

## **APPENDIX A: AVERAGE CONDITION MODELS**

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This appendix presents the descriptive statistics and estimation results for the data used to estimate average condition models as described in Section 1. They are presented here organized as follows:

1. Two Lane Rural Highways
  - a. Segment Models (2U)
  - b. Intersection Models
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## A.1 TWO LANE RURAL HIGHWAYS

### A.1.1 Segment Models (2U)

#### Descriptive Statistics for Average Condition SPFs (Two Lane 2U)

WA (N=15208)	Total Crashes (2008-2012)	Mean	S.D.	Min	Max
Segment length		0.289	0.504	0.01	7.51
AADT		3897.180	3755.830	41	25023
Lane width		12.421	3.144	8	38
Left shoulder width		4.174	2.961	0	37
Right shoulder width		4.216	3.091	0	40
KABCO	21619	1.422	4.910	0	310
KABC	8399	0.552	1.962	0	107
KAB	4596	0.302	1.141	0	63
RE	4114	0.271	1.329	0	50
SSD	268	0.018	0.217	0	21
SD	4382	0.288	1.412	0	52
HO	294	0.019	0.163	0	5
SOD	756	0.050	0.279	0	11
TOD	3242	0.213	0.969	0	50
OD	4292	0.282	1.173	0	56
MV	9014	0.593	2.400	0	92
RO	4505	0.296	1.145	0	58
FO	5350	0.352	1.244	0	58
MO	189	0.012	0.123	0	4
SV	12877	0.847	3.162	0	223

### Average Condition SPFs (Two Lane 2U)

Crash type (WA, N=15208)	$b_0$	$b_1$	$c$	-2LL	AIC
KABCO	-5.8438	0.9368	1.4157	40603	40609
	(<.0001)	(<.0001)	(<.0001)		
KABC	-6.5246	0.905	1.1284	25218	25224
	(<.0001)	(<.0001)	(<.0001)		
KAB	-5.7981	0.7456	0.884	17701	17707
	(<.0001)	(<.0001)	(<.0001)		
RE	-14.5284	1.745	0.8514	15357	15363
	(<.0001)	(<.0001)	(<.0001)		
SSD	-11.6675	1.1092	-0.712	2475.1	2481.1
	(<.0001)	(<.0001)	(0.0006)		
SD	-13.9423	1.6861	0.8433	16135	16141
	(<.0001)	(<.0001)	(<.0001)		
HO	-10.8966	1.0288	-0.3343	2587.7	2593.7
	(<.0001)	(<.0001)	(0.1558)		
SOD	-10.2969	1.0691	0.4186	5450.1	5456.1
	(<.0001)	(<.0001)	(0.0026)		
TOD	-10.6089	1.2763	0.2271	15377	15383
	(<.0001)	(<.0001)	(<.0001)		
OD	-9.7879	1.2129	0.5259	18296	18302
	(<.0001)	(<.0001)	(<.0001)		
MV	-10.4451	1.3704	0.9196	26751	26757
	(<.0001)	(<.0001)	(<.0001)		
RO	-4.5777	0.5937	0.4885	15804	15810
	(<.0001)	(<.0001)	(<.0001)		
FO	-5.3026	0.7052	0.6298	19416	19422
	(<.0001)	(<.0001)	(<.0001)		
MO	-13.1558	1.2419	-0.3045	2016.6	2022.6
	(<.0001)	(<.0001)	(0.2961)		
SV	-4.4781	0.7117	1.1281	29497	29503
	(<.0001)	(<.0001)	(<.0001)		

## A.1.2 Intersection Models

### A.1.2.1 Three-leg Stop Controlled (3ST) Models

#### Descriptive Statistics for Average Condition SPFs (Two Lane 3ST)

MN (N=755)	Total Crashes (2003-2009)	Mean	S.D.	Minimum	Maximum
AADT_maj		3591.560	3428.110	307.8571	21328.57
AADT_min		593.331	742.723	4	6418
KABCO	1546	2.048	3.050	0	29
KABC	544	0.721	1.317	0	15
KAB	240	0.318	0.700	0	5
RE	306	0.405	1.148	0	19
SSD	75	0.099	0.352	0	3
SD	381	0.505	1.293	0	19
ID	212	0.281	0.785	0	11
HO	117	0.155	0.506	0	6
SOD	51	0.068	0.271	0	2
TOD	68	0.090	0.364	0	3
OD	236	0.313	0.747	0	7
MV	829	1.098	2.157	0	24
RO	169	0.224	0.534	0	4
FO	321	0.425	0.892	0	10
MO	771	1.021	2.136	0	25
SV	1312	1.738	2.782	0	29

### Average Condition SPFs (Two Lane 3ST)

Crash type (MN, N=755)	$b_0$	$b_1$	$b_2$	$k$	-2LL	AIC
KABCO	-7.1893	0.7189	0.3368	0.5587	1294.22	2596.44
	(<.0001)	(<.0001)	(<.0001)			
KABC	-8.4186	0.7178	0.3678	0.5921	784.6808	1577.362
	(<.0001)	(<.0001)	(<.0001)			
KAB	-8.9605	0.6821	0.371	0.6187	496.123	1000.246
	(<.0001)	(<.0001)	(<.0001)			
RE	-15.1448	1.4242	0.3835	0.9063	488.571	985.1427
	(<.0001)	(<.0001)	(<.0001)			
SSD	-15.5973	1.1795	0.5578	0.2732	202.754	413.5073
	(<.0001)	(<.0001)	(<.0001)			
SD	-15.0675	1.4146	0.4191	0.8338	551.155	1110.311
	(<.0001)	(<.0001)	(<.0001)			
ID	-11.38	0.6385	0.7707	0.6066	417.313	842.6263
	(<.0001)	(<.0001)	<.0001			
HO	-8.0695	0.5351	0.3114	2.5433	320.58	649.1601
	(<.0001)	(0.0002)	(0.0034)			
SOD	-8.4785	0.4701	0.3295	0.7355	181.852	371.7049
	(<.0001)	(0.0142)	(0.0151)			
TOD	-14.7476	0.657	1.0688	0.8009	183.587	375.1748
	(<.0001)	(0.0014)	(<.0001)			
OD	-8.8003	0.5757	0.481	0.8598	488.811	985.6215
	(<.0001)	(<.0001)	(<.0001)			
MV	-11.0951	0.9851	0.4961	0.5969	891.611	1791.223
	(<.0001)	(<.0001)	(<.0001)			
RO	-4.9379	0.2951	0.1833	0.9274	430.567	869.1342
	(<.0001)	(0.0078)	(0.0167)			
FO	-5.5748	0.421	0.2236	1.2016	628.576	1265.152
	(<.0001)	(<.0001)	(0.0002)			
MO	-12.1675	1.0651	0.5448	0.6569	838.155	1684.31
	(<.0001)	(<.0001)	(<.0001)			
SV	-7.8213	0.7325	0.3913	0.6043	1191.23	2390.456
	(<.0001)	(<.0001)	(<.0001)			

**A.1.2.2 Four-leg Stop Controlled (4ST) Models****Descriptive Statistics for Average Condition SPFs (Two Lane 4ST)**

<b>MN (N=1348)</b>	<b>Total Crashes (2003-2009)</b>	<b>Mean</b>	<b>S.D.</b>	<b>Minimum</b>	<b>Maximum</b>
AADT_maj		3139.440	2465.180	112	19670.8
AADT_min		691.930	876.522	4	11270.8
KABCO	3920	2.908	4.079	0	39
KABC	1541	1.143	1.983	0	20
KAB	669	0.519	1.049	0	11
RE	687	0.510	1.202	0	12
SSD	251	0.186	0.471	0	4
SD	938	0.696	1.413	0	14
ID	1314	0.975	2.042	0	27
HO	202	0.150	0.442	0	5
SOD	120	0.089	0.317	0	3
TOD	163	0.121	0.379	0	3
OD	485	0.360	0.731	0	5
MV	2737	2.030	3.379	0	39
RO	284	0.211	0.520	0	4
FO	413	0.306	0.663	0	6
MO	2757	2.045	3.528	0	38
SV	3635	2.697	3.985	0	42

### Average Condition SPFs (Two Lane 4ST)

Crash type (MN, N=1348)	$b_0$	$b_1$	$b_2$	$k$	-2LL	AIC
KABCO	-7.0573	0.6587	0.4446	0.397	2589.91	5187.828
	(<.0001)	(<.0001)	(<.0001)			
KABC	-7.6375	0.5559	0.5187	0.661	1751.96	3511.914
	(<.0001)	(<.0001)	(<.0001)			
KAB	-7.965	0.5049	0.5126	0.7048	1172.82	2353.638
	(<.0001)	(<.0001)	(<.0001)			
RE	-13.122	1.2289	0.3748	0.6563	1049.79	2107.581
	(<.0001)	(<.0001)	(<.0001)			
SSD	-10.1188	0.7831	0.3385	0.2415	624.25	1256.501
	(<.0001)	(<.0001)	(<.0001)			
SD	-11.7731	1.1123	0.3692	0.4945	1271.67	2551.333
	(<.0001)	(<.0001)	(<.0001)			
ID	-8.2058	0.3771	0.7923	0.841	1539.82	3087.636
	(<.0001)	(<.0001)	(<.0001)			
HO	-9.7990	0.8817	0.1300	0.8387	561.44	1130.879
	(<.0001)	(<.0001)	(0.0798)			
SOD	-11.2564	0.8029	0.3732	0.3229	376.628	761.2564
	(<.0001)	(<.0001)	(0.0001)			
TOD	-12.1517	0.6138	0.7783	0.1332	430.089	868.177
	(<.0001)	(<.0001)	(<.0001)			
OD	-9.893	0.7964	0.3865	0.3211	-928.926	1865.851
	(<.0001)	(<.0001)	(<.0001)			
MV	-8.5841	0.7006	0.5658	0.4861	2172.31	4352.626
	(<.0001)	(<.0001)	(<.0001)			
RO	-5.0925	0.4084	0.0507	1.0963	741.277	1490.554
	(<.0001)	(<.0001)	(0.4286)			
FO	-7.9231	0.6466	0.2516	0.6385	-893.555	1795.109
	(<.0001)	(<.0001)	(<.0001)			
MO	-8.9737	0.701	0.623	0.4984	2144.21	4296.412
	(<.0001)	(<.0001)	(<.0001)			
SV	-7.6087	0.665	0.5076	0.4072	2475.86	4959.718
	(<.0001)	(<.0001)	(<.0001)			

**A.1.2.3 Four-leg Signalized (4SG) Models****Descriptive Statistics for Average Condition SPFs (Two Lane 4SG)**

<b>MN (N=63)</b>	<b>Total Crashes (2003-2008)</b>	<b>Mean</b>	<b>S.D.</b>	<b>Minimum</b>	<b>Maximum</b>
AADT_maj		9230.920	3931.290	2125	19500
AADT_min		4046.080	2579.930	352.75	10664.5
KABCO	499	7.921	7.402	0	38
KABC	145	2.302	2.650	0	14
KAB	45	0.714	0.906	0	3
RE	168	2.667	3.268	0	16
SSD	45	0.714	1.007	0	4
SD	213	3.381	3.549	0	18
ID	130	2.063	2.382	0	11
HO	16	0.254	0.538	0	2
SOD	11	0.175	0.525	0	3
TOD	51	0.810	1.342	0	9
OD	78	1.238	1.820	0	10
MV	421	6.683	6.283	0	34
RO	5	0.079	0.326	0	2
FO	31	0.492	0.948	0	5
MO	448	7.111	6.764	0	36
SV	498	7.905	7.246	0	38



### Average Condition SPFs (Two Lane 4SG)

Crash type (MN, N=63)	$b_0$	$b_1$	$b_2$	$k$	-2LL	AIC
KABCO	-10.9499	1.0927	0.3673	0.2726	174.697	357.3947
	(<.0001)	(<.0001)	(0.0003)			
KABC	-13.8282	1.3356	0.2934	0.2098	111.586	231.1709
	(<.0001)	(<.0001)	(0.0267)			
KAB (using Poisson)	-13.9284	1.2679	0.2418	0.9991*	64.0752	134.1504
	(0.0002)	(0.0019)	(0.2079)			
RE	-14.7148	1.3865	0.3597	0.3248	119.314	246.6276
	(<.0001)	(<.0001)	(0.0106)			
SSD	-7.1957	0.1958	0.6181	0.3764	68.934	145.868
	(0.0712)	(0.6661)	(0.0185)			
SD	-12.7288	1.1578	0.406	0.2505	130.119	268.238
	(<.0001)	(<.0001)	(0.0012)			
ID	-10.3638	1.0025	0.236	0.4452	113.598	235.1963
	(0.0003)	(0.0024)	(0.1299)			
HO (not significant – only 16 crashes)	-11.7212	0.6492	0.5387	0.318	37.5054	83.0107
	(0.0685)	(0.3547)	(0.1783)			
SOD (not significant – only 11 crashes)	-13.7515	0.7028	0.6821	3.1592	29.2201	66.4402
	(0.2047)	(0.5063)	(0.2661)			
TOD	-6.3836	0.0613	0.6809	0.4541	73.2445	154.489
	(0.0829)	(0.8882)	(0.0089)			
OD	-7.6005	0.2912	0.6273	0.678	91.0779	190.1559
	(0.0316)	(0.4679)	(0.0049)			
MV	-9.7083	0.9244	0.3848	0.2976	167.916	343.8313
	(<.0001)	(<.0001)	(0.0003)			
RO (not significant – only 5 crashes)	-29.5044	2.5247	0.4468	4.1016	15.9347	39.8694
	(0.1649)	(0.2124)	(0.5729)			
FO	-22.7574	2.2505	0.1542	0.3947	51.2639	110.5277
	(0.0001)	(0.0002)	(0.5615)			
MO	-10.4028	0.9998	0.3918	0.2788	169.483	346.965
	(<.0001)	(<.0001)	(0.0002)			
SV	-10.3429	1.0412	0.3515	0.2611	174.756	357.5117
	(<.0001)	(<.0001)	(0.0004)			

\*Poisson scale factor

**Average Condition SPFs Using Total AADT (Two Lane 4SG)**

Crash type (MN, N=63)	$b_0$	$b_3$	$k$	-2LL	AIC
HO+SOD	-14.4069	1.4254	1.8651	52.0539	110.1079
	(0.0486)	(0.0625)			
TOD	-9.9439	1.0247	0.5969	75.2492	156.4983
	(0.0151)	(0.0169)			
OD	-10.5987	1.1378	0.7839	92.9449	191.8899
	(0.0069)	(0.0058)			

## A.2 MULTI-LANE RURAL HIGHWAYS

### A.2.1 Segment Models

#### A.2.1.1 Undivided (4U)

##### Descriptive Statistics for Average Condition SPFs (Multilane 4U)

<b>TX (N=1251)</b>	<b>No. of crashes</b>	<b>Mean</b>	<b>S.D.</b>	<b>Min</b>	<b>Max</b>
Segment Length		0.516	0.746	0.1	6.467
AADT		6187.600	4361.510	250	28000
Lane width		11.92	0.635	10	13.75
Shoulder width		5.42	3.827	0	17
KABCO	1828	1.461	2.970	0	39
KABC	711	0.568	1.359	0	19
KAB	447	0.357	0.984	0	17
Head-on	116	0.093	0.413	0	7
Rear-end	295	0.236	1.021	0	18
Angle	15	0.012	0.109	0	1
Single	1158	0.926	2.064	0	25
SSD	188	0.150	0.517	0	8
SSD + RE	483	0.386	1.318	0	21
<b>OH (N=63)</b>	<b>No. of crashes</b>	<b>Mean</b>	<b>S.D.</b>	<b>Min</b>	<b>Max</b>
Segment length		0.551	0.496	0.102	2.511
AADT		11951.79	6170.75	740	23744
Lane width		11.635	0.540	9.5	12
Shoulder width		6.190	2.206	1	8
SOD	15	0.238	0.560	0	2
SOD + HO	18	0.286	0.682	0	3

#### Average Condition SPFs (Multilane 4U)

Crash type (TX, N=1251)	$b_0$	$b_1$	$c$	-2LL	AIC
KABCO	-7.863 (< 0.001)	0.898 (< 0.001)	1.403	3308.8	3314.8
KABC	-7.735 (< 0.001)	0.777 (< 0.001)	1.111	2026.1	2032.1
KAB	-6.831 (< 0.001)	0.622 (< 0.001)	0.923	1529.6	1535.6
Head-on	-13.492 (< 0.001)	1.223 (< 0.001)	0.147	608.9	614.9
Rear-end	-18.741 (< 0.001)	1.895 (< 0.001)	0.324	1151.9	1157.9
Angle*	-	-	-	-	-
Single-vehicle	-5.290 (< 0.001)	0.555 (< 0.001)	1.039	2606.7	2612.7
SSD	-16.180 (< 0.001)	1.572 (< 0.001)	0.653	945.8	951.8
SSD + RE	-16.709 (< 0.001)	1.729 (< 0.001)	0.714	1634.0	1640.0
Crash type (OH, N=63)	$b_0$	$b_1$	$c$	-2LL	AIC
SOD*	-	-	-	-	-
SOD + HO**	-9.468 (0.075)	0.816 (0.141)	1.390	74.8	80.8

\* Model was not converged

\*\*Model was not significant

#### A.2.1.2 Divided (4D)

#### Descriptive Statistics for Average Condition SPFs (Multilane 4D)

OH (N=1261)	No. of crashes	Mean	S.D.	Min	Max
Segment length		0.527	0.582	0.100	9.422
AADT		9896.954	5600.405	233	38710
Lane width		11.733	0.484	9	12
Shoulder width		6.452	2.504	0	8
Median width		43.410	21.616	10	100
KABCO	2551	2.023	4.034	0	59
KABC	810	0.642	1.512	0	22
KAB	588	0.466	1.071	0	15
Head-on	6	0.005	0.069	0	1
Rear-end	514	0.408	1.739	0	39
Angle	76	0.060	0.410	0	11
Single-vehicle	1362	1.080	2.094	0	26
SSD	415	0.329	0.817	0	13
SSD + RE	928	0.736	2.237	0	47

### Average Condition SPFs (Multilane 4D)

Crash type (OH, N=1261)	$b_0$	$b_1$	$c$	-2LL	AIC
KABCO	-9.453 (< 0.001)	1.044 (< 0.001)	1.219	3974.1	3980.1
KABC	-9.217 (< 0.001)	0.897 (< 0.001)	0.853	2318.9	2324.9
KAB	-8.678 (< 0.001)	0.806 (< 0.001)	0.807	1967.4	1973.4
Head-on*	-	-	-	-	-
Rear-end	-19.226 (< 0.001)	1.893 (< 0.001)	0.039	1554.0	1560.0
Angle	-9.270 (0.001)	0.651 (0.026)	-1.830	502.6	508.6
Single-vehicle	-7.198 (< 0.001)	0.738 (< 0.001)	1.312	3002.5	3008.5
SSD	-13.832 (< 0.001)	1.316 (< 0.001)	1.375	1560.3	1566.3
SSD + RE	-16.008 (< 0.001)	1.625 (< 0.001)	0.660	2323.1	2329.1

\* The model for head-on crashes was not converged.

