5.2	Correcting the Iteration Problem.....	422
10.5.3	Another Problem: The Daily Service Volumes .....	428
10.5.4	A New Category of Two-Lane Highway .....	429
10.5.5	Estimating Capacity .....	430
10.5.6	Summary .....	431
10.6	Sample Problems.....	431
	References .....	431
	<b>Appendix: Sample Problems in Two-Lane Highway Analysis.....</b>	<b>432</b>
	Problem 10A.1: – A Rural Two-Lane Highway in General Terrain .....	432
	Sample Problem 10A.2: – A Specific Grade Analysis.....	441
<b>11</b>	<b>The Future of the Highway Capacity Manual .....</b>	<b>451</b>
11.1	The Issues Keep Coming.....	451
11.2	The Overall Form and Organization of the HCM .....	452
11.2.1	How Big? and How to Manage the Process .....	454
11.2.2	Who's the Audience? .....	456
11.3	Where Do We Go with Level of Service?.....	458
11.4	Uninterrupted Flow vs. Interrupted Flow? Or Points and Segments vs. Facilities and Systems? .....	461
11.5	The Software Is the Manual!.....	462
11.6	The Sixth Edition of the HCM .....	463
11.7	Some Specific Recommendations .....	465
11.8	Some Closing Thoughts .....	466
	<b>Subject Index.....</b>	<b>467</b>