### A.2.2 Intersection Models

#### A.2.2.1 Three-leg Stop Controlled (3ST)

### Descriptive Statistics for Average Condition SPFs (Multilane 3ST)

OH (N=562)	No. of crashes	Mean	S.D.	Min	Max
Major AADT		8528.80	5,719.60	620	38710
Minor AADT		1208.96	1,704.01	65	16480
Total AADT		9739.76	6005.02	831	39404
KABCO	831	1.479	2.332	0	29
KABC	328	0.584	1.065	0	10
KAB	211	0.375	0.769	0	6
Head-on	7	0.013	0.111	0	1
Rear-end	182	0.324	1.013	0	15
Angle	216	0.384	0.954	0	9
Single-vehicle	180	0.320	0.652	0	5
SSD	78	0.139	0.449	0	5
SSD + RE	260	0.463	1.248	0	20
SOD	30	0.053	0.233	0	2
SOD + HO	37	0.066	0.255	0	2

### Average Condition SPFs (Multilane 3ST)

Crash type (OH, N=562)	$b_0$	$b_1$	$b_2$	$b_3$	$k$	-2LL	AIC
KABCO	-8.675 (< 0.001)	0.772 (< 0.001)	0.152 (0.002)	-	0.7534	1774.0	1782.0
KABC	-11.136 (< 0.001)	0.911 (< 0.001)	0.191 (0.003)	-	0.7393	1089.0	1097.0
KAB	-12.513 (< 0.001)	0.997 (< 0.001)	0.212 (0.005)	-	0.7210	835.6	843.6
Head-on*	-	-	-	-	-	-	-
Rear-end	-13.626 (< 0.001)	1.097 (< 0.001)	0.215 (0.038)	-	2.1083	737.9	745.9
Angle	-11.289 (< 0.001)	0.869 (< 0.001)	0.211 (0.019)	-	2.2084	853.6	861.6
Single-vehicle	-10.043 (< 0.001)	-	-	0.8522 (< 0.001)	0.5114	784.0	790.0
SSD	-14.021 (< 0.001)	1.004 (< 0.001)	0.276 (0.003)	-	1.3960	439.1	447.1
SSD+RE	-13.127 (< 0.001)	1.065 (< 0.001)	0.2375 (< 0.001)	-	1.3739	925.4	933.4
SOD*	-	-	-	-	-	-	-
SOD+HO*	-	-	-	-	-	-	-

\*Model was not converged

### A.2.2.2 Four-leg Stop Controlled (4ST)

#### Descriptive Statistics for Average Condition SPFs (Multilane 4ST)

OH (N=570)	No. of crashes	Mean	S.D.	Min	Max
Major AADT		8299.80	5324.14	841	38710
Minor AADT		995.35	1457.06	41	20623
Total AADT		9295.15	5677.76	1221	41246
KABCO	1373	2.409	3.188	0	22
KABC	548	0.961	1.744	0	14
KAB	425	0.746	1.476	0	13
Head-on	7	0.012	0.125	0	2
Rear-end	190	0.333	0.790	0	7
Angle	583	1.023	2.026	0	15
Single-vehicle	226	0.397	0.769	0	6
SSD	82	0.144	0.415	0	3
SSD + RE	272	0.477	0.976	0	8
SOD	20	0.035	0.202	0	2
SOD + HO	27	0.047	0.236	0	2

#### Average Condition SPFs (Multilane 4ST)

Crash type (OH, N=570)	$b_0$	$b_1$	$b_2$	$b_3$	$k$	-2LL	AIC
KABCO	-7.990 (< 0.001)	0.651 (< 0.001)	0.298 (< 0.001)	-	0.711	2218.8	2226.8
KABC	-11.870 (< 0.001)	0.915 (< 0.001)	0.380 (< 0.001)	-	1.274	1412.0	1420.04
KAB	-13.446 (< 0.001)	1.056 (< 0.001)	0.385 (< 0.001)	-	1.545	1217.8	1225.8
Head-on (no crashes)	-	-	-	-	-	-	-
Rear-end	-13.388 (< 0.001)	1.064 (< 0.001)	0.242 (0.005)	-	1.265	781.9	789.9
Angle	-10.088 (< 0.001)	0.766 (< 0.001)	0.326 (< 0.001)	-	1.767	1471.7	1479.7
Single-vehicle	-10.199 (< 0.001)	0.799 (< 0.001)	0.154 (0.032)	-	0.783	902.6	910.5
SSD	-13.148 (< 0.001)	-	-	1.106 (< 0.001)	0.952	466.0	472.0
SSD + RE	-13.057 (< 0.001)	1.025 (< 0.001)	0.301 (< 0.001)	-	1.015	967.3	975.3
SOD	-17.028 (< 0.001)	-	-	1.370 (0.006)	3.855	163.4	169.4
SOD + HO	-14.914 (< 0.001)	-	-	1.176 (0.005)	3.389	208.5	214.5

#### A.2.2.3 Four-leg Signalized (4SG)

#### Descriptive Statistics for Average Condition SPFs (Multilane 4SG)

OH (N=147)	No. of crashes	Mean	S.D.	Min	Max
Major AADT		8830.96	7060.75	880	38710
Minor AADT		3355.35	4313.23	157	27520
Total AADT		12186.31	9236.54	1522	55210
KABCO	1246	8.476	9.464	0	70
KABC	350	2.381	3.689	0	26
KAB	213	1.449	2.524	0	17
Head-on	7	0.048	0.244	0	2
Rear-end	455	3.095	4.565	0	28
Angle	253	1.721	2.119	0	10
Single-vehicle	107	0.728	0.976	0	5
SSD	103	0.701	1.382	0	10
SSD + RE	558	3.796	5.675	0	36
SOD	16	0.109	0.391	0	3
SOD + HO	23	0.157	0.464	0	3

### Average Condition SPFs (Multilane 4SG)

Crash type (OH, N=147)	$b_0$	$b_1$	$b_2$	$b_3$	$k$	-2LL	AIC
KABCO	-7.374 (< 0.001)	0.742 (< 0.001)	0.222 (< 0.001)	-	0.366	847.2	855.2
KABC	-12.145 (< 0.001)	1.046 (< 0.001)	0.304 (< 0.001)	-	0.649	520.6	528.6
KAB	-12.270 (< 0.001)	1.002 (< 0.001)	0.310 (0.001)	-	0.848	423.1	431.1
Head-on	-17.283 (< 0.001)	-	-	1.385 (0.051)	2.965	51.4	57.4
Rear-end	-12.608 (< 0.001)	1.177 (< 0.001)	0.243 (< 0.001)	-	0.459	564.9	572.9
Angle	-8.234 (< 0.001)	0.736 (< 0.001)	0.138 (0.066)	-	0.530	489.5	497.5
Single-vehicle	-5.531 (< 0.001)	-	-	0.443 (0.003)	0.237	332.6	338.5
SSD	-12.509 (< 0.001)	0.884 (< 0.001)	0.387 (< 0.001)	-	0.842	296.4	304.4
SSD + RE	-12.216 (< 0.001)	1.136 (< 0.001)	0.268 (< 0.001)	-	0.490	614.6	622.6
SOD	-15.772 (< 0.001)	0.846 (0.061)	0.596 (0.017)	-	0.876	89.8	97.8
SOD + HO	-14.718 (< 0.001)	0.804 (0.014)	0.562 (0.003)	-	0.001	116.4	124.4



## A.3 URBAN/SUBURBAN ARTERIALS

### A.3.1 Segment Models

#### A.3.1.1 Descriptive Statistics

Presented here are the models calibrated for average condition sites, including those with only exposure variables and those with additional non-exposure variables. The process of developing these models involved developing a set of initial models using Ohio data, validating these models using Minnesota data and then re-estimating the models using the combined Ohio and Minnesota data. Only the final models calibrated using the combined data and descriptive statistics for the combined data are reported.

Following are the ranges of the AADT by site type for the combined Ohio and Minnesota data for the Average Condition Site AADT Data for Urban/Suburban Segment Models.

Site Type	AADT
2U	100 to 26,670
3T	1,356 to 23,780
4U	386 to 41,906
4D	256 to 73,102
5T	4,785 to 54,298

#### OH and MN Segment Length and Crash Type Totals for 5 Year Period for Average Condition Sites (Urban/Suburban Arterial Segments)

Site Type	Length (mi.)	KABCO	KABC	KAB	KA	MVD	RE	HO	SSD	SOD	MVN Other	SV	Night
2U	690.83	5973	1962	1176	304	578	2112	78	253	318	690	1918	867
3T	177.76	2213	600	284	58	390	1055	24	110	68	292	266	246
4D	308.33	5103	1491	690	158	309	2381	43	686	72	558	1036	702
4U	368.39	5947	1615	728	172	849	2177	77	987	197	942	674	736
5T	299.85	8665	2439	1161	220	1772	3690	47	1041	139	1254	649	859

### OH and MN Segment Crash Type Statistics for 5 Year Period for Average Condition Sites (Urban/Suburban Arterial Segments)

Site Type	Stat.	KABCO	KABC	KAB	KA	MVD	RE	HO	SSD	SOD	MVN Other	SV	NIGHT
2U	N	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610
2U	MIN	0	0	0	0	0	0	0	0	0	0	0	0
2U	MAX	93	34	23	6	18	66	2	7	8	14	42	17
2U	MEAN	3.71	1.22	0.73	0.19	0.36	1.31	0.05	0.16	0.20	0.43	1.19	0.54
2U	STD	8.03	2.77	1.84	0.61	1.23	3.89	0.23	0.56	0.67	1.14	3.05	1.37
3T	N	646	646	646	646	646	646	646	646	646	646	646	646
3T	MIN	0	0	0	0	0	0	0	0	0	0	0	0
3T	MAX	111	25	14	4	26	74	1	7	4	9	14	14
3T	MEAN	3.43	0.93	0.44	0.09	0.60	1.63	0.04	0.17	0.11	0.45	0.41	0.38
3T	STD	8.47	2.36	1.29	0.40	2.11	4.89	0.19	0.54	0.43	1.12	1.12	1.10
4D	N	1038	1038	1038	1038	1038	1038	1038	1038	1038	1038	1038	1038
4D	MIN	0	0	0	0	0	0	0	0	0	0	0	0
4D	MAX	252	80	45	10	21	172	2	28	4	22	40	24
4D	MEAN	4.92	1.44	0.66	0.15	0.30	2.29	0.04	0.66	0.07	0.54	1.00	0.68
4D	STD	14.95	4.49	2.31	0.61	1.38	9.25	0.22	1.97	0.33	1.56	3.05	1.85
4U	N	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
4U	MIN	0	0	0	0	0	0	0	0	0	0	0	0
4U	MAX	146	42	20	7	35	78	3	32	8	34	17	18
4U	MEAN	4.33	1.17	0.53	0.13	0.62	1.58	0.06	0.72	0.14	0.69	0.49	0.54
4U	STD	10.87	3.23	1.65	0.54	2.42	4.89	0.27	1.90	0.62	2.01	1.31	1.36
5T	N	735	735	735	735	735	735	735	735	735	735	735	735
5T	MIN	0	0	0	0	0	0	0	0	0	0	0	0
5T	MAX	247	59	34	7	80	122	3	36	4	44	21	25
5T	MEAN	11.79	3.32	1.58	0.30	2.41	5.02	0.06	1.42	0.19	1.71	0.88	1.17
5T	STD	27.75	7.83	3.84	0.86	7.04	13.59	0.28	3.44	0.59	4.26	2.09	2.89

### OH and MN Segment Continuous Variable Statistics for Average Condition Sites (Urban/Suburban Arterial Segments)

Site Type	Stat.	Length	AADT	Med Width	Parking Prop	FO Density	Offset FO	Maj Comm	Min Comm	Maj Ind	Min Ind	Maj Res	Min Res	Other Dwy
2U	N	1610	1610	1610	1610	1610	1596	1610	1610	1610	1610	1610	1610	1610
2U	MIN	0.01	100	0	0	0	2	0	0	0	0	0	0	0
2U	MAX	6.29	26,670	0	1	211	30	13	42	6	28	4	281	5
2U	MEAN	0.43	7,822	0.00	0.11	50.81	10.23	0.20	2.40	0.07	0.64	0.04	9.39	0.04
2U	STD	0.58	4,385	0.00	0.27	29.76	5.06	0.90	4.86	0.42	2.04	0.29	19.24	0.28
3T	N	646	646	646	646	646	646	646	646	646	646	646	646	646
3T	MIN	0.01	1356	0	0	0	2	0	0	0	0	0	0	0
3T	MAX	3.29	23780	0	2	95	30	18	66	12	10	3	187	2
3T	MEAN	0.28	10875	0.00	0.07	44.54	10.44	0.92	4.78	0.24	0.40	0.07	5.96	0.03
3T	STD	0.38	3962	0.00	0.24	17.67	7.58	2.15	8.59	0.88	1.15	0.35	15.78	0.21
4D	N	1038	1038	1037	1038	1038	1038	1038	1038	1038	1038	1038	1038	1038
4D	MIN	0.01	256	3	0	0	2	0	0	0	0	0	0	0
4D	MAX	5.25	73102	100	1	100	31	33	47	8	5	4	136	2
4D	MEAN	0.30	17595	23.70	0.03	38.40	19.66	0.39	1.00	0.09	0.13	0.03	0.88	0.01
4D	STD	0.52	9685	23.89	0.14	24.17	6.95	1.71	3.66	0.49	0.57	0.25	6.14	0.13
4U	N	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
4U	MIN	0.01	386	0	0	0	2	0	0	0	0	0	0	0
4U	MAX	6.97	41906	0	2	118	30	31	107	17	18	12	233	4
4U	MEAN	0.27	14572	0.00	0.15	48.75	8.71	0.63	4.18	0.24	0.42	0.08	4.41	0.06
4U	STD	0.48	7018	0.00	0.41	17.60	5.72	1.77	9.18	1.03	1.46	0.56	14.09	0.33
5T	N	735	735	735	735	735	733	735	735	735	735	735	735	735
5T	MIN	0.01	4785	0	0	0	2	0	0	0	0	0	0	0
5T	MAX	5.42	54298	0	1	141	30	81	185	26	30	11	153	7
5T	MEAN	0.41	18601	0.00	0.02	50.05	8.23	2.47	10.05	0.41	0.44	0.10	4.09	0.08
5T	STD	0.59	71473	0.00	0.14	20.83	5.20	6.13	19.50	1.59	1.72	0.57	13.26	0.43

**OH and MN Segment Categorical Variable Total Mileage (mi.) for Average Condition Sites (Urban/Suburban Arterial Segments)**

Variable	2U	3T	4U	4D	5T
Lighting	Yes – 172.265 No – 518.565	Yes – 105.963 No – 71.800	Yes – 248.324 No – 120.064	Yes – 131.027 No – 177.307	Yes – 222.63 No – 77.216
Automated Enforcement	Yes – 0 No – 690.830	Yes – 0 No – 177.763	Yes – 0 No – 368.388	Yes – 0 No – 308.334	Yes – 0 No – 299.846
Speed Limit (mph)	<=30 – 53.204 >30 – 637.626	<=30 – 21.448 >30 – 156.315	<=30 – 73.038 >30 – 295.35	<=30 – 16.845 >30 – 291.489	<=30 – 38.953 >30 – 260.893
Parking	Yes – 91.284 No – 599.546	Yes – 10.346 No – 167.417	Yes – 57.579 No – 310.809	Yes – 9.263 No – 299.071	Yes – 14.186 No – 285.660
Parking Type	Angle(comm/ind) – 5.098 Angle(residential) – 3.709 None – 599.676 Parallel(comm/ind) – 28.628 Parallel(residential) – 46.174	Angle(comm/ind) – 0.000 Angle(residential) – 0.725 None – 167.417 Parallel(comm/ind) – 3.216 Parallel(residential) – 4.301	Angle(comm/ind) – 2.620 Angle(residential) – 0.147 None – 310.809 Parallel(comm/ind) – 38.945 Parallel(residential) – 10.566	Angle(comm/ind) – 0.120 Angle(residential) – 0.062 None – 280.680 Parallel(comm/ind) – 5.397 Parallel(residential) – 2.256	Angle(comm/ind) – 0.260 Angle(residential) – 0.000 None – 285.660 Parallel(comm/ind) – 11.316 Parallel(residential) – 2.207

#### *A.3.1.2 Average Condition Models with only AADT and length*

These models include all available sites and only length and AADT as explanatory variables. Thus for all other explanatory variables these apply to the 'average' condition. Models have been developed for the following crash types:

- Total
- Multiple-vehicle
- Rear-end
- Sideswipe-same-direction
- Head-on + sideswipe-opposite-direction
- Multiple-vehicle non-driveway other
- Single-vehicle
- Night time
- All KABC
- All KAB
- All KA

For any other crash type, it is recommended to use a proportion. For example, if single-vehicle run-off-road crashes were of interest than the model for single-vehicle crashes would be applied with the proportion of single-vehicle crashes that are run-off-road as a multiplicative factor.

The model form for all models is as follows:

$$\text{Crashes per year} = (\text{length})^{\exp(\text{Alpha1} + \text{Ohio})} \text{AADT}^{(\text{Beta1})}$$

The dispersion parameter is modeled as:

$$\text{Dispersion parameter} = \exp^{(\text{Alpha2})} (\text{length})^{(\text{Beta2})}$$

Following is documentation of all models developed. For each parameter its estimate and standard error (in brackets) are provided. For some estimates the standard error indicates it is not statistically significant at the 95% confidence level but are consistent with other site types and/or crash types in the direction of effect and magnitude. Where this is the case the variables have been kept in the models.

For 2U segments no satisfactory model for Single-Vehicle crashes was estimated. The modeling did not show a relationship between AADT and single-vehicle crashes. It is recommended to use the proportion of single-vehicle crashes be applied to a model for Total crashes.

**Total**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-6.2938 (0.4935)	-0.3489 (0.0941)	0.7985 (0.0539)	-0.2570 (0.0768)	-0.4130 (0.0563)
3T	-12.9379 (1.5003)	-0.0690 (0.1464)	1.4891 (0.1612)	-0.0666 (0.1482)	-0.3224 (0.0873)
4U	-12.7554 (0.8330)	-0.6896 (0.0938)	1.5142 (0.0876)	0.2426 (0.0990)	-0.1440 (0.0539)
4D	-12.3315 (0.7819)	-0.3014 (0.0908)	1.4019 (0.0784)	-0.3997 (0.1115)	-0.3315 (0.0616)
5T	-12.3834 (1.2745)	-0.3279 (0.1452)	1.4565 (0.1315)	0.0111 (0.0973)	-0.3067 (0.0627)

**All Multiple-Vehicle (includes driveway and non-driveway related)**

*Note: for average condition models where number of driveways is not known it is logical to combine multiple-vehicle driveway and multiple-vehicle non-driveway*

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-11.2516 (0.6224)	-0.3977 (0.1068)	1.3088 (0.0677)	-0.1895 (0.0862)	-0.4608 (0.0608)
3T	-14.4321 (1.6273)	-0.1516 (0.1560)	1.6410 (0.1749)	0.0163 (0.1496)	-0.3466 (0.0898)
4U	-14.8171 (0.9299)	-0.7569 (0.1022)	1.7184 (0.0978)	0.3667 (0.1013)	-0.1604 (0.0550)
4D	-15.1924 (0.9148)	-0.4153 (0.0988)	1.6766 (0.0916)	-0.2431 (0.1189)	-0.3258 (0.0646)
5T	-14.1638 (1.3967)	-0.3826 (0.1536)	1.6322 (0.1441)	0.1439 (0.0986)	-0.2975 (0.0639)

**Rear-End**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-16.2785 (0.8611)	-0.3093 (0.1315)	1.7755 (0.0927)	0.0889 (0.1025)	-0.3929 (0.0767)
3T	-19.3309 (2.0134)	-0.2398 (0.1867)	2.1026 (0.2158)	0.0879 (0.1660)	-0.3944 (0.1024)
4U	-20.9883 (1.2000)	-0.6998 (0.1227)	2.2496 (0.1253)	0.3994 (0.1229)	-0.1276 (0.0713)
4D	-20.9633 (1.2470)	-0.5195 (0.1173)	2.1986 (0.1243)	0.0888 (0.1346)	-0.2403 (0.0770)
5T	-19.5436 (1.6404)	-0.5779 (0.1784)	2.1079 (0.1686)	0.2838 (0.1100)	-0.2986 (0.0748)

**SSSD**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-11.6771 (1.5059)	-1.4475 (0.2108)	1.1522 (0.1655)	0.5887 (0.2324)	-0.4993 (0.1431)
3T	-14.4915 (3.2424)	-0.7704 (0.3049)	1.3985 (0.3481)	-0.5623 (0.5474)	-0.7902 (0.3238)
4U	-16.0534 (1.2928)	-1.2112 (0.1265)	1.7151 (0.1350)	0.2972 (0.1542)	-0.1670 (0.0879)
4D	-12.5972 (1.2197)	-0.3183 (0.1340)	1.2318 (0.1214)	-0.3105 (0.1863)	-0.2585 (0.1233)
5T	-15.0742 (1.7864)	-0.5756 (0.1985)	1.5406 (0.1834)	0.0709 (0.1408)	-0.2579 (0.1100)

**HO+SSOD**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-8.0001 (1.0743)	-0.3847 (0.1947)	0.6922 (0.1164)	-0.0295 (0.2032)	-0.3841 (0.2106)
3T	-16.0846 (3.5122)	-1.1428 (0.2742)	1.5762 (0.3743)	-0.4222 (0.6378)	-0.2489 (0.4444)
4U	-12.3096 (1.8573)	1.0686 (0.1952)	1.1783 (0.1938)	0.5439 (0.2222)	-0.2465 (0.1517)
4D	-8.5679 (2.0962)	-1.0946 (0.2278)	0.7000 (0.2100)	-0.2926 (0.5993)	-0.5178 (0.3654)
5T	-12.1092 (2.5543)	-1.0206 (0.2935)	1.1084 (0.2627)	-0.3789 (0.3670)	-0.2406 (0.3109)

**MultiVehicle NonDriveway – Other (includes any that are not RE, HO, SOD or SSD)**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-8.8178 (0.9284)	-0.3682 (0.1813)	0.8463 (0.1006)	-0.1240 (0.1588)	-0.8411 (0.1148)
3T	-9.5257 (2.2922)	-0.3193 (0.2197)	0.9349 (0.2460)	-0.1341 (0.2844)	-0.3841 (0.2056)
4U	-9.9992 (1.2771)	-0.8831 (0.1463)	1.0581 (0.1344)	0.5275 (0.1398)	-0.2866 (0.0859)
4D	-9.9524 (1.3628)	-0.5990 (0.1613)	0.9678 (0.1366)	-0.0212 (0.1986)	-0.5860 (0.1073)
5T	-9.5693 (1.8737)	-0.4100 (0.2221)	0.9933 (0.1933)	0.1493 (0.1223)	-0.5157 (0.0880)

**Single Vehicle**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	0.542 is proportion of total crashes				
3T	-7.9041 (2.1866)	-0.1468 (0.2364)	0.7335 (0.2340)	-0.1910 (0.2801)	-0.4157 (0.2042)
4U	-4.5607 (1.1251)	-0.7848 (0.1333)	0.4453 (0.1184)	-0.0359 (0.1776)	-0.2246 (0.1227)
4D	-6.0167 (0.9960)	0.1252 (0.1367)	0.5573 (0.1000)	-0.1201 (0.1447)	-0.2800 (0.1264)
5T	-3.6979 (1.6636)	-0.2102 (0.2382)	0.3090 (0.1721)	-0.1064 (0.1576)	-0.4853 (0.1445)

**NIGHT**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-3.9202 (0.7242)	-0.8498 (0.1335)	0.3684 (0.0797)	-0.1625 (0.1381)	-0.4520 (0.1138)
3T	-14.9761 (2.5194)	-0.8162 (0.2145)	1.5361 (0.2691)	-0.1481 (0.3143)	-0.3334 (0.2116)
4U	-12.7732 (1.2263)	-1.3234 (0.1244)	1.3519 (0.1282)	0.0023 (0.1765)	-0.2060 (0.1049)
4D	-10.9900 (1.1714)	-0.6497 (0.1282)	1.0956 (0.1169)	-0.3795 (0.1922)	-0.3657 (0.1181)
5T	-11.5082 (1.6850)	-0.6827 (0.2021)	1.1670 (0.1732)	0.0562 (0.1503)	-0.2955 (0.1186)

**All KABC**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-5.9715 (0.6161)	-0.3664 (0.1199)	0.6414 (0.0672)	-0.2076 (0.0999)	-0.4934 (0.0816)
3T	-13.8791 (1.8853)	-0.2073 (0.1908)	1.4602 (0.2017)	-0.2266 (0.2224)	-0.4613 (0.1508)
4U	-13.1722 (1.0460)	-0.5701 (0.1233)	1.4098 (0.1097)	0.0291 (0.1252)	-0.3140 (0.0767)
4D	-12.8907 (0.9892)	-0.3578 (0.1097)	1.3366 (0.0986)	-0.3939 (0.1433)	-0.3189 (0.0884)
5T	-14.0910 (1.4446)	-0.1774 (0.1911)	1.4855 (0.1484)	-0.0967 (0.1157)	-0.4762 (0.0834)



**All KAB**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-5.2918 (0.7133)	0.1910 (0.1634)	0.4518 (0.0773)	-0.1659 (0.1159)	-0.6202 (0.1134)
3T	-12.9035 (2.3076)	0.2246 (0.2634)	1.2351 (0.2463)	-0.1745 (0.2833)	-0.4065 (0.2303)
4U	-12.8216 (1.2708)	0.2374 (0.1840)	1.2150 (0.1321)	0.1007 (0.1578)	-0.2804 (0.1217)
4D	-12.0919 (1.1832)	0.3356 (0.1546)	1.1188 (0.1175)	-0.4544 (0.1892)	-0.3752 (0.1514)
5T	-14.7803 (1.6203)	0.7442 (0.2898)	1.3899 (0.1651)	-0.1565 (0.1403)	-0.5038 (0.1212)

**All KA**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2
2U	-5.0847 (1.1092)	0.2330 (0.2746)	0.2746 (0.1201)	-0.0944 (0.2500)	-0.6773 (0.2475)
3T	-15.5526 (4.7936)	0.1463 (0.5405)	1.3563 (0.5091)	0.6247 (0.4937)	-0.6695 (0.4714)
4U	-9.9115 (2.0648)	0.7087 (0.3989)	0.7143 (0.2137)	0.4359 (0.2863)	0.0000 (n/a)
4D	-10.4154 (1.9523)	0.4139 (0.2861)	0.7952 (0.1935)	0.0079 (0.3484)	-0.0934 (0.3495)
5T	-10.1477 (2.5644)	0.5842 (0.5033)	0.7758 (0.2595)	0.1092 (0.2582)	-0.6677 (0.2553)

**A.3.1.3 Average Condition Multi-Variable Models**

Documented here are the multi-variable average condition models for urban and suburban arterial segments calibrated using Ohio and Minnesota data. If n/a is indicated for a model that indicates no variables other than AADT were able to be included and the exposure only average condition models would apply. In other cases no satisfactory model could be developed and an appropriate note is made.

Two additional variables were defined in developing these models:

Lighting - no=0; yes=1

SpeedCat - <=30 mph = 0; >30 mph = 1

Models were calibrated for the following crash types:

- Total
- Multiple-Vehicle Driveway
- Rear-end
- Sideswipe-same-direction
- Head-on + sideswipe-opposite-direction
- Multiple-vehicle non-driveway other
- Single-vehicle

- Night time
- KABC
- KAB
- KA

The model forms are:

Crashes/year =

$(\text{length}) * \exp^{(\text{Alpha1} + \text{Ohio})} * \text{AADT}^{\text{Beta1}} * \exp(\text{beta3} * \text{DWYDENS} + \text{beta4} * \text{FODensity} + \text{beta5} * \text{MedWidth} + \text{beta6} * \text{Lighting} + \text{beta7} * \text{SpeedCat})$

Dispersion parameter =  $\exp^{(\text{Alpha2})} (\text{length})^{(\text{Beta2})}$

**Total**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-6.4775 (0.4951)	-0.3637 (0.0939)	0.8199 (0.0545)	-0.2793 (0.0773)	-0.4186 (0.0564)	0.0027 (0.0014)	-	-	-0.2774 (0.0764)	-
3T	n/a									
4U	-13.2460 (0.8305)	-0.6494 (0.0928)	1.5355 (0.0867)	0.2358 (0.0092)	-0.1258 (0.0543)	0.0066 (0.0013)	-	-	-	-
4D	-11.8859 (0.7803)	-0.2067 (0.0911)	1.3560 (0.0780)	-0.4139 (0.1118)	-0.3106 (0.0621)	0.0077 (0.0022)	-	-0.0076 (0.0022)	-	-
5T	-12.3144 (1.2829)	-0.3771 (0.1483)	1.4671 (0.1325)	-0.0049 (0.0975)	-0.3158 (0.0627)	-	-	-	-0.1821 (0.1113)	-

**MultiVehicle Driveway**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-13.168 (1.268)	0.2613 (0.249)	1.1237 (0.131)	0.4129 (0.137)	-0.6301 (0.1328)	0.0134 (0.0029)	-	-	-	0.6781 (0.262)
3T	n/a									
4U	-18.235 (1.814)	0.5481 (0.245)	1.6840 (0.188)	0.7427 (0.1433)	-0.5045 (0.0990)	0.0179 (0.0032)	-	-	-	-
4D	-17.423 (2.694)	1.1117 (0.347)	1.5197 (0.265)	0.7454 (0.2209)	-0.7359 (0.1330)	0.0259 (0.0068)	0.0106 (0.0064)	-0.0484 (0.0108)	-	-
5T	-11.994 (2.007)	0.4907 (0.283)	1.1376 (0.208)	0.4152 (0.118)	-0.5856 (0.097)	0.0089 (0.004)	-	-	-	-

**Rear-End**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	n/a									
3T	n/a									
4U	-21.235 (1.212)	-0.722 (0.123)	2.292 (0.128)	0.386 (0.123)	-0.134 (0.071)	-	-	-	-0.216 (0.110)	-
4D	n/a									
5T	-19.355 (1.652)	-0.654 (0.182)	2.115 (0.170)	0.265 (0.110)	-0.308 (0.075)	-	-	-	-0.274 (0.135)	-

**SSSD**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	n/a									
3T	n/a									
4U	n/a									
4D	n/a									
5T	-14.8740 (1.7838)	-0.6417 (0.2012)	1.5453 (0.1831)	0.0414 (0.1420)	-0.2710 (0.1106)	-	-	-	-0.2674 (0.1377)	-

**HO+SSOD**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-8.5126 (1.0883)	-0.3595 (0.1954)	0.7632 (0.1181)	-0.1208 (0.2116)	-0.4008 (0.2140)	-	-	-	-0.6242 (0.1568)	-
3T	n/a									
4U	n/a									
4D	n/a									
5T	-14.8740 (1.7838)	-0.6417 (0.2012)	1.5453 (0.1831)	0.0414 (0.1420)	-0.2710 (0.1106)	-	-	-	-0.2674 (0.1377)	-

**MultiVehicle NonDriveway Other**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-9.0073 (0.9332)	-0.3062 (0.1815)	0.8553 (0.1008)	-0.1317 (0.1591)	-0.8274 (0.1154)	-	-	-	0.6136 (0.2215)	-
3T	n/a									
4U	n/a									
4D	-9.0818 (1.3600)	-0.4921 (0.1608)	0.9038 (0.1357)	-0.1301 (0.2088)	-0.6041 (0.1113)	-	-	-0.0168 (0.0043)	-	-
5T	n/a									

**SV**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-1.4716 (0.6112)	-0.4737 (0.1335)	0.1179 (0.0676)	-0.1944 (0.0975)	-0.5088 (0.0877)	-	-	-	-0.6575 (0.1011)	0.3788 (0.1609)
3T	-8.2302 (2.1820)	-0.1758 (0.2375)	0.7907 (0.2347)	-0.2658 (0.2918)	-0.4573 (0.2090)	-	-	-	-0.3200 (0.1710)	-
4U	n/a									
4D	n/a									
5T	-3.7780 (1.6192)	-0.4119 (0.2368)	0.3830 (0.1681)	-0.2664 (0.1677)	-0.5035 (0.1523)	-	-	-	-0.6914 (0.1341)	-

**NIGHT**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-4.1911 (0.7302)	-0.8482 (0.1339)	0.4088 (0.0808)	-0.2053 (0.1407)	-0.4756 (0.1138)	-	-	-	-0.3513 (0.1122)	-
3T	n/a									
4U	-13.2667 (1.2446)	-1.2944 (0.1242)	1.3824 (0.1288)	0.0034 (0.1753)	-0.1863 (0.1057)	0.0047 (0.0020)	-	-	-	-
4D	-10.5227 (1.1762)	-0.5894 (0.1289)	1.0643 (0.1169)	-0.4151 (0.1962)	-0.3671 (0.1201)	-	-	-0.0100 (0.0035)	-	-
5T	-11.0732 (1.6775)	-0.7661 (0.2034)	1.1556 (0.1718)	0.0157 (0.1522)	-0.3016 (0.1195)	-	-	-	-0.3551 (0.1396)	-

**KABC**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-6.3425 (0.6188)	-0.3694 (0.1196)	0.6962 (0.0680)	-0.2645 (0.1019)	-0.5076 (0.00821)	-	-	-	-0.4504 (0.0913)	-
3T	n/a									
4U	-13.905 (1.0852)	-0.6443 (0.1325)	1.4592 (0.1116)	0.0110 (0.1258)	-0.3187 (0.0771)	0.0038 (0.0017)	-	-	-	0.2335 (0.1228)
4D	-12.413 (0.9886)	-0.2711 (0.1099)	1.2970 (0.0982)	-0.4198 (0.1445)	-0.2962 (0.0903)	0.0047 (0.0027)	-	-	-	-
5T	-13.868 (1.4467)	-0.2583 (0.1931)	1.4942 (0.1486)	-0.1409 (0.1169)	-0.4972 (0.0838)	-	-	-	-0.3369 (0.1212)	-

**KAB**

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-5.9045 (0.7280)	0.1205 (0.1695)	0.5098 (0.0777)	-0.2700 (0.1209)	-0.6560 (0.1159)	-	-	-	-0.5073 (0.1102)	0.3033 (0.1839)
3T	-13.012 (2.2967)	0.2266 (0.2633)	1.2640 (0.2455)	-0.2409 (0.2882)	-0.4266 (0.2308)	-	-	-	-0.2880 (0.1702)	-
4U	-13.125 (1.2830)	0.1221 (0.1924)	1.2305 (0.1327)	0.0690 (0.1596)	-0.3033 (0.1220)	-	-	-	-	0.3187 (0.1558)
4D	-11.658 (1.1875)	0.3182 (0.1567)	1.1086 (0.1174)	-0.5443 (0.1988)	-0.4331 (0.1544)	-	-	-0.0087 (0.0035)	-0.2971 (0.1213)	-
5T	-14.289 (1.5960)	0.6307 (0.2911)	1.3861 (0.1621)	-0.2913 (0.1487)	-0.5705 (0.1259)	-	-	-	-0.5114 (0.1262)	-

KA

Site Type	Alpha1	Ohio	Beta1	Alpha2	Beta2	Beta3	Beta4	Beta5	Beta6	Beta7
2U	-5.4393 (1.1162)	0.2427 (0.2746)	0.3263 (0.1210)	-0.1812 (0.2613)	-0.6974 (0.2555)	-	-	-	-0.5092 (0.1717)	-
3T	-15.831 (4.7531)	0.1184 (0.5362)	1.4201 (0.5064)	0.5111 (0.5123)	-0.6679 (0.4950)	-	-	-	-0.5428 (0.3278)	-
4U	n/a									
4D	n/a									
5T	n/a									

### A.3.2 Intersection Models

For intersection models, two model forms were explored:

Model A included as the starting point the following independent variables in the following form:

$$Y = e^a \times e^{b \times \left(\frac{AADT_{tot}}{10000}\right)} \times (AADT_{tot})^c \times e^{d \times \left(\frac{AADT_{min}}{AADT_{tot}}\right)} \times \left(\frac{AADT_{min}}{AADT_{tot}}\right)^e$$

Model B included as the starting point the following independent variables in the following form:

$$Y = e^a \times e^{b \times \left(\frac{AADT_{maj}}{10000}\right)} \times (AADT_{maj})^c \times e^{d \times \left(\frac{AADT_{min}}{10000}\right)} \times (AADT_{min})^e$$

where Y is the predicted number of crashes in one year, and a, b, c, d, and e are parameters to be estimated.  $AADT_{tot}$  is the total intersection AADT,  $AADT_{maj}$  is the major road AADT, and  $AADT_{min}$  is the minor road AADT.

#### A.3.2.1 Descriptive Statistics



### Distribution of Categorical Variables by Intersection Type (Urban/Suburban Arterials)

Variable		3SG	3ST	4SG	4ST
Number of legs with left-turn lanes	0	485	7214	803	2342
	1	301	315	210	74
	2	189	48	692	106
	3	0	0	323	11
	4	0	0	734	2
Number of legs with right-turn lanes	0	721	7470	1985	2466
	1	204	101	430	59
	2	50	6	243	8
	3	0	0	68	2
	4	0	0	36	0
Number of legs with left-turn lanes on major road	0	619	7282	998	2374
	1	323	282	331	69
	2	33	13	1433	92
Number of legs with right-turn lanes on major road	0	865	7523	2286	2496
	1	105	54	359	38
	2	5	0	117	1
Number of legs with left-turn lanes on minor road	0	703	7481	1396	2474
	1	254	89	430	48
	2	18	7	936	13
Number of legs with right-turn lanes on minor road	0	792	7518	2221	2498
	1	177	59	411	33
	2	6	0	130	4
Lighting	Not Present	91	2407	278	680
	Present	884	5170	2484	1855
Number of approaches prohibiting right-turn-on-red	0	852	7574	2454	2532
	1	84	0	98	0
	2	39	0	79	0
	3	0	0	35	0
	4	0	0	96	0
Red-light camera	Not Present	963	7576	2708	2535
	Present	12	0	54	0
Schools within 1000 feet	Not Present	849	6961	2420	2289
	Present	126	616	342	246
Number of liquor stores within 1000 feet	0	937	7341	2559	2437
	1 to 8	38	236	203	98
Number of bus stops within 1000 feet	0	707	6615	2322	2318
	1 or 2	32	179	101	50
	3 or more	236	783	339	167

**Descriptive Statistics for Average Condition SPFs (Urban/Suburban Arterial Stop Controlled Intersections)**

Site Type	Variable	Total Crashes (2009-2011)	Min	Max	Mean	Std Dev
3ST (N=7577)	Major AADT		270	46940	10548	6048
	Minor AADT		33	19620	2363	1385
	Total AADT		540	56920	12912	6549
	Minor AADT/Total AADT		0	0.5	0.21	0.11
	Left Turn	1084	0	10	0.14	0.53
	Right Angle	4807	0	21	0.63	1.39
	Rear End	9631	0	39	1.27	2.33
	Sideswipe Same Direction	2982	0	16	0.39	1.03
	Sideswipe Opposite Direction	722	0	6	0.1	0.35
	Head-on	215	0	3	0.03	0.17
	Head-on & Sideswipe Opposite	937	0	7	0.12	0.4
	Multi Vehicle	22601	0	89	2.98	4.56
	Multi Vehicle Other	3165	0	12	0.42	1
	Night	5394	0	19	0.71	1.25
	Single Vehicle	3385	0	13	0.45	0.86
	Total	26543	0	90	3.5	4.85
	KABC	7033	0	22	0.93	1.48
	KAB	3613	0	12	0.48	0.87
	KA	826	0	3	0.11	0.35
4ST (N=2535)	Major AADT		430	41160	9466	5681
	Minor AADT		50	15203	2221	1317
	Total AADT		810	43020	11687	6101
	Minor AADT/Total AADT		0.01	0.5	0.21	0.11
	Left Turn	595	0	24	0.23	0.86
	Right Angle	3282	0	24	1.29	2.16
	Rear End	3417	0	43	1.35	2.41
	Sideswipe Same Direction	846	0	8	0.33	0.83
	Sideswipe Opposite Direction	259	0	6	0.1	0.36
	Head-on	78	0	2	0.03	0.18
	Head-on & Sideswipe Opposite	337	0	8	0.13	0.42
	Multi Vehicle	9836	0	51	3.88	4.91
	Multi Vehicle Other	1360	0	10	0.54	1
	Night	2105	0	14	0.83	1.29
	Single Vehicle	1142	0	10	0.45	0.79
	Total	11200	0	51	4.42	5.21
	KABC	3187	0	16	1.26	1.87
	KAB	1711	0	11	0.67	1.2
	KA	416	0	4	0.16	0.46

**Descriptive Statistics for Average Condition SPFs ((Urban/Suburban Arterial Signalized Intersections))**

Site Type	Variable	Total Crashes (2009-2011)	Min.	Max.	Mean	Std Dev
3SG (N=975)	Major AADT		2449	51301	13505	5993
	Minor AADT		110	22913	4945	3731
	Total AADT		4195	68612	18450	7824
	Minor AADT/Total AADT		0.01	0.5	0.26	0.13
	Left Turn	652	0	16	0.67	1.37
	Right Angle	2760	0	27	2.83	3.77
	Rear End	4704	0	100	4.82	5.85
	Sideswipe Same Direction	2377	0	37	2.44	4.04
	Sideswipe Opposite Direction	219	0	13	0.22	0.66
	Head-on	80	0	4	0.08	0.32
	Head-on & Sideswipe Opposite Direction	299	0	15	0.31	0.78
	Multi Vehicle	12027	0	174	12.34	12.38
	Multi Vehicle Other	1237	0	13	1.27	1.94
	Night	2608	0	58	2.67	3.54
	Single Vehicle	765	0	15	0.78	1.23
	Total	13154	0	179	13.49	13.05
	KABC	3114	0	48	3.19	3.58
	KAB	1409	0	14	1.45	1.87
	KA	260	0	3	0.27	0.55
4SG (N=2762)	Major AADT		1620	61580	14315	7266
	Minor AADT		20	33345	5449	4349
	Total AADT		2061	79494	19765	9632
	Minor AADT/Total AADT		0	0.5	0.27	0.13
	Left Turn	5687	0	55	2.06	3.51
	Right Angle	11577	0	40	4.19	4.76
	Rear End	25237	0	116	9.14	11.56
	Sideswipe Same Direction	6188	0	36	2.24	3.34
	Sideswipe Opposite Direction	812	0	5	0.29	0.61
	Head-on	360	0	4	0.13	0.4
	Head-on & Sideswipe Opposite Direction	1172	0	7	0.42	0.78
	Multi Vehicle	53801	0	182	19.48	20.79
	Multi Vehicle Other	3950	0	21	1.43	2.03
	Night	11046	0	65	4	4.96
	Single Vehicle	2532	0	12	0.92	1.24
	Total	57484	0	187	20.81	21.42
	KABC	14901	0	53	5.4	6.13
	KAB	6604	0	26	2.39	3.05
	KA	1248	0	6	0.45	0.82

### A.3.2.2 Three-leg Stop Controlled (3ST)

#### Average Condition SPFs (Urban/Suburban Arterial 3ST)

3ST: Average Condition Models (7577 Intersections)						
Parameter	Total Crashes		KABC		KAB	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-7.7350 (.7060)	-5.6906 (.5165)	-7.2944 (.8941)	-6.0546 (.7050)	-4.9953 (1.0197)	-4.0783 (.2517)
b	.3472 (.0607)	.3602 (.0604)	.4088 (.0770)	.4418 (.0763)	.5138 (.0869)	.6766 (.0307)
c	.7351 (.0787)	.5543 (.0634)	.5816 (.1055)	.4493 (.0858)	.2546 (.1203)	
d	.8023 (.3028)	1.0287 (.0890)		.6994 (.1119)		
e	-.1336 (.0507)					.1859 (.0335)
k	.7967 (.0199)	.7970 (.0199)	.7430 (.0354)	.7441 (.0354)	.6995 (.0537)	.7043 (.0537)
AIC	33960	33964	19023	19028	13473	13476
BIC	34002	33998	19050	19062	13501	13504
Parameter	KA		Night		Single Vehicle	
	Model B Est(SE)	Model A Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a			-8.2778 (.9924)	-6.7557 (.7838)	-2.8573 (.2509)	-1.3146 (.3629)
b			.2465 (.0861)	.2000 (.0858)	.2307 (.0338)	.1393 (.0353)
c			.7103 (.1173)	.5157 (.0955)		
d				1.2256 (.1245)	1.5848 (.4870)	1.2151 (.2532)
e			.1360 (.0333)		-.1829 (.0830)	-.1365 (.0545)
k			.9278 (.0465)	.9277 (.0465)	1.1043 (.0701)	1.1027 (.0700)
AIC			16838	16835	13508	13502
BIC			16872	16870	13543	13537
Parameter	Multi Vehicle		Right Angle		Left Turn	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-11.6177 (.8241)	-8.7440 (.5959)	-9.8008 (1.2987)	-7.6829 (1.0162)	-11.3326 (2.5178)	-9.8833 (1.9720)
b	.1689 (.0684)	.2056 (.0674)	.3631 (.1128)	.4042 (.1125)	.7086 (.1964)	.7214 (.1928)
c	1.1558 (.0920)	.8824 (.0728)	.8102 (.1535)	.5716 (.1240)	.7498 (.2939)	.5962 (.2369)
d	.6937 (.3312)	1.0773 (.0963)		1.2316 (.1511)		1.1964 (.2405)
e	-.1262 (.0549)					
k	.9137 (.0238)	.9147 (.0238)	1.8568 (.0804)	1.8535 (.0804)	2.9613 (.2707)	2.9572 (.2707)
AIC	31393	31402	15166	15168	5745	5748
BIC	31435	31437	15193	15203	5773	5782
Parameter	Rear End		Sideswipe Same Direction		Head-on plus Sideswipe Opposite I	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-15.3314 (.3541)	-12.5817 (.4125)	-20.1735 (.6659)	-16.4830 (.7188)	-11.6167 (.7005)	-9.7403 (.6063)
b						
c	1.4883 (.0385)	1.3283 (.0332)	1.8761 (.0665)	1.3490 (.0522)	.8916 (.0734)	.6832 (.0662)
d		1.0944 (.2037)	1.1197 (.2968)	1.0145 (.3241)		.9778 (.2233)
e	-.1563 (.0294)	-.1218 (.0478)		.2045 (.0858)		
k	1.1310 (.0399)	1.1271 (.0399)	1.8464 (.1045)	1.8574 (.1051)	1.2609 (.2001)	1.2550 (.1991)
AIC	21273	21274	11034	11050	5739	5736
BIC	21300	21309	11062	11085	5760	5764

**Average Condition SPFs (Urban/Suburban Arterial 3ST) (contd.)**

<b>3ST: Average Condition Models (7577 Intersections), <i>contd.</i></b>			
<b>Parameter</b>	<b>Multi vehicle other</b>		
	<b>Model A Est(SE)</b>	<b>Model B Est(SE)</b>	
<b>a</b>	-14.1325 ( 1.4502)	-11.0326 ( 1.1224)	
<b>b</b>	-.3377 ( .1247)	-.4167 ( .1253)	
<b>c</b>	1.3194 ( .1700)	1.0008 ( .1370)	
<b>d</b>	.8998 ( .2657)	1.2744 ( .1788)	
<b>e</b>			
<b>k</b>	2.1317 ( .1087)	2.1171 ( .1081)	
<b>AIC</b>	12465	12453	
<b>BIC</b>	12500	12488	

### A.3.2.3 Four-leg Stop Controlled (4ST)

#### Average Condition SPFs (Urban/Suburban Arterial 4ST)

4ST: Average Condition Models (2535 Intersections)						
Parameter	Total Crashes		KABC		KAB	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-4.5814 ( .9251)	-2.8927 ( .7414)	-4.4455 ( 1.2706)	-1.7852 ( .0680)	-2.4755 ( .1252)	-2.2268 ( .0827)
b	.3754 ( .0970)	.3803 ( .0953)	.4603 ( .1273)	.5632 ( .0464)	.5779 ( .0579)	.4209 ( .0561)
c	.4658 ( .1113)	.2822 ( .0924)	.2981 ( .1518)			
d	.5910 ( .1934)	1.2638 ( .1597)	.9338 ( .2669)	1.3401 ( .2085)	1.1848 ( .3268)	1.2693 ( .2534)
e						
k	.7355 ( .0295)	.7360 ( .0295)	.9977 ( .0617)	1.0023 ( .0618)	1.2860 ( .1019)	1.2922 ( .1022)
AIC	12655	12655	7620	7621	5605	5608
BIC	12684	12684	7649	7645	5629	5632
Parameter	KA		Night		Single Vehicle	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-3.6634 ( .2045)	-3.4397 ( .1332)	-5.9509 ( 1.3846)	-4.8284 ( 1.0950)	-5.3506 ( .6004)	-4.5320 ( .5191)
b	.4302 ( .0932)	.2933 ( .0919)	.3053 ( .1343)	.2759 ( .1305)		
c			.4772 ( .1649)	.3258 ( .1351)	.3721 ( .0644)	.2773 ( .0584)
d	1.0518 ( .5341)	1.0196 ( .3830)		1.2063 ( .2194)		.5656 ( .2500)
e			.1069 ( .0484)			
k	1.5897 ( .3229)	1.5918 ( .3233)	.7724 ( .0663)	.7755 ( .0662)	.6756 ( .0974)	.6730 ( .0972)
AIC	2381	2382	6189	6187	4522	4522
BIC	2404	2405	6218	6216	4539	4546
Parameter	Multi Vehicle		Right Angle		Left Turn	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-4.8389 ( 1.0002)	-3.0497 ( .7999)	-1.6812 ( .1101)	-1.4418 ( .0748)	-18.0788 ( 1.4506)	-4.0550 ( .1485)
b	.4153 ( .1048)	.4239 ( .1028)	.4433 ( .0534)	.2410 ( .0526)		1.0918 ( .0932)
c	.4721 ( .1203)	.2773 ( .0997)			1.4734 ( .1312)	
d	.6370 ( .2076)	1.3401 ( .1715)	1.3537 ( .2913)	1.5160 ( .2386)	3.2820 ( 1.1803)	1.0533 ( .4036)
e					-.5465 ( .1790)	
k	.8469 ( .0346)	.8477 ( .0346)	1.5818 ( .0835)	1.5776 ( .0832)	2.5878 ( .3035)	2.7075 ( .3102)
AIC	12069	12069	7806	7801	2748	2755
BIC	12099	12099	7829	7825	2777	2778
Parameter	Rear End		Sideswipe Same Direction		Head-on plus Sideswipe Opposite I	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-15.4726 ( .5750)	-12.7228 ( .4831)	-17.3785 ( .9351)	-12.3807 ( 2.1181)	-4.1461 ( .2232)	-3.9049 ( .1445)
b				.4848 ( .2269)	.5947 ( .0964)	.4127 ( .0959)
c	1.5556 ( .0609)	1.2655 ( .0530)	1.6076 ( .0982)	.7208 ( .2575)		
d		1.1250 ( .2158)			1.2843 ( .5891)	1.5057 ( .4081)
e				.3895 ( .0768)		
k	1.0225 ( .0622)	1.0295 ( .0625)	1.4753 ( .1735)	1.4686 ( .1734)	1.4013 ( .3540)	1.3886 ( .3516)
AIC	7317	7328	3422	3421	2044	2042
BIC	7334	7352	3439	3451	2067	2066

**Average Condition SPFs (Urban/Suburban Arterial 4ST) (contd.)**

<b>4ST: Average Condition Models (2535 Intersections), <i>contd.</i></b>			
<b>Parameter</b>	<b>Multi vehicle other</b>		
	<b>Model A Est(SE)</b>	<b>Model B Est(SE)</b>	
<b>a</b>	-6.5157 ( .6675)	-6.3425 ( .6259)	
<b>b</b>			
<b>c</b>	.5489 ( .0747)	.3114 ( .0642)	
<b>d</b>			
<b>e</b>	.1800 ( .0619)	.2377 ( .0573)	
<b>k</b>	1.4018 ( .1244)	1.3981 ( .1242)	
<b>AIC</b>	4970	4968	
<b>BIC</b>	4993	4991	

### A.3.2.3 Three-leg Signalized (3SG)

#### Average Condition SPFs (Urban/Suburban Arterial 3SG)

3SG: Average Condition Models (975 Intersections)						
Parameter	Total Crashes		KABC		KAB	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	.3066 (.0800)	-1.0611 (.5223)	-8.6609 (.7052)	-3.7753 (.3354)	-10.1049 (.9035)	-4.4776 (.4249)
b	.4395 (.0323)	.3092 (.0422)		.3954 (.0497)		.4395 (.0614)
c			.9214 (.0714)		.9809 (.0911)	
d	1.1532 (.1883)	.3654 (.1441)				
e		.2287 (.0700)	.2243 (.0487)	.3902 (.0406)	.1796 (.0612)	.3716 (.0512)
k	.5172 (.0274)	.5159 (.0274)	.5369 (.0426)	.5348 (.0425)	.6215 (.0685)	.6205 (.0685)
AIC	6806	6805	4301	4299	3106	3105
BIC	6825	6830	4320	4319	3125	3125
Parameter	KA		Night		Single Vehicle	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-9.4832 (1.5679)	-8.9194 (1.4902)	-8.1762 (.7803)	-4.6273 (.3781)	-6.9103 (1.0611)	
b				.2928 (.0554)		
c	.7208 (.1590)	.4791 (.1529)	.8739 (.0790)		.6314 (.1070)	
d						
e		.2358 (.0890)	.3640 (.0555)	.4876 (.0459)	.4345 (.0773)	
k	.3559 (.2116)	.3530 (.2110)	.6726 (.0528)	.6705 (.0527)	.6040 (.0957)	
AIC	1252	1253	4037	4036	2321	
BIC	1266	1273	4057	4055	2340	
Parameter	Multi Vehicle		Right Angle		Left Turn	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	.2121 (.0822)		-1.1139 (.1241)	-3.4707 (.4148)	-17.3528 (1.4908)	-16.8689 (1.4112)
b	.4503 (.0332)	.3138 (.0428)	.3055 (.0488)	.1401 (.0634)		
c					1.6327 (.1494)	1.1527 (.1410)
d	1.0875 (.1938)	.6379 (.0780)	1.6430 (.2892)			
e		.0721 (.0090)		.3847 (.0507)	.1870 (.0960)	.5188 (.0807)
k	.5475 (.0292)	.5490 (.0293)	1.0657 (.0725)	1.0777 (.0731)	1.3693 (.1748)	1.3503 (.1732)
AIC	6659	6661	4210	4218	2022	2019
BIC	6678	6680	4230	4237	2042	2038
Parameter	Rear End		Sideswipe Same Direction		Head-on plus Sideswipe Opposite I	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-11.8147 (.6667)	-8.2387 (.6160)	-1.6641 (.1381)		-3.3736 (.1772)	-6.4118 (.7784)
b			.4174 (.0551)		.5378 (.0779)	.4990 (.1072)
c	1.2478 (.0679)	.8769 (.0657)				
d		.6499 (.0744)	2.1516 (.3342)			
e						.4056 (.0936)
k	.5195 (.0364)	.5197 (.0365)	1.4203 (.0984)		1.0356 (.2306)	1.0187 (.2281)
AIC	4898	4900	3858		1343	1342
BIC	4913	4920	3878		1358	1361



### A.3.2.4 Four-leg Signalized (4SG)

#### Average Condition SPFs (Urban/Suburban Arterial 4SG)

4SG: Average Condition Models (2762 Intersections)						
Parameter	Total Crashes		KABC		KAB	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-6.5416 (.8030)	-5.0487 (.7059)	-9.1332 (1.0224)	-7.4564 (.8971)	-8.3011 (1.2209)	-6.6871 (1.0800)
b	.1953 (.0475)	.1557 (.0579)	.1646 (.0566)	.1467 (.0691)	.2321 (.0651)	.2707 (.0803)
c	.7936 (.0908)	.5588 (.0810)	.9270 (.1149)	.6469 (.1021)	.7472 (.1367)	.4391 (.1223)
d	.5937 (.1074)	.4879 (.0691)	.5170 (.1253)	.4237 (.0807)	.4780 (.1474)	.3458 (.0972)
e		.1261 (.0357)		.1569 (.0446)		.1876 (.0564)
k	.4828 (.0147)	.4845 (.0147)	.5126 (.0211)	.5143 (.0212)	.5557 (.0303)	.5568 (.0303)
AIC	20981	20992	14165	14175	10542	10549
BIC	21010	21028	14195	14211	10571	10585
Parameter	KA		Night		Single Vehicle	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-13.2609 (.7103)	-9.5336 (.6849)	-10.1801 (1.1240)	-9.0375 (.5200)	-6.8222 (.5084)	-6.5376 (.4791)
b			.1315 (.0612)			
c	1.1325 (.0714)	.7620 (.0726)	.9940 (.1261)	.7572 (.0384)	.5948 (.0509)	.3372 (.0517)
d	.5179 (.2406)	.5510 (.0673)	1.0550 (.1365)	.5064 (.0895)		
e				.2041 (.0505)	.1534 (.0401)	.2553 (.0329)
k	.5886 (.0871)	.5927 (.0873)	.5690 (.0250)	.5686 (.0250)	.5442 (.0503)	.5442 (.0504)
AIC	4708	4712	12766	12767	7154	7155
BIC	4732	4736	12796	12797	7177	7179
Parameter	Multi Vehicle		Right Angle		Left Turn	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-6.9130 (.8313)	-5.3363 (.7306)	-8.9004 (.3834)	-6.1909 (.5136)	-14.8858 (.5633)	-12.9295 (.7904)
b	.2002 (.0491)	.1633 (.0598)				
c	.8225 (.0940)	.5771 (.0838)	.9078 (.0390)	.5298 (.0399)	1.4799 (.0562)	1.0232 (.0567)
d	.6003 (.1107)	.5013 (.0712)	.9175 (.1454)	.4309 (.0930)		.2857 (.1344)
e		.1285 (.0367)		.1416 (.0499)	.1474 (.0416)	.2983 (.0765)
k	.5108 (.0156)	.5130 (.0156)	.7297 (.0292)	.7276 (.0291)	1.1633 (.0551)	1.1612 (.0550)
AIC	20647	20659	13498	13494	9775	9775
BIC	20676	20695	13521	13524	9798	9805
Parameter	Rear End		Sideswipe Same Direction		Head-on plus Sideswipe Opposite I	
	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)	Model A Est(SE)	Model B Est(SE)
a	-11.3634 (1.0432)	-8.9202 (.9165)	-15.9836 (.4980)	-12.1290 (.6932)	-12.4167 (.7267)	-14.4145 (1.9958)
b	.1198 (.0585)	.1394 (.0707)				-.3545 (.1389)
c	1.2161 (.1174)	.8432 (.1034)	1.5479 (.0503)	.9949 (.0499)	1.0288 (.0733)	1.1465 (.2256)
d	.3748 (.1273)	.4316 (.0830)	.9947 (.1666)	.5336 (.1141)	.9905 (.2467)	.3027 (.1570)
e		.1674 (.0442)		.2252 (.0659)		.2209 (.1010)
k	.6199 (.0213)	.6256 (.0214)	.7682 (.0400)	.7761 (.0403)	.5915 (.0914)	.5867 (.0910)
AIC	16623	16646	10013	10028	4566	4567
BIC	16653	16682	10037	10058	4590	4603

**Average Condition SPFs (Urban/Suburban Arterial 4SG) (contd.)**

**4SG: Average Condition Models (2762 Intersections), *contd.***

Parameter	Multi vehicle other	
	Model A Est(SE)	Model B Est(SE)
<b>a</b>	-1.3504 ( .0713)	
<b>b</b>	.1676 ( .0246)	
<b>c</b>		
<b>d</b>	.9351 ( .1842)	
<b>e</b>		
<b>k</b>	.9319 ( .0505)	
<b>AIC</b>	9018	
<b>BIC</b>	9041	

## APPENDIX B: CRASH SEVERITIES – ORDERED PROBIT FRACTIONAL SPLIT MODELING APPROACH

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### B.1 OVERVIEW

In general, crashes are classified into five severity levels: (K) fatal injury; (A) incapacitating injury; (B) non-incapacitating injury; (C) possible injury; and (O) no injury or property damage only. For analyzing the crash severities, several methodologies were attempted. At the first attempt, the research team developed ordered logit and probit models using each crash as an observation. In the preliminary results, some roadway geometric characteristics were found to be statistically significant. The preliminary results showed that higher maximum speed limits and paved shoulders decrease the severity of the crash whereas wider lanes increase it. Nevertheless, it is suspected that omitted variable bias occurred in the models as they do not include individual characteristics (e.g., driver, passenger, vehicle, etc.). An alternative approach to investigate crashes by severity was proposed in this research. As opposed to modeling the number of crashes, the research team explored a fractional split modeling approach to study the proportion of crashes by each severity level. The methodology and modeling results from this section is excerpted from the paper by Yasmin et al. (2016).

### B.2 METHODOLOGY

This section explains the formulation of the Ordered Probit Fractional Split (OPFS) approach for modeling the proportion of crashes by severity level. It should be noted that traditional maximum likelihood approaches were not suited for fractional split models and the research team relied on a quasi-likelihood approach (Papke & Woolridge, 1993). Let  $q$  ( $q = 1, 2, \dots, Q$ ) be an index to represent the road segment, and let  $k$  ( $k = 1, 2, 3, \dots, K$ ) be an index to represent the severity category. The latent propensity equation for the severity category at the  $q^{\text{th}}$  site is given as follows.

$$y_q^* = \alpha' z_q + \xi_q, \quad (\text{B.1})$$

This latent propensity,  $y_q^*$ , is mapped to the actual severity category proportion,  $y_{qk}$ , by the  $\psi$  thresholds ( $\psi_0 = -\infty$  and  $\psi_K = \infty$ ).  $z_q$  is an  $(L \times 1)$  column vector of attributes (not including the constant) that influences the propensity associated with the severity category;  $\alpha$  is a corresponding  $L \times 1$  column vector of mean effects.  $\xi_q$  is an idiosyncratic random error term assumed to be identically and independently standard normal distributed across segments,  $q$ .

The model cannot be estimated using conventional Maximum Likelihood approaches. Hence we resort to a quasi-likelihood based approach for our methodology. The parameters to be estimated in Equation (B.1) are  $\alpha$  and the  $\psi$  thresholds. To estimate the parameter vector, we assume the following:

$$E(y_{qk}|z_{qk}) = H_{qk}(\alpha, \psi); 0 \leq H_{qk} \leq 1; \sum_{k=1}^K H_{qk} = 1 \quad (\text{B.2})$$

$H_{qk}$  in our model takes the ordered probit probability ( $P_{qk}$ ) form for severity category  $k$  defined as

$$P_{qk} = \{G[\psi_k - \alpha_q' z_q] - G[\psi_{k-1} - \alpha_q' z_q]\} \quad (\text{B.3})$$

The proposed model ensures that the proportion for each severity category is between 0 and 1 including the limits. Then, the quasi-likelihood function, for a given value of  $\delta_q$  vector may be written for site  $q$  as shown in Equation (B.4). See Papke and Woolridge (1993) for a discussion on asymptotic properties of the quasi-likelihood, proposed.

$$L_q(\alpha, \psi) = \prod_{k=1}^K \{G[\psi_k - \alpha_q' z_q] - G[\psi_{k-1} - \alpha_q' z_q]\}^{d_{qk}} \quad (\text{B.4})$$

where  $G(\cdot)$  is the cumulative distribution of the standard normal distribution and  $d_{qk}$  is the proportion of crashes in severity category  $k$ .

### B.3 DATA PREPARATION

The three-year data (2009-2011) used in this study were obtained from Florida's multilane highway segments. The crashes were classified by the number of crash-involved vehicles: single-vehicle (SV) and multi-vehicle (MV) crashes. Subsequently, the MV crashes are further classified by manner of collision: head-on, rear-end, angle, and sideswipe. Table B-1 provides the severity proportions by crash type. The collected data consist of lane widths, shoulder widths, posted speed limits, and median divisions. If a segment has no crashes, data from the segment cannot be used for modeling. Thus, the crash data were aggregated by arterial because there were segments without a crash. The weighted average for traffic and roadway data by segment length of candidate independent variables was calculated (Table B-2).

**Table B-1: Proportion of Crashes by Severity**

Crash Type	Property Damage Only	Minor Injury	Non-incapacitating Injury	Incapacitating injury	Fatal injury	Sample Size
Single Vehicle	0.406	0.208	0.228	0.135	0.023	124
Head-on	0.261	0.292	0.197	0.173	0.076	59
Rear-end	0.427	0.322	0.205	0.046	0.001	126
Angular	0.521	0.254	0.157	0.065	0.004	114
Sideswipe	0.794	0.082	0.077	0.046	0.000	100

**Table B-2: Descriptive Statistics**

Variable	Description	Mean	Standard Deviation	Minimum	Maximum
w_aadt	Average AADT weighted by segment length	22,618	11,380	2500	50,000
w_kfctr	Average K-factor weighted by segment length	8.998	0.354	7.50	9.50
w_dfctr	Average D-factor weighted by segment length	58.565	8.940	50.80	99.90
w_tfctr	Average T-factor weighted by segment length	5.421	3.591	1.00	20.75
length	Segment length (sum of segment length)	5.756	6.471	0.143	33.585
w_lw	Average lane width weighted by segment length	11.857	0.433	10	13
w_sw	Average shoulder width weighted by segment length	4.101	1.811	1.5	10
p_div	Proportion of divided segment (opposed to undivided)	0.946	0.192	0.000	1.000
w_speed	Average speed limit width weighted by segment length	46.135	7.929	30	65

## B.4 MODELING RESULTS

### B.4.1 Single-Vehicle Crash Model

The coefficients in Table B-3 represent the estimation results of the SV crash model. The threshold parameters identify the demarcation points between severity categories and have no substantial interpretation. With respect to traffic volume, lower weighted average AADTs (weighted average AADT < 10000 vpd) categories were found to be associated with lower proportions of severe crash injury outcomes relative to the higher weighted average AADT category (weighted average AADT  $\geq$  10000 vpd). As expected, for narrower lanes (weighted average lane widths less than 12 ft), proportions of higher injury severity levels were found to be higher in SV crash events relative to SV crashes on wider lanes (Weighted average lane width  $\geq$  12 ft). Narrow shoulder widths are also found to be positively associated with higher proportions of SV crashes. We found that severe SV crashes are higher in the locations with narrow shoulders (weighted average shoulder width < 3 ft) compared to road sections with wider shoulders. It is speculated that narrower lanes or shoulders may provide less space and less scope for error correction in the event of an impending crash, which in turn may result in more severe SV crashes (for instance run-off-road crashes). As expected, the indicator variable representing higher speed limits (weighted average speed > 50 mph) increases the proportion of severe SV crashes compared to lower speed limit locations. From the results of interaction terms, it is interpreted that the effect of lower volumes (weighted average AADT < 20000 vpd) in a lower speed limit location (weighted average speed  $\leq$  40 mph) increases the proportion of property damage only SV crashes. On the other hand, roadways with lower volumes (weighted average AADT < 20000 mph) and wider shoulders (weighted average shoulder width > 5 ft) increase the likelihood of more severe SV crashes. This is possible due to the sense of false safety that drivers feel under low traffic conditions.

**Table B-3: Modeling Result for Single-Vehicle Crash Proportion by Severity**

Explanatory Variables	Coefficient (t-stat)
<i>Threshold Parameters</i>	
Threshold between property damage only and minor injury	-0.011 (-0.106)
Threshold between minor and non-incapacitating injury	0.533 (5.226)
Threshold between non-incapacitating and incapacitating injury	1.269 (11.367)
Threshold between incapacitating and fatal injury	2.299 (11.164)
<i>Weighted average AADT (Base: Weighted average AADT &gt;10000 vpd)</i>	
Weighted average AADT <10000 vpd	-0.403 (-2.125)
<i>Weighted average lane width (Base: Weighted average lane width ≥ 12 ft)</i>	
Weighted average lane width less than 12 ft	0.207 (1.926)
<i>Weighted average shoulder width (Base: Weighted average shoulder width ≥ 3 ft)</i>	
Weighted average shoulder width < 3 ft	0.164 (1.186)
<i>Weighted average speed (base: Weighted average speed ≤ 50 mph)</i>	
Weighted average speed > 50 mph	0.468 (3.607)
<i>Interaction terms</i>	
Weighted average speed ≤ 40×Weighted average AADT < 20000 vpd	-0.340 (-1.466)
Weighted average shoulder width greater than 5 ft ×Weighted average AADT < 20000 vpd	0.542 (2.268)

**B.4.2 Multi-Vehicle Crash Model**

The coefficients in Table B-4 represent the estimation results of MV crash models. In terms of traffic volume, MV model results suggest that the impact of weighted average AADT variables varies across different MV collision types. Increase in weighted average AADT increases the likelihood of more severe rear-end crashes. On the other hand, lower AADTs (weighted average AADT < 20000 vpd) have a positive association with more severe angular crashes. The results related to rear-end collisions are perhaps indicating lower headways in higher traffic volume. On the other hand, speeding during low volume conditions may result in more severe angular collisions. Sideswipe collision results reveal lower proportions of severe crash outcomes for higher volumes (weighted average AADT 20000-30000 vpd and weighted average AADT >30000 vpd) relative to lower volumes (weighted average AADT < 20000 vpd) conditions. Results related to weighted average T-factors indicate an increase in severe crash proportions for rear-end collisions. The weighted average shoulder width has no significant impact on head-on and rear-end crashes. From the model estimates, we found that in the presence of wider shoulders (weighted

average shoulder width > 5 ft) on roadways, the possibility of more severe angular collisions increases. On the contrary, narrow shoulders (weighted average shoulder width < 3 ft) on roadway sections increase the possibility of more severe sideswipe crashes. In the presence of narrower shoulders, drivers presumably exhibit unsafe behaviors by shifting towards the left-most side of the lane and thereby increase the possibility of more severe sideswipe crashes. The weighted average lane width has a significant impact in the rear-end collision model only. We found that, for rear-end collisions, the likelihood of more severe crashes increases in the presence of wider lane widths. It is possible that drivers are less conscious of vehicles in the presence of wider lanes resulting in more rear-end crashes. Higher proportions of divided segments increase the possibility of more severe head-on and sideswipe collisions, with greater impact on head-on collisions followed by sideswipe collisions. In terms of the weighted average speed limit, higher speed limits (weighted average speed > 50 mph indicator relative to lower speed limit) have a positive impact on the proportion of both head-on and angular collisions. It is interesting to note that the speed limit does not influence rear-end and sideswipe collision proportions. Among interaction terms, the head-on collision model reveals a positive impact of the weighted average speed,  $\leq 40$  mph, in low traffic volume conditions (weighted average AADT < 30000 vpd) on severe crash proportions. Finally, the interaction term representing wider shoulder widths (weighted average shoulder width > 5 ft) and weighted average AADT < 20000 vpd increases the probability of more severe rear-end crashes and reduces the possibility of more severe angular collision.

**Table B-4: Modeling Results for Multi-Vehicle Crash Proportion by Severity**

Explanatory Variables	Collision Types			
	Head-on	Rear-end	Angular	Sideswipe
	Coefficient (t-stat)	Coefficient (t-stat)	Coefficient (t-stat)	Coefficient (t-stat)
<i>Threshold Parameters</i>				
Threshold between property damage only and minor injury	1.503 (1.027)	2.260 (1.376)	0.228 (2.888)	1.565 (3.039)
Threshold between minor and non-incapacitating injury	2.315 (1.595)	3.122 (1.910)	0.944 (10.115)	1.915 (3.680)
Threshold between non-incapacitating and incapacitating injury	2.888 (1.963)	4.139 (2.500)	1.682 (15.367)	2.475 (4.501)
Threshold between incapacitating and fatal injury	3.697 (2.509)	5.500 (3.345)	2.915 (15.640)	6.384 (9.214)
<i>Weighted average AADT</i>				
<i>Weighted average AADT/1000</i>	-	0.098 (1.822)	-	-
Weighted average AADT <20000 vpd	-	-	0.239 (1.675)	-
Weighted average AADT 20000-30000 vpd	-	-	-	-0.456 (-1.902)
Weighted average AADT >30000 vpd	-	-	-	-0.491 (-2.486)
<i>Weighted average T-factor</i>	-	0.276 (1.035)	-	-
<i>Weighted average shoulder width</i>				
Weighted average shoulder width <3 ft	-	-	-	0.303 (1.208)
Weighted average shoulder width 3-5 ft	-	-	-	-
Weighted average shoulder width > 5 ft	-	-	0.344 (1.892)	-
<i>Weighted average lane width</i>	-	0.177 (1.255)	-	-
<i>Proportion of divided segments (opposed to undivided)</i>	1.904 (1.277)	-	-	1.001 (1.848)
<i>Weighted average speed</i>				
Weighted average speed ≤ 50 mph	-	-	-	-
Weighted average speed > 50 mph	0.622 (2.379)	-	0.226 (1.810)	-
<i>Interaction terms</i>				
Weighted average speed ≤ 40×Weighted average AADT <30000 vpd	0.663 (1.779)	-	-	-
Weighted average shoulder width greater than 5 ft ×Weighted average AADT <20000 vpd	-	0.276 (1.035)	-1.078 (-3.722)	-



## B. 5 CONCLUSIONS

Traditionally, the transportation safety literature has evolved along two major streams: crash frequency analysis and crash severity analysis. In crash frequency analysis, the focus is on identifying attributes that result in traffic crashes and effective countermeasures to improve the roadway design and operational attributes are proposed. On the other hand, crash severity analysis is focused on examining crash events, identifying factors that impact the crash outcome and providing solutions to reduce the consequences in unfortunate events (injuries and fatalities) of traffic crashes. More recently, the research in transportation safety has focused on bridging the gap between crash frequency models and crash severity models. Specifically, researchers are examining crash frequency levels by severity while recognizing that for the same observation record, crash frequencies by different levels of severity are likely to be dependent. Hence, as opposed to adopting the univariate crash frequency models as earlier, researchers developed multivariate crash frequency models.

In multivariate approaches that are aimed at studying frequency and severity, the impact of exogenous variables is quantified through the propensity component of count models. The main interaction across different severity level variables is sought through unobserved effects. That is, there is no interaction of observed effects across the multiple count models. While this might not be a limitation per se, it might be beneficial to evaluate the impact of exogenous variables in the framework that directly relates a single exogenous variable to all severity count variables simultaneously. It is a framework where the observed propensities of crashes by severity level are modeled directly, while also recognizing the inherent ordering of crash severity outcomes.

The fractional split approach is not without limitations. In field data, there are often no crashes for specific types in a segment. In this case, such segment cannot be used for modeling. In order to prevent zero crashes, the research team aggregated segments into an arterial. It means we assumed that the severity proportions are consistent in an arterial, which is not very practical. In addition, once we aggregate the segments, roadway segment specific information is lost. In the future, if the crash data are sufficiently obtained by segments so that there are very few segments without a crash for particular collision types, the fractional split approach would be a very useful and practical methodology.



## **APPENDIX C: DRAFT CONTENT FOR HIGHWAY SAFETY MANUAL, 2<sup>ND</sup> EDITION**

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This appendix includes suggested markup of existing content in the *Highway Safety Manual*, 1<sup>st</sup> Edition, 2010, published by AASHTO (HSM1) to incorporate the results of this project for the 2<sup>nd</sup> Edition of the Manual (HSM2). Existing HSM1 chapters and appendices are marked up with insertions underlined and deletions marked in margin balloons. Comments are also inserted to indicate changes that are required requiring content or information that was beyond the scope of this project. We note that other NCHRP projects are likely generating content that would also be incorporated into these chapters; we leave it to the HSM2 contractor to combine all of these revisions.

Following are the HSM1 chapters and appendices that are marked up:

- Chapter 10: Predictive Method For Rural Two-Lane, Two-Way Roads
- Chapter 11: Predictive Method For Rural Multilane Highways
- Chapter 12: Predictive Method For Urban And Suburban Arterials
- Appendix A: Specialized Procedures Common To All Part C Chapters

These marked up chapters follow, each paginated independently for consistency with the existing HSM1 content.



## CHAPTER 10. PREDICTIVE METHOD FOR RURAL TWO-LANE, TWO-WAY ROADS

### 10.1. INTRODUCTION

This chapter presents the predictive method for rural two-lane, two-way roads. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in the Part C—Introduction and Applications Guidance.

The predictive method for rural two-lane, two-way roads provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for a rural two-lane, two-way facility with known characteristics. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians and animal crashes. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency of a prior time period (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the predictive method in Chapter 10 is documented by Harwood et al. (5), Ivan et al. (x). In some cases, SPFs could not be reliably estimated and alternative crash prediction approaches need to be considered. Guidelines for developing those approaches are provided in Chapter 14 under the heading “Guidelines for HSM users for crash predictions where SPFs could not be reliably estimated”

This chapter presents the following information about the predictive method for rural two-lane, two-way roads:

- A concise overview of the predictive method.
- The definitions of the facility types, crash types and severity levels included in Chapter 10 and site types for which predictive models have been developed for Chapter 10.
- The steps of the predictive method in graphical and descriptive forms.

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**Commented [IJ2]:** 17-71: Update reference to NCHRP 17-62 report when it is completed.

- Details for dividing a rural two-lane, two-way facility into individual sites consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for rural two-lane, two-way roads by crash type and severity level.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 10.
- Guidance for applying the Chapter 10 predictive method and limitations of the predictive method specific to Chapter 10.
- Sample problems illustrating the Chapter 10 predictive method for rural two-lane, two-way roads.

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## 10.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the “expected average crash frequency,”  $N_{\text{expected}}$  (by total crashes, crash severity and collision type), of a roadway network, facility, or site. In the predictive method, the roadway is divided into individual sites which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments referred to as “sites.” Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type, a number of different site types may exist, such as divided and undivided roadway segments and signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities.

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The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The estimate relies on estimates made using predictive models which are combined with observed crash data using the Empirical Bayes (EB) Method.

The predictive models used within the Chapter 10 predictive method are described in detail in Section 10.3.

The predictive models used in Chapter 10 to determine the predicted average crash frequency,  $N_{\text{predicted}}$ , are of the general form shown in Equation 10-1.

$$N_{\text{predicted}} = N_{\text{spf } x} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) \times C_x \quad (10-1)$$

Where:

$N_{\text{predicted}}$  = predicted average crash frequency for a specific year for site type  $x$ ;

$N_{\text{spf } x}$  = predicted average crash frequency determined for base conditions of the SPF developed for site type  $x$ ;

$CMF_{1x}$  = crash modification factors specific to site type  $x$  and specific geometric design and traffic control features  $y$ ; and

$C_x$  = calibration factor to adjust SPF for local conditions for site type  $x$ .

**Commented [IJ6]:** 17-71: Note that CMFs that apply to the new crash type and severity SPFs must be identified and added to the Chapter. Existing CMFs may be suitable for the models for total crashes of all severities. This issue arises many places in this chapter as well as 11 and 12. These will be marked with the comment “note CMF issue”

## 10.3. RURAL TWO-LANE, TWO-WAY ROADS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 10

This section provides the definitions of the facility and site types, along with crash types and crash severities, and the predictive models for each of the site types included in Chapter 10. These predictive models are applied following the steps of the predictive method presented in Section 10.4.

10.3.1. Definition of Chapter 10 Facility and Site Types

The predictive method in Chapter 10 addresses all types of rural two-lane, two-way highway facilities, including rural two-lane, two-way highways with center two-way left-turn lanes or added passing lanes, and rural two-lane, two-way highways containing short sections of rural four-lane highway that serve exclusively to increase passing opportunities (i.e., side-by-side passing lanes). Facilities with four or more lanes are not covered in Chapter 10.

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The terms “highway” and “road” are used interchangeably in this chapter and apply to all rural two-lane, two-way facilities independent of official state or local highway designation.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas is based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas which have a population less than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area.

Table 10-1 identifies the site types on rural two-lane, two-way roads for which SPFs have been developed for predicting average crash frequency, severity, and collision type.

Table 10-1. Rural Two-Lane, Two-Way Road Site Type with SPFs in Chapter 10

Site Type	Site Types with SPFs in Chapter 10
Roadway Segments	Undivided rural two-lane, two-way roadway segments (2U)
	Unsignalized three-leg (stop control on minor-road approaches) (3ST)
Intersections	Unsignalized four-leg (stop control on minor-road approaches) (4ST)
	Signalized four-leg (4SG)

These specific site types are defined as follows:

- *Undivided roadway segment (2U)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier. In addition, the definition includes a section with three lanes where the center lane is a two-way left-turn lane (TWLTL) or a section with added lanes in one or both directions of travel to provide increased passing opportunities (e.g., passing lanes, climbing lanes, and short four-lane sections).
- *Three-leg intersection with stop control (3ST)*—an intersection of a rural two-lane, two-way road and a minor road. A stop sign is provided on the minor road approach to the intersection only.
- *Four-leg intersection with stop control (4ST)*—an intersection of a rural two-lane, two-way road and two minor roads. A stop sign is provided on both minor road approaches to the intersection.
- *Four-leg signalized intersection (4SG)*—an intersection of a rural two-lane, two-way road and two other rural two-lane, two-way roads. Signalized control is provided at the intersection by traffic lights.

10.3.2. Definition of Chapter 10 Crash Types and Severity Levels

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Following is the list of crash types that were estimated for facility and site types in Chapter 10:

- Same Direction (SD) Crashes, including rear-end (RE), sideswipe same direction (SSD) and turning same direction (TSD);
- Intersecting Direction (ID) Crashes, including angle (ANG) and turning intersecting direction (TID);

- Opposite Direction (OD) Crashes, including head one (HO), sideswipe opposite direction (SOD) and turning opposite direction (TOD); and
- Single Vehicle (SV) Crashes, including rollover or overturn (RO), fixed object (FO) and moving object (MO).

Note that animal collisions are not included in any of the crash types (they are most likely to be identified as single-vehicle crashes). Also, SPFs for ID crashes were not estimated for segments because crashes of this type were all coded as intersection crashes.

Crashes are classified into five severity levels: fatal injury (K); incapacitating injury (A); non-incapacitating injury (B); possible injury (C); and no injury or property damage only (O). Cumulative crash count SPFs are provided, building from the highest level, e.g., KA indicates K and A level crashes, KAB indicates K, A and B crashes, etc. KABCO crash count SPFs predict crashes at all severity levels for the respective crash type or total crashes.

### 10.3.3. Predictive Models for Rural Two-Lane, Two-Way Roadway Segments

The predictive models can be used to estimate total predicted average crash frequency (i.e., all crash severities and collision types) or can be used to predict average crash frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines a SPF with CMFs and a calibration factor.

For rural two-lane, two-way undivided roadway segments the predictive model is shown in Equation 10-2:

$$N_{\text{predicted } rs} = N_{\text{spf } rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{12r}) \quad (10-2)$$

Where:

$N_{\text{predicted } rs}$  = predicted average crash frequency for an individual roadway segment for a specific year;

$N_{\text{spf } rs}$  = predicted average crash frequency for base conditions for an individual roadway segment;

$C_r$  = calibration factor for roadway segments of a specific type developed for a particular jurisdiction or geographical area; and

$CMF_{1r} \dots CMF_{12r}$  = crash modification factors for rural two-lane, two-way roadway segments.

This model estimates the predicted average crash frequency of non-intersection related crashes (i.e., crashes that would occur regardless of the presence of an intersection).

### 10.3.4. Predictive Models for Rural Two-Lane, Two-Way Intersections

The predictive models for intersections estimate the predicted average crash frequency of crashes occurring within the limits of an intersection (i.e., at-intersection crashes) and crashes that occur on the intersection legs and are attributed to the presence of an intersection (i.e., intersection-related crashes).

For all intersection types in Chapter 10 the predictive model is shown in Equation 10-3:

$$N_{\text{predicted } int} = N_{\text{spf } int} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{4i}) \quad (10-3)$$

Where:

$N_{\text{predicted } int}$  = predicted average crash frequency for an individual intersection for the selected year;



$N_{spf\ int}$  = predicted average crash frequency for an intersection with base conditions;

$CMF_{I1} \dots CMF_{4i}$  = crash modification factors for intersections; and

$C_i$  = calibration factor for intersections of a specific type developed for use for a particular jurisdiction or geographical area.

The SPFs for rural two-lane, two-way roads are presented in Section 10.6. The associated CMFs for each of the SPFs are presented in Section 10.7 and summarized in Table 10-7. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors,  $C_r$  and  $C_i$ , are determined in the Part C, Appendix A.1.1. Due to continual change in the crash frequency and severity distributions with time, the value of the calibration factors may change for the selected year of the study period.

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#### 10.4. PREDICTIVE METHOD FOR RURAL TWO-LANE, TWO-WAY ROADS

The predictive method for rural two-lane, two-way road is shown in Figure 10-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for a rural two-lane, two-way facility. The components of the predictive models in Chapter 10 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information that is needed to apply each step is provided in the following sections and in the Part C, Appendix A.

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There are 18 steps in the predictive method. In some situations, certain steps will not be needed because the data is not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated, such as if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario, or proposed treatment option within the same period to allow for comparison.

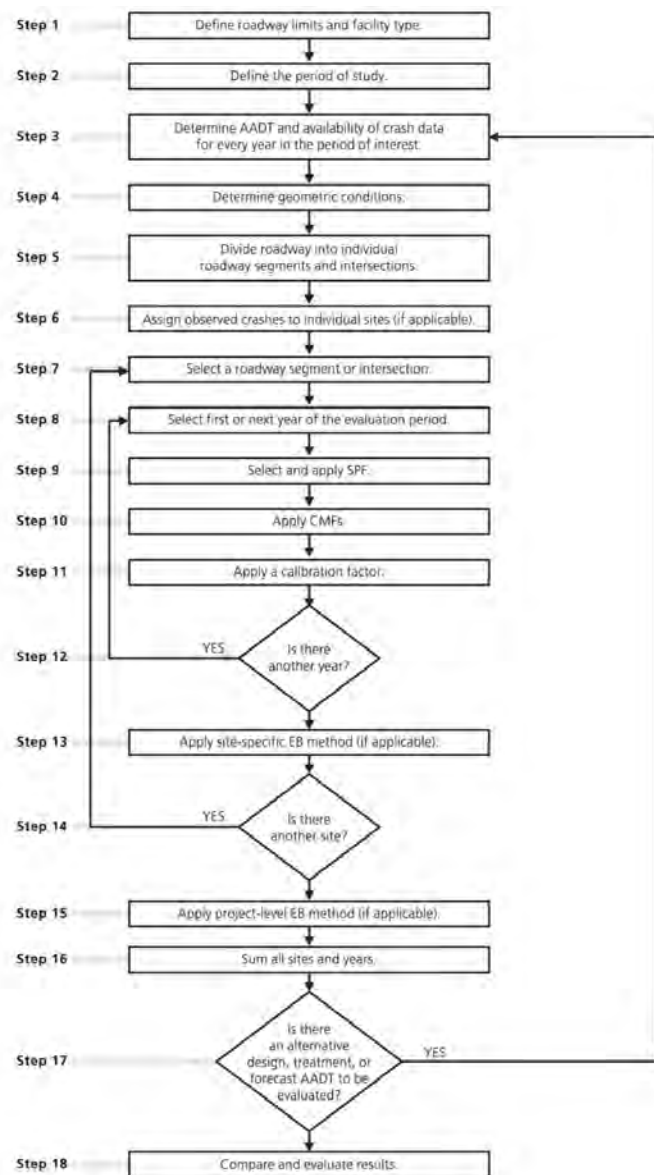
The following explains the details of each step of the method as applied to two-lane, two-way rural roads.

##### Step 1—Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated.

The predictive method can be undertaken for a roadway network, a facility, or an individual site. A site is either an intersection or a homogeneous roadway segment. There are a number of different types of sites, such as signalized and unsignalized intersections. The definitions of a rural two-lane, two-way road, an intersection, and a roadway segment, along with the site types for which SPFs are included in Chapter 10, are provided in Section 10.3.

The predictive method can be applied to an existing roadway, a design alternative for an existing roadway, or a design alternative for new roadway (which may be either unconstructed or yet to experience enough traffic to have observed crash data).

The limits of the roadway of interest will depend on the nature of the study. The study may be limited to only one specific site or a group of contiguous sites. Alternatively, the predictive method can be applied to a long corridor for the purposes of network screening (determining which sites require upgrading to reduce crashes) which is discussed in Chapter 4.



**Figure 10-1.** The HSM Predictive Method

**Step 2—Define the period of interest.**

The predictive method can be undertaken for either a past or future period measured in years. Years of interest will be determined by the availability of observed or forecast average annual daily traffic (AADT) volumes, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

- A past period (based on observed AADTs) for:
  - An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features, and traffic volumes are known.
  - An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).
- A future period (based on forecast AADTs) for:
  - An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
  - An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
  - A new roadway network, facility, or site that does not currently exist, but is proposed for construction during some future period.

**Step 3—For the study period, determine the availability of annual average daily traffic volumes and, for an existing roadway network, the availability of observed crash data to determine whether the EB Method is applicable.**

#### *Determining Traffic Volumes*

The SPFs used in Step 9 (and some CMFs in Step 10), include AADT volumes (vehicles per day) as a variable. For a past period, the AADT may be determined by automated recording or estimated from a sample survey. For a future period the AADT may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models, or based on the assumption that current traffic volumes will remain relatively constant.

For each roadway segment, the AADT is the average daily two-way, 24-hour traffic volume on that roadway segment in each year of the evaluation period selected in Step 8.

For each intersection, two values are required in each predictive model. These are the AADT of the major street,  $AADT_{maj}$ , and the two-way AADT of the minor street,  $AADT_{min}$ .

In Chapter 10,  $AADT_{maj}$  and  $AADT_{min}$  are determined as follows. If the AADTs on the two major road legs of an intersection differ, the larger of the two AADT values is used for the intersection. For a three-leg intersection, the minor road AADT is the AADT of the single minor road leg. For a four-leg intersection, if the AADTs of the two minor road legs differ, the larger of the two AADTs values is used for the intersection. If AADTs are available for every roadway segment along a facility, the major road AADTs for intersection legs can be determined without additional data.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated as appropriate. If there is no established procedure for doing this, the following default rules may be applied within the predictive method to estimate the AADTs for years for which data are not available.

- If AADT data are available for only a single year, that same value is assumed to apply to all years of the before period.
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation.
- The AADTs for years before the first year for which data are available are assumed to be equal to the AADT for that first year.
- The AADTs for years after the last year for which data are available are assumed to be equal to the last year.

If the EB Method is used (discussed below), AADT data are needed for each year of the period for which observed crash frequency data are available. If the EB Method will not be used, AADT data for the appropriate time period—past, present, or future—determined in Step 2 are used.

***Determining Availability of Observed Crash Data***

Where an existing site or alternative conditions to an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable observed crash data are available for the specific study roadway network, facility, or site. Observed data may be obtained directly from the jurisdiction's crash report system. At least two years of observed crash frequency data are desirable to apply the EB Method. **Crash counts must be gathered for each combination of crash type and severity (as defined in the previous sections) that is to be predicted.** The EB Method and criteria to determine whether the EB Method is applicable are presented in Part C, Appendix A.2.1.

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but cannot be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash data are not available, then Steps 6, 13, and 15 of the predictive method are not conducted. In this case, the estimate of expected average crash frequency is limited to using a predictive model (i.e., the predicted average crash frequency).

**Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the study network.**

In order to determine the relevant data needs and avoid unnecessary data collection, it is necessary to understand the base conditions of the SPFs in Step 9 and the CMFs in Step 10. The base conditions are defined in Section 10.6.1 for roadway segments and in Section 10.6.2 for intersections.

The following geometric design and traffic control features are used to select a SPF and to determine whether the site specific conditions vary from the base conditions and, therefore, whether a CMF is applicable:

- Length of segment (miles)
- AADT (vehicles per day)
- Lane width (feet)
- Shoulder width (feet)
- Shoulder type (paved/gravel/composite/turf)
- Presence or absence of horizontal curve (curve/tangent). If the segment has one or more curve:
  - Length of horizontal curve (miles), (this represents the total length of the horizontal curve and includes spiral transition curves, even if the curve extends beyond the limits of the roadway segment being analyzed);
  - Radius of horizontal curve (feet);
  - Presence or absence of spiral transition curve, (this represents the presence or absence of a spiral transition curve at the beginning and end of the horizontal curve, even if the beginning and/or end of the horizontal curve are beyond the limits of the segment being analyzed); and
  - Superelevation of horizontal curve and the maximum superelevation ( $e_{max}$ ) used according to policy for the jurisdiction, if available.
- Grade (percent), considering each grade as a straight grade from Point of Vertical Intersection (PVI) to PVI (i.e., ignoring the presence of vertical curves)
- Driveway density (driveways per mile)
- Presence or absence of centerline rumble strips
- Presence or absence of a passing lane
- Presence or absence of a short four-lane section
- Presence or absence of a two-way left-turn lane
- Roadside hazard rating

- Presence or absence of roadway segment lighting
- Presence or absence of automated speed enforcement

For all intersections within the study area, the following geometric design and traffic control features are identified:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor road stop or signal control)
- Intersection skew angle (degrees departure from 90 degrees)
- Number of approaches with intersection left-turn lanes (0, 1, 2, 3, or 4), not including stop-controlled approaches
- Number of approaches with intersection right-turn lanes (0, 1, 2, 3, or 4), not including stop-controlled approaches
- Presence or absence of intersection lighting

**Step 5—Divide the roadway network or facility under consideration into individual homogenous roadway segments and intersections which are referred to as sites.**

Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 10 predictive models are provided in Section 10.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will decrease data collection and management efforts.

**Step 6—Assign observed crashes to the individual sites (if applicable).**

Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, proceed to Step 7. In Step 3, the availability of observed data and whether the data could be assigned to specific locations was determined. The specific criteria for assigning crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

Crashes that occur at an intersection or on an intersection leg, and are related to the presence of an intersection, are assigned to the intersection and used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections and are not related to the presence of an intersection are assigned to the roadway segment on which they occur; such crashes are used in the EB Method together with the predicted average crash frequency for the roadway segment.

**Step 7—Select the first or next individual site in the study network. If there are no more sites to be evaluated, proceed to Step 15.**

In Step 5, the roadway network within the study limits is divided into a number of individual homogenous sites (intersections and roadway segments).

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, which is the sum of the all of the individual sites, for each year in the study, for each desired combination of crash type and severity. Note that this value will be the number of crashes expected to occur totaled over all sites during the period of interest. If a crash frequency (crashes per year) is desired, the prediction can be divided by the number of years in the period of interest.

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The estimation for each site (roadway segments or intersection) is conducted one at a time. Steps 8 through 14, described below, are repeated for each site.

**Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 15.**

Steps 8 through 14 are repeated for each site in the study and for each year in the study period.

The individual years of the evaluation period may have to be analyzed one year at a time for any particular roadway segment or intersection because SPFs and some CMFs (e.g., lane and shoulder widths) are dependent on AADT which may change from year to year.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features and the crash type and severity.**

Steps 9 through 13 are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 10 follow the general form shown in Equation 10-1. Each predictive model consists of an SPF for a particular crash type and severity, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site and that crash type and severity. The resultant value is the predicted average crash frequency for the selected year. The SPFs available for rural two-lane, two-way highways are presented in Section 10.6.

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The SPF (which is a statistical regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 10.6. A detailed explanation and overview of the SPFs in Part C is provided in Section C.6.3. Note that SPFs are provided for twenty (20) combinations of crash type and severity, that is, KABCO, KABC, KAB and KA count models for total, same direction, intersecting direction, opposite direction and single vehicle crashes.

The SPFs for specific site types (and base conditions) developed for Chapter 10 are summarized in Table 10-2. For the selected site, determine the appropriate SPF for the site type (roadway segment or one of three intersection types and the desired combination of crash type and severity). The SPF is calculated using the AADT volume determined in Step 3 (AADT for roadway segments or  $AADT_{maj}$  and  $AADT_{min}$  for intersections) for the selected year.

SPFs are provided for combinations of crash type (total crashes, same direction crashes, intersecting direction crashes, opposite direction crashes and single vehicle crashes) and crash severity (KABCO, KABC, KAB and KA). For some facility types, SPFs are not reported for one or more combinations of crash type and severity due to small crash sample size, poor model fit or unacceptable model estimation. No SPFs are provided for K only crashes due to small crash sample sizes. For K crashes of any type and other combinations of crash type and severity, for which SPFs were not estimated, users are recommended to compute distributions based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

**Deleted:** Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type. The default distributions are presented in Tables 10-3 and 10-4 for roadway segments and in Tables 10-5 and 10-6 for intersections.

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**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.**

In order to account for differences between the base conditions (Section 10.6) and site specific conditions, CMFs are used to adjust the SPF estimates by crash type and severity. An overview of CMFs and guidance for their use is provided in Section C.6.4. This overview includes the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Chapter 10 have the same base conditions as the SPFs used in Chapter 10 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 10.7 may be used as part of the Chapter 10 predictive method. Table 10-7 indicates which CMFs are applicable to the SPFs in Section 10.6.

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**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods. Calibration of the SPFs to local conditions will account for differences. A calibration factor ( $C_r$  for roadway segments or  $C_i$  for intersections) is applied to each SPF in the predictive method. An overview of the use of calibration factors is provided in Section C.6.5. Detailed guidance for the development of calibration factors is included in Part C, Appendix A.1.1.

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Steps 9, 10, and 11 together implement the predictive models in Equations 10-2 and 10-3 to determine predicted average crash frequency.

**Step 12—If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 13.**

This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

**Step 13—Apply site-specific EB Method (if applicable).**

Whether the site-specific EB Method is applicable is determined in Step 3. The site-specific EB Method combines the Chapter 10 predictive model estimate of predicted average crash frequency,  $N_{\text{predicted}}$ , with the observed crash frequency of the specific site,  $N_{\text{observed}}$ . This provides a more statistically reliable estimate of the expected average crash frequency of the selected site **for each crash type and severity**.

In order to apply the site-specific EB Method, overdispersion parameter,  $k$ , for the SPF is used. This is in addition to the material in Part C, Appendix A.2.4. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to  $N_{\text{predicted}}$  and  $N_{\text{observed}}$ . Overdispersion parameters are provided for each SPF in Section 10.6.

Apply the site-specific EB Method to a future time period, if appropriate.

The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Part C, Appendix A.2.6 provides method to convert the past period estimate of expected average crash frequency into **a future time period**.

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**Step 14—If there is another site to be evaluated, return to Step 7, otherwise, proceed to Step 15.**

This step creates a loop through Steps 7 to 13 that is repeated for each roadway segment or intersection within the facility.

**Step 15—Apply the project level EB Method (if the site-specific EB Method is not applicable).**

This step is only applicable to existing conditions when observed crash data are available, but cannot be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in Part C, Appendix A.2.5.

**Step 16—Sum all sites and years in the study to estimate total crash frequency.**

The total estimated number of crashes **for each crash type and severity** within the network or facility limits during a study period of  $n$  years is calculated using Equation 10-4:

$$N_{\text{total}} = \sum_{\text{all roadway segments}} N_{rs} + \sum_{\text{all intersections}} N_{int} \quad (10-4)$$

Where:

$N_{\text{total}}$  = total expected number of crashes **by type and severity** within the limits of a rural two-lane, two-way facility for the period of interest. Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits within the study period;

$N_{rs}$  = expected average crash frequency **by type and severity** for a roadway segment using the predictive method for one specific year; and

$N_{int}$  = expected average crash frequency **by type and severity** for an intersection using the predictive method for one specific year.

Equation 10-4 represents the total expected number of crashes estimated to occur during the study period **by type and severity**. Equation 10-5 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total average}} = \frac{N_{\text{total}}}{n} \quad (10-5)$$

Where:

$N_{\text{total average}}$  = total expected average crash frequency estimated to occur within the defined network or facility limits during the study period; and

$n$  = number of years in the study period.

**Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.**

Steps 3 through 16 of the predictive method are repeated, as appropriate, not only for the same roadway limits, but also for alternative conditions, treatments, periods of interest, or forecast AADTs.

**Step 18—Evaluate and compare results.**

The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time, for given geometric design and traffic control features, and known or estimated AADT. In addition to estimating total crashes, the estimate can be made for different crash severity types and different collision types. **As noted above, default distributions of crash severity and type are provided in Section 10.6 for combinations for which SPF's are not available. Users are strongly encouraged to update these default distributions** based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

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## 10.5. ROADWAY SEGMENTS AND INTERSECTIONS

Section 10.4 provides an explanation of the predictive method. Sections 10.5 through 10.8 provide the specific detail necessary to apply the predictive method steps in a rural two-lane, two-way road environment. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

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In Step 5 of the predictive method, the roadway within the defined roadway limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as "sites." A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections **by crash type and severity**. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA *Interactive Highway Safety Design Model* (IHSDM) (3).

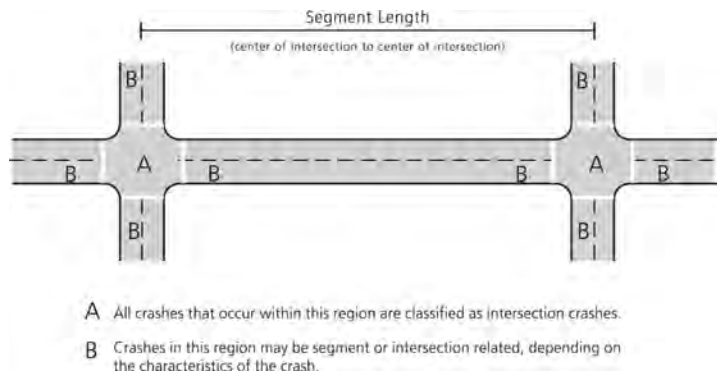
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Roadway segments begin at the center of an intersection and end at either the center of the next intersection, or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Figure 10-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

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The Chapter 10 predictive method addresses stop controlled (three- and four-leg) and signalized (four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 10-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 10-2).





**Figure 10-2.** Definition of Segments and Intersections

The segmentation process produces a set of roadway segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes, roadway design characteristics, and traffic control features. Figure 10-2 shows the segment length,  $L$ , for a single homogenous roadway segment occurring between two intersections. However, it is likely that several homogenous roadway segments will occur between two intersections. A new (unique) homogeneous segment begins at the center of each intersection or at any of the following:

- Beginning or end of a horizontal curve (spiral transitions are considered part of the curve).
- Point of vertical intersection (PVI) for a crest vertical curve, a sag vertical curve, or an angle point at which two different roadway grades meet. Spiral transitions are considered part of the horizontal curve they adjoin and vertical curves are considered part of the grades they adjoin (i.e., grades run from PVI to PVI with no explicit consideration of any vertical curve that may be present).
- Beginning or end of a passing lane or short four-lane section provided for the purpose of increasing passing opportunities.
- Beginning or end of a center two-way left-turn lane.

Also, a new roadway segment starts where there is a change in at least one of the following characteristics of the roadway:

- Average annual daily traffic volume (vehicles per day)
- Lane width  
For lane widths measured to a 0.1-ft level of precision or similar, the following rounded lane widths are recommended before determining “homogeneous” segments:

Measured Lane Width	Rounded Lane Width
9.2 ft or less	9 ft or less
9.3 ft to 9.7 ft	9.5 ft
9.8 ft to 10.2 ft	10 ft
10.3 ft to 10.7 ft	10.5 ft
10.8 ft to 11.2 ft	11 ft
11.3 ft to 11.7 ft	11.5 ft
11.8 ft or more	12 ft or more

- Shoulder width  
For shoulder widths measures to a 0.1-ft level of precision or similar, the following rounded paved shoulder widths are recommended before determining “homogeneous” segments:

Measured Shoulder Width	Rounded Shoulder Width
0.5 ft or less	0 ft
0.6 ft to 1.5 ft	1 ft
1.6 ft to 2.5 ft	2 ft
2.6 ft to 3.5 ft	3 ft
3.6 ft to 4.5 ft	4 ft
4.6 ft to 5.5 ft	5 ft
5.6 ft to 6.5 ft	6 ft
6.6 ft to 7.5 ft	7 ft
7.6 ft or more	8 ft or more

- Shoulder type
- Driveway density (driveways per mile)  
For very short segment lengths (less than 0.5-miles), the use of driveway density for the single segment length may result in an inflated value since driveway density is determined based on length. As a result, the driveway density used for determining homogeneous segments should be for the facility (as defined in Section 10.2) length rather than the segment length.
- Roadside hazard rating  
As described later in Section 10.7.1, the roadside hazard rating (a scale from 1 to 7) will be used to determine a roadside design CMF. Since this rating is a subjective value and can differ marginally based on the opinion of the assessor, it is reasonable to assume that a “homogeneous” segment can have a roadside hazard rating that varies by as much as 2 rating levels. An average of the roadside hazard ratings can be used to compile a “homogeneous” segment as long as the minimum and maximum values are not separated by a value greater than 2.

For example, if the roadside hazard rating ranges from 5 to 7 for a specific road, an average value of 6 can be assumed and this would be considered one homogeneous roadside design condition. If, on the other hand, the roadside hazard ratings ranged from 2 to 5 (a range greater than 2) these would not be considered “homogeneous” roadside conditions and smaller segments may be appropriate.

- Presence/absence of centerline rumble strip
- Presence/absence of lighting

- Presence/absence of automated speed enforcement

There is no minimum roadway segment length for application of the predictive models for roadway segments. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results.

In order to apply the site-specific EB Method, observed crashes **(by type and severity, or in total)** are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway-segment-related. The methodology for assignment of crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3.

## 10.6. SAFETY PERFORMANCE FUNCTIONS

In Step 9 of the predictive method, the appropriate safety performance functions (SPFs) are used to predict average crash frequency for the selected year for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for the HSM, the dependent variable estimated is the predicted average crash frequency **in total or by type and severity** for a roadway segment or intersection under base conditions and the independent variables are the AADTs of the roadway segment or intersection legs (and, for roadway segments, the length of the roadway segment).

The SPFs used in Chapter 10 were originally formulated by Vogt and Bared (13, 14, 15). **Updated SPFs were developed by Ivan et al. (x).**

The predicted crash frequencies for base conditions are calculated from the predictive models in Equations 10-2 and 10-3. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2, and C.6.3.

Each SPF also has an associated overdispersion parameter,  $k$ . The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. **This parameter is used in the EB Method discussed in Part C, Appendix A. The SPFs in Chapter 10 are summarized in Table 10-2. Note that SPFs are not provided for some combinations of crash type and severity level due to an insufficient number of observed crashes of that combination, failure of the estimated SPF to converge in the estimation process, estimated parameters failing modest significance tests, estimated parameters taking unrealistic values, or a combination of these reasons.**

**Table 10-2.** Safety Performance Functions included in Chapter 10

Chapter 10 SPFs for Rural Two-Lane, Two-Way Roads	SPF Equations and <del>Tables</del>
Rural two-lane, two-way roadway segments	Equation 10-6, <del>Table 10-</del>
Three-leg stop controlled intersections	Equation 10-8 <del>or 10-9</del> , <del>Table 10-</del>
Four-leg stop controlled intersections	Equation <del>10-8 or 10-9</del> , <del>Table 10-</del>
Four-leg signalized intersections	Equation <del>10-8 or 10-9</del> , <del>Table 10-</del>

Some highway agencies may have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience. These models may be substituted for models presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Part C, Appendix A.

### 10.6.1. Safety Performance Functions for Rural Two-Lane, Two-Way Roadway Segments

The predictive model for predicting average crash frequency for base conditions on a particular rural two-lane, two-way roadway segment was presented in Equation 10-2. The effect of traffic volume (AADT) on crash frequency is

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**Deleted:** A few aspects of the Harwood et al. (5) and Vogt and Bared (13, 14, 15) work have been updated to match recent changes to the crash prediction module of the FHWA *Interactive Highway Safety Design Model* (3) software. The SPF coefficients, default crash severity and collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (12).

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incorporated through an SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs.

The base conditions for roadway segments on rural two-lane, two-way roads are:

▪ Lane width (LW)	12 feet
▪ Shoulder width (SW)	6 feet
▪ Shoulder type	Paved
▪ Roadside hazard rating (RHR)	3
▪ Driveway density (DD)	5 driveways per mile
▪ Horizontal curvature	None
▪ Vertical curvature	None
▪ Centerline rumble strips	None
▪ Passing lanes	None
▪ Two-way left-turn lanes	None
▪ Lighting	None
▪ Automated speed enforcement	None
▪ Grade Level	0% (see note below)

A zero percent grade is not allowed by most states and presents issues such as drainage. The SPF uses zero percent as a numerical base condition that must always be modified based on the actual grade.

The form of the SPFs for predicted average crash frequency for rural two-lane, two-way roadway segments is shown in Equation 10-6 and presented graphically in Figure 10-3.

$$N_{spfrs} = L \times e^{b_0} \times AADT^{b_1} \quad (10-6)$$

Where:

$N_{spfrs}$  = predicted total crash frequency for roadway segment base conditions for any given combination of crash type and severity;

$L$  = length of roadway segment (miles)

$AADT$  = average annual daily traffic volume (vehicles per day); and

$b_0$  and  $b_1$  = estimated parameters that vary by combination of crash type and severity; these are provided in Table 10-1.

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 10.4. The coefficients for the SPF for each crash type and severity combination is given in Table 10-1 along with the applicable range of AADT values and the number of crashes in the data set used to estimate each SPF. Application to sites with AADTs substantially outside this range may not provide reliable results.

The value of the overdispersion parameter associated with the SPF for rural two-lane, two-way roadway segments is determined as a function of the roadway segment length using Equation 10-7. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. The value is determined as:

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$$N_{spfrs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \quad (10-6)$$

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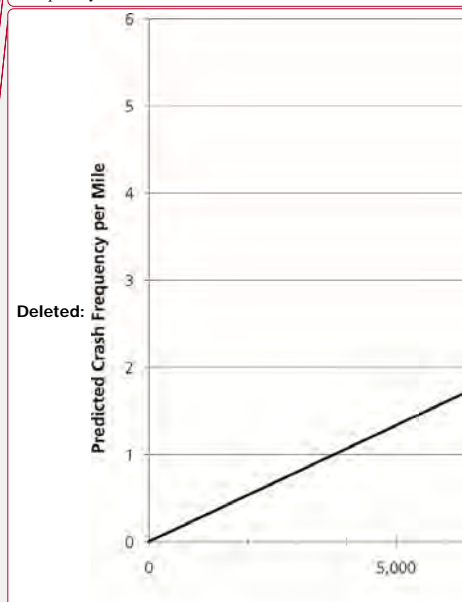
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Deleted:  $L$  = length of roadway segment (miles).¶

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$$k = 1 / \exp[c + \ln(L)] \quad (10-7)$$

Where:

$k$  = overdispersion parameter

$c$  = estimated parameter that varies by combination of crash type and severity provided in Table ; and

$L$  = length of roadway segment (miles).

Table 10-. Base condition SPFs, Two-lane Two way rural roads

Crash Type Washington (N = 361, 164.19 mi.)	Severity	$b_0$	$b_1$	$c$	Number of crashes
Total	KABCO	-7.463	0.927	1.999	996
	KABC	-9.006	0.977	1.479	330
	KAB	-8.499	0.852	1.100	187
	KA	-9.853	0.872	2.527	57
Same direction	KABCO	-15.456	1.658	1.214	204
	KABC	-17.721	1.807	1.326	79
	KAB	-16.183	1.526	1.355	30
	KA	*	*	*	2
Opposite direction	KABCO	-10.525	1.085	0.636	176
	KABC	-11.461	1.100	0.582	80
	KAB	-10.972	0.999	0.228	55
	KA	-11.190	0.947	30.408	31
Single vehicle	KABCO	-5.798	0.674	2.005	616
	KABC	-6.582	0.613	1.117	171
	KAB	-6.919	0.592	0.809	102
	KA	-10.949	0.899	0.446	24

\* = no model is available; estimate a proportion as indicated in the procedure.

Minimum AADT = 210; Maximum AADT = 21,622

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### Safety Performance Functions for Intersections

The predictive model for predicting average crash frequency at particular rural two-lane, two-way road intersections was presented in Equation 10-3. The effect of the major and minor road traffic volumes (AADTs) on crash frequency is incorporated through SPFs, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPFs for rural two-lane, two-way highway intersections are presented in this section.

SPFs have been developed for three types of intersections on rural two-lane, two-way roads. The three types of intersections are:

- Three-leg intersections with minor-road stop control (3ST)
- Four-leg intersections with minor-road stop control (4ST)
- Four-leg signalized intersections (4SG)

SPFs for three-leg signalized intersections on rural two-lane, two-way roads are not available. Other types of intersections may be found on rural two-lane, two-way highways but are not addressed by these procedures.

The SPFs for each of the intersection types listed above estimates predicted average crash frequency by crash type and severity (as defined previously) for intersection-related crashes within the limits of a particular intersection and on the intersection legs. The distinction between roadway segment and intersection crashes is discussed in Section 10.5 and a detailed procedure for distinguishing between roadway-segment-related and intersection-related crashes is presented in Part C, Appendix A.2.3. These SPFs address intersections that have only two lanes on both the major and minor road legs, not including turn lanes. The SPFs for each of the three intersection types may take one of two different forms as presented in Equations 10-8 and 10-9.

$$N_{spf} = \exp[b_0 + b_1 \times \ln(AADT_{maj}) + b_2 \times \ln(AADT_{min})] \quad (10-8)$$

$$N_{spf} = \exp[b_0 + b_3 \times \ln(AADT_{total})] \quad (10-9)$$

Where:

$N_{spf\ 3ST}$  = estimate of intersection-related predicted average crash frequency for base conditions for three-leg stop-controlled intersections;

$AADT_{maj}$  = AADT (vehicles per day) on the major road;

$AADT_{min}$  = AADT (vehicles per day) on the minor road

$AADT_{total}$  = Total of the major and minor road AADTs; and

$b_0, b_1, b_2$  and  $b_3$  = coefficients that were estimated and vary by crash type and severity.

The parameter values and overdispersion parameter ( $k$ ) for the SPF for each combination of crash type and severity is given in the following sections. Guidance on the estimation of traffic volumes for the major and minor road legs for use in the SPFs is presented in Section 10.4, Step 3.

The base conditions which apply to the SPFs in these equations are:

- Intersection skew angle 0° (except for four-leg signalized intersections)
- Intersection left-turn lanes None on approaches without stop control
- Intersection right-turn lanes None on approaches without stop control
- Lighting None (for stop controlled intersections); Present (for signalized intersections)

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Crash Severity Level

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**Three-Leg Stop-Controlled Intersections**

The coefficients for the SPF for each crash type and severity combination is given in Table 10- along with the applicable range of AADT values and the number of crashes in the data set used to estimate each SPF for three-leg stop-controlled intersections.

**Table 10- . Base Condition SPFs, Two-Lane Three-Leg Stop-Controlled (3ST) Intersections**

Crash Type Minnesota (N = 141)	Severity	$b_0$	$b_1$	$b_2$	$b_3$	$k$	Number of crashes
Total	KABCO	-7.924	0.656	0.295	-	0.622	323
	KABC	-9.628	0.725	0.312	-	0.974	114
	KAB	-10.241	0.581	0.468	-	1.383	47
	KA	-11.873	-	-	0.908	5.123	10
Same direction	KABCO	-15.506	1.291	0.452	-	1.777	83
	KABC	-18.598	1.569	0.420	-	2.775	35
	KAB	-16.952	-	-	1.501	5.281	12
	KA	-13.794	-	-	0.984	0.412*	3
Intersecting direction	KABCO	-14.120	0.818	0.753	-	0.995	39
	KABC	-15.174	0.977	0.583	-	1.583	18
	KAB	-13.383	-	-	1.017	0.487*	6
	KA	-10.629	-	-	0.556	0.344	2
Opposite direction	KABCO	-11.716	0.746	0.455	-	0.826*	39
	KABC	-15.272	1.025	0.476	-	1.415	13
	KAB	#	#	#	#	#	9
	KA	-12.867	-	-	0.8752	0.416*	3
Single vehicle	KABCO	-5.916	0.409	0.173	-	0.535	162
	KABC	-5.398	-	-	0.302	0.787	48
	KAB	#	#	#	#	#	20
	KA (2 crashes)	#	#	#	#	#	2

\*Poisson distribution used; scale = square root of Deviance/DOF.

# No significant model was estimated.

These SPFs are applicable to an  $AADT_{maj}$  range from 308 to 20,092 vehicles per day and  $AADT_{min}$  range from 0 to 3,064 vehicles per day, or for models with total entering vehicular volume, in a range from 316 to 20,824 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide reliable results.

**Four-Leg Stop-Controlled Intersections**

The coefficients for the SPF for each crash type and severity combination is given in Table 10- along with the applicable range of AADT values and the number of crashes in the data set used to estimate each SPF for four-leg stop-controlled intersections.

**Table 10- . Base Condition SPFs, Two-Lane Four-Leg Stop-Controlled (4ST) Intersections**

Crash Type Minnesota (N = 198)	Severity	$b_0$	$b_1$	$b_2$	$b_3$	$k$	Number of crashes
Total	KABCO	-6.620	0.451	0.339	-	0.435	345
	KABC	-8.747	-	-	0.825	0.929	123
	KAB	-8.511	-	-	0.723	1.564	70
	KA	-10.539	-	-	0.799	4.683	17
Same direction	KABCO	-7.914	0.364	0.399	-	0.895*	70
	KABC	#	#	#	#	#	19
	KAB	#	#	#	#	#	10

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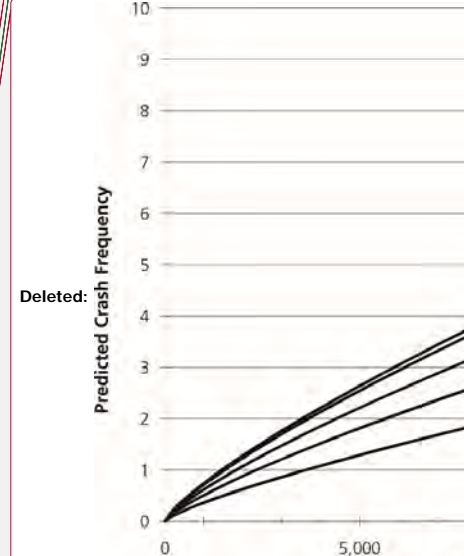
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## 10.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 10.4, crash modification factors (CMFs) are applied to account for the effects of site-specific geometric design and traffic control features. CMFs are used in the predictive method in Equations 10-2 and 10-3. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the safety performance functions presented in Section 10.6.

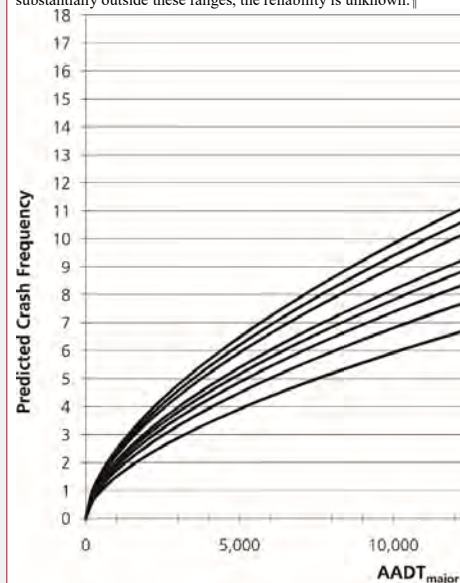
Crash modification factors (CMFs) are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 10 shown in Equation 10-1. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has a CMF with a value greater than 1.00. Any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 10 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions. The CMFs presented in Chapter 10 and the specific site types to which they apply are summarized in Table 10-7.

**Table 10-7.** Summary of Crash Modification Factors (CMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

Facility Type	CMF	CMF Description	CMF Equations and Tables
Rural Two-Lane Two-Way Roadway Segments	CMF <sub>1r</sub>	Lane Width	Table 10-8, Figure 10-7, Equation 10-11
	CMF <sub>2r</sub>	Shoulder Width and Type	Tables 10-9, 10-10, Figure 10-8, Equation 10-12
	CMF <sub>3r</sub>	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	Equation 10-13
	CMF <sub>4r</sub>	Horizontal Curves: Superelevation	Equations 10-14, 10-15, 10-16
	CMF <sub>5r</sub>	Grades	Table 10-11
	CMF <sub>6r</sub>	Driveway Density	Equation 10-17
	CMF <sub>7r</sub>	Centerline Rumble Strips	See text
	CMF <sub>8r</sub>	Passing Lanes	See text
	CMF <sub>9r</sub>	Two-Way Left-Turn Lanes	Equations 10-18, 10-19
	CMF <sub>10r</sub>	Roadside Design	Equation 10-20
	CMF <sub>11r</sub>	Lighting	Equations 10-21, Table 10-12
	CMF <sub>12r</sub>	Automated Speed Enforcement	See text
Three- and four-leg stop control intersections and four-leg signalized intersections	CMF <sub>1i</sub>	Intersection Skew Angle	Equations 10-22, 10-23
	CMF <sub>2i</sub>	Intersection Left-Turn Lanes	Table 10-13
	CMF <sub>3i</sub>	Intersection Right-Turn Lanes	Table 10-14
	CMF <sub>4i</sub>	Lighting	Equation 10-24, Table 10-15

**Deleted:** The overdispersion parameter (k) for this SPF is 0.11. This SPF is applicable to an AADT<sub>maj</sub> range from zero to 25,200 vehicles per day and AADT<sub>min</sub> range from zero to 12,500 vehicles per day. For instances when application is made to sites with AADT substantially outside these ranges, the reliability is unknown.¶



**Figure 10-6.** Graphical Representation of the SPF for Four-leg Signalized (4SG) Intersections (Equation 10-10)¶  
 Tables 10-5 and 10-6 provide the default proportions for crash severity levels and collision types, respectively. These tables may be used to separate the crash frequencies from Equations 10-8 through 10-10 into components by severity level and collision type. The default proportions for severity levels and collision types shown in Tables 10-5 and 10-6 may be updated based on local data for a particular jurisdiction as part of the calibration process described in Part C, Appendix A.¶  
**Table 10-5.** Default Distribution for Crash Severity Level at Rural Two-Lane, Two-Way Intersections¶  
**Crash Severity Level** ...

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### 10.7.1. Crash Modification Factors for Roadway Segments

The CMFs for geometric design and traffic control features of rural two-lane, two-way roadway segments are presented below. These CMFs are applied in Step 10 of the predictive method and used in Equation 10-2 to adjust the SPF for rural two-lane, two-way roadway segments presented in Equation 10-6, to account for differences between the base conditions and the local site conditions.

#### ***CMF<sub>lw</sub>*—Lane Width**

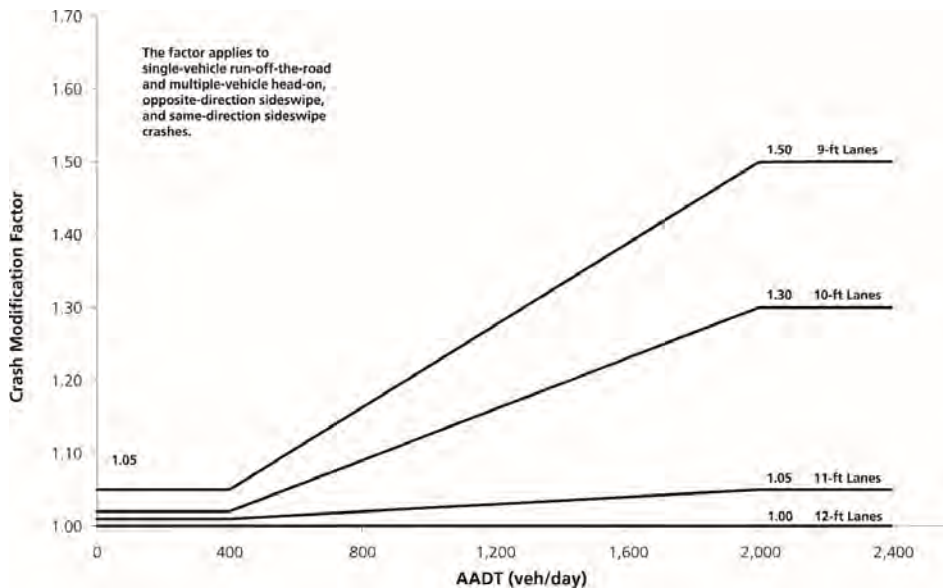
The CMF for lane width on two-lane highway segments is presented in Table 10-8 and illustrated by the graph in Figure 10-7. This CMF was developed from the work of Zegeer et al. (16) and Griffin and Mak (4). The base value for the lane width CMF is 12 ft. In other words, the roadway segment SPF will predict safety performance of a roadway segment with 12-ft lanes. To predict the safety performance of the actual segment in question (e.g., one with lane widths different than 12 ft), CMFs are used to account for differences between base and actual conditions. Thus, 12-ft lanes are assigned a CMF of 1.00. *CMF<sub>lw</sub>* is determined from Table 10-8 based on the applicable lane width and traffic volume range. The relationships shown in Table 10-8 are illustrated in Figure 10-7. Lanes with widths greater than 12 ft are assigned a CMF equal to that for 12-ft lanes.

For lane widths with 0.5-ft increments that are not depicted specifically in Table 10-8 or Figure 10-7, a CMF value can be interpolated using either of these exhibits since there is a linear transition between the various AADT effects.

**Table 10-8.** CMF for Lane Width on Roadway Segments ( $CMF_{rw}$ )

Lane Width	AADT (vehicles per day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4} (AADT - 400)$	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4} (AADT - 400)$	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5} (AADT - 400)$	1.05
12 ft or more	1.00	1.00	1.00

Note: The collision types related to lane width to which this CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

**Figure 10-7.** Crash Modification Factor for Lane Width on Roadway Segments

If the lane widths for the two directions of travel on a roadway segment differ, the CMF are determined separately for the lane width in each direction of travel and the resulting CMFs are then be averaged.

The CMFs shown in Table 10-8 and Figure 10-7 apply only to the crash types that are most likely to be affected by lane width: single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. These are the only crash types assumed to be affected by variation in lane width, and other crash types are assumed to remain unchanged due to the lane width variation. The CMFs expressed on this basis are, therefore, adjusted to total crashes within the predictive method. This is accomplished using Equation 10-11:

$$CMF_{lr} = (CMF_{rw} - 1.0) \times p_{rw} + 1.0 \quad (10-11)$$

Where:

$CMF_{lr}$  = crash modification factor for the effect of lane width on total crashes;

$CMF_{ra}$  = crash modification factor for the effect of lane width on related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), such as the crash modification factor for lane width shown in Table 10-8; and

$p_{ra}$  = proportion of total crashes constituted by related crashes.

The proportion of related crashes,  $p_{ra}$ , (i.e., single-vehicle run-off-the-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes crashes) is estimated as 0.574 (i.e., 57.4 percent) based on the default distribution of crash types presented in Table 10-4. This default crash type distribution, and therefore the value of  $p_{ra}$ , may be updated from local data as part of the calibration process.

#### **$CMF_{2r}$ —Shoulder Width and Type**

The CMF for shoulders has a CMF for shoulder width ( $CMF_{wra}$ ) and a CMF for shoulder type ( $CMF_{tra}$ ). The CMFs for both shoulder width and shoulder type are based on the results of Zegeer et al. (16, 17). The base value of shoulder width and type is a 6-foot paved shoulder, which is assigned a CMF value of 1.00.

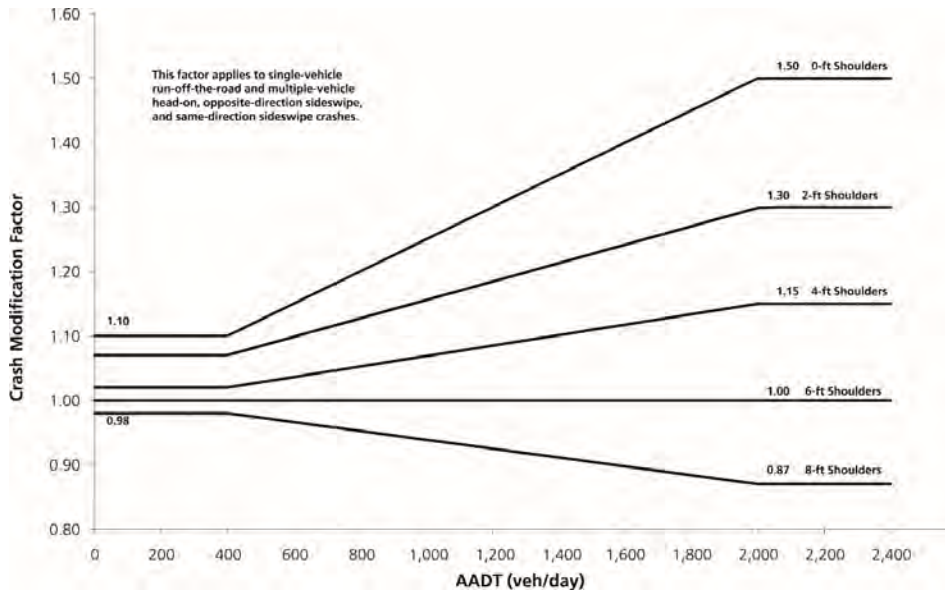
$CMF_{wra}$  for shoulder width on two-lane highway segments is determined from Table 10-9 based on the applicable shoulder width and traffic volume range. The relationships shown in Table 10-9 are illustrated in Figure 10-8.

Shoulders over 8-ft wide are assigned a  $CMF_{wra}$  equal to that for 8-ft shoulders. The CMFs shown in Table 10-9 and Figure 10-8 apply only to single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

**Table 10-9.** CMF for Shoulder Width on Roadway Segments ( $CMF_{wra}$ )

Shoulder Width	AADT (vehicles per day)		
	< 400	400 to 2000	> 2000
0 ft	1.10	$1.10 + 2.5 \times 10^{-4} (AADT - 400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4} (AADT - 400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5} (AADT - 400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5} (AADT - 400)$	0.87

Note: The collision types related to shoulder width to which this CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.



**Figure 10-8.** Crash Modification Factor for Shoulder Width on Roadway Segments

The base condition for shoulder type is paved. Table 10-10 presents values for  $CMF_{tra}$  which adjusts for the safety effects of gravel, turf, and composite shoulders as a function of shoulder width.

**Table 10-10.** Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments ( $CMF_{tra}$ )

Shoulder Type	Shoulder Width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

If the shoulder types and/or widths for the two directions of a roadway segment differ, the CMF are determined separately for the shoulder type and width in each direction of travel and the resulting CMFs are then be averaged.

The CMFs for shoulder width and type shown in Tables 10-9 and 10-10, and Figure 10-8 apply only to the collision types that are most likely to be affected by shoulder width and type: single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. The CMFs expressed on this basis are, therefore, adjusted to total crashes using Equation 10-12.

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0 \quad (10-12)$$

Where:

- $CMF_{2r}$  = crash modification factor for the effect of shoulder width and type on total crashes;
- $CMF_{wra}$  = crash modification factor for related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), based on shoulder width (from Table 10-9);
- $CMF_{ra}$  = crash modification factor for related crashes based on shoulder type (from Table 10-10); and
- $p_{ra}$  = proportion of total crashes constituted by related crashes.

The proportion of related crashes,  $p_{ra}$ , (i.e., single-vehicle run-off-the-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes crashes) is estimated as 0.574 (i.e., 57.4 percent) based on the default distribution of crash types presented in Table 10-4. This default crash type distribution, and therefore the value of  $p_{ra}$ , may be updated from local data by a highway agency as part of the calibration process.

#### **$CMF_{3r}$ —Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions**

The base condition for horizontal alignment is a tangent roadway segment. A CMF has been developed to represent the manner in which crash experience on curved alignments differs from that of tangents. This CMF applies to total roadway segment crashes.

The CMF for horizontal curves has been determined from the regression model developed by Zegeer et al. (18).

The CMF for horizontal curvature is in the form of an equation and yields a factor similar to the other CMFs in this chapter. The CMF for length, radius, and presence or absence of spiral transitions on horizontal curves is determined using Equation 10-13.

$$CMF_{3r} = \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \quad (10-13)$$

Where:

- $CMF_{3r}$  = crash modification factor for the effect of horizontal alignment on total crashes;
- $L_c$  = length of horizontal curve (miles) which includes spiral transitions, if present;
- $R$  = radius of curvature (feet); and
- $S$  = 1 if spiral transition curve is present; 0 if spiral transition curve is not present; 0.5 if a spiral transition curve is present at one but not both ends of the horizontal curve.

Some roadway segments being analyzed may include only a portion of a horizontal curve. In this case,  $L_c$  represents the length of the entire horizontal curve, including portions of the horizontal curve that may lie outside the roadway segment of interest.

In applying Equation 10-13, if the radius of curvature ( $R$ ) is less than 100-ft,  $R$  is set to equal to 100 ft. If the length of the horizontal curve ( $L_c$ ) is less than 100 feet,  $L_c$  is set to equal 100 ft.

CMF values are computed separately for each horizontal curve in a horizontal curve set (a curve set consists of a series of consecutive curve elements). For each individual curve, the value of  $L_c$  used in Equation 10-13 is the total length of the compound curve set and the value of  $R$  is the radius of the individual curve.

If the value of  $CMF_{3r}$  is less than 1.00, the value of  $CMF_{3r}$  is set equal to 1.00.

#### **$CMF_{4r}$ —Horizontal Curves: Superelevation**

The base condition for the CMF for the superelevation of a horizontal curve is the amount of superelevation identified in *A Policy on Geometric Design of Highways and Streets*—also called the AASHTO Green Book (1). The superelevation in the AASHTO Green Book is determined by taking into account the value of maximum superelevation rate,  $e_{max}$ , established by highway agency policies. Policies concerning maximum superelevation rates for horizontal curves vary between highway agencies based on climate and other considerations.

The CMF for superelevation is based on the superelevation variance of a horizontal curve (i.e., the difference between the actual superelevation and the superelevation identified by AASHTO policy). When the actual superelevation meets or exceeds that in the AASHTO policy, the value of the superelevation CMF is 1.00. There is no effect of superelevation variance on crash frequency until the superelevation variance exceeds 0.01. The general functional form of a CMF for superelevation variance is based on the work of Zegeer et al. (18, 19).

The following relationships present the CMF for superelevation variance:

$$CMF_{sv} = 1.00 \text{ for } SV < 0.01 \quad (10-14)$$

$$CMF_{sv} = 1.00 + 6 \times (SV - 0.01) \text{ for } 0.01 \leq SV < 0.02 \quad (10-15)$$

$$CMF_{sv} = 1.06 + 3 \times (SV - 0.02) \text{ for } SV \geq 0.02 \quad (10-16)$$

Where:

$CMF_{sv}$  = crash modification factor for the effect of superelevation variance on total crashes; and

$SV$  = superelevation variance (ft/ft), which represents the superelevation rate contained in the AASHTO Green Book minus the actual superelevation of the curve.

$CMF_{sv}$  applies to total roadway segment crashes for roadway segments located on horizontal curves.

#### **$CMF_{gr}$ —Grades**

The base condition for grade is a generally level roadway. Table 10-11 presents the CMF for grades based on an analysis of rural two-lane, two-way highway grades in Utah conducted by Miaou (8). The CMFs in Table 10-11 are applied to each individual grade segment on the roadway being evaluated without respect to the sign of the grade. The sign of the grade is irrelevant because each grade on a rural two-lane, two-way highway is an upgrade for one direction of travel and a downgrade for the other. The grade factors are applied to the entire grade from one point of vertical intersection (PVI) to the next (i.e., there is no special account taken of vertical curves). The CMFs in Table 10-11 apply to total roadway segment crashes.

**Table 10-11.** Crash Modification Factors ( $CMF_{gr}$ ) for Grade of Roadway Segments

Approximate Grade (%)		
Level Grade ( $\leq 3\%$ )	Moderate Terrain ( $3\% < \text{grade} \leq 6\%$ )	Steep Terrain ( $> 6\%$ )
1.00	1.10	1.16

#### **$CMF_{dd}$ —Driveway Density**

The base condition for driveway density is five driveways per mile. As with the other CMFs, the model for the base condition was established for roadways with this driveway density. The CMF for driveway density is determined using Equation 10-17, derived from the work of Muskaug (9).

$$CMF_{6r} = \frac{0.322 + DD \times [0.05 - 0.005 \times \ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(AADT)]} \quad (10-17)$$

Where:

$CMF_{6r}$  = crash modification factor for the effect of driveway density on total crashes;

$AADT$  = average annual daily traffic volume of the roadway being evaluated (vehicles per day); and

$DD$  = driveway density considering driveways on both sides of the highway (driveways/mile).

If driveway density is less than 5 driveways per mile,  $CMF_{6r}$  is 1.00. Equation 10-17 can be applied to total roadway crashes of all severity levels.

Driveways serving all types of land use are considered in determining the driveway density. All driveways that are used by traffic on at least a daily basis for entering or leaving the highway are considered. Driveways that receive only occasional use (less than daily), such as field entrances are not considered.

#### **$CMF_{7r}$ —Centerline Rumble Strips**

Centerline rumble strips are installed on undivided highways along the centerline of the roadway which divides opposing directions of traffic flow. Centerline rumble strips are incorporated in the roadway surface to alert drivers who unintentionally cross, or begin to cross, the roadway centerline. The base condition for centerline rumble strips is the absence of rumble strips.

The value of  $CMF_{7r}$  for the effect of centerline rumble strips for total crashes on rural two-lane, two-way highways is derived as 0.94 from the CMF value presented in Chapter 13 and crash type percentages found in Chapter 10. Details of this derivation are not provided.

The CMF for centerline rumble strips applies only to two-lane undivided highways with no separation other than a centerline marking between the lanes in opposite directions of travel. Otherwise the value of this CMF is 1.00.

#### **$CMF_{8r}$ —Passing Lanes**

The base condition for passing lanes is the absence of a lane (i.e., the normal two-lane cross section). The CMF for a conventional passing or climbing lane added in one direction of travel on a rural two-lane, two-way highway is 0.75 for total crashes in both directions of travel over the length of the passing lane from the upstream end of the lane addition taper to the downstream end of the lane drop taper. This value assumes that the passing lane is operationally warranted and that the length of the passing lane is appropriate for the operational conditions on the roadway. There may also be some safety benefit on the roadway downstream of a passing lane, but this effect has not been quantified.

The CMF for short four-lane sections (i.e., side-by-side passing lanes provided in opposite directions on the same section of roadway) is 0.65 for total crashes over the length of the short four-lane section. This CMF applies to any portion of roadway where the cross section has four lanes and where both added lanes have been provided over a limited distance to increase passing opportunities. This CMF does not apply to extended four-lane highway sections.

The CMF for passing lanes is based primarily on the work of Harwood and St. John (6), with consideration also given to the results of Rinde (11) and Nettelblad (10). The CMF for short four-lane sections is based on the work of Harwood and St. John (6).

#### **$CMF_{9r}$ —Two-Way Left-Turn Lanes**

The installation of a center two-way left-turn lane (TWLTL) on a rural two-lane, two-way highway to create a three-lane cross-section can reduce crashes related to turning maneuvers at driveways. The base condition for two-way left-turn lanes is the absence of a TWLTL. The CMF for installation of a TWLTL is:

$$CMF_{9r} = 1.0 - (0.7 \times p_{dwy} \times p_{LT/D}) \quad (10-18)$$



Where:

$CMF_{9r}$  = crash modification factor for the effect of two-way left-turn lanes on total crashes;

$P_{dwy}$  = driveway-related crashes as a proportion of total crashes; and

$P_{LT/D}$  = left-turn crashes susceptible to correction by a TWLTL as a proportion of driveway-related crashes.

The value of  $p_{dwy}$  can be estimated using Equation 10-19 (6).

$$p_{dwy} = \frac{(0.0047 \times DD) + (0.0024 \times DD^{(2)})}{1.199 + (0.0047 \times DD) + (0.0024 \times DD^{(2)})} \quad (10-19)$$

Where:

$P_{dwy}$  = driveway-related crashes as a proportion of total crashes; and

$DD$  = driveway density considering driveways on both sides of the highway (driveways/mile).

The value of  $p_{LT/D}$  is estimated as 0.5 (6).

Equation 10-18 provides the best estimate of the CMF for TWLTL installation that can be made without data on the left-turn volumes within the TWLTL. Realistically, such volumes are seldom available for use in such analyses though Part C, Appendix A.1 describes how to appropriately calibrate this value. This CMF applies to total roadway segment crashes.

The CMF for TWLTL installation is not applied unless the driveway density is greater than or equal to five driveways per mile. If the driveway density is less than five driveways per mile, the CMF for TWLTL installation is 1.00.

#### **$CMF_{10r}$ —Roadside Design**

For purposes of the HSM predictive method, the level of roadside design is represented by the roadside hazard rating (1–7 scale) developed by Zegeer et al. (16). The CMF for roadside design was developed in research by Harwood et al. (5). The base value of roadside hazard rating for roadway segments is 3. The CMF is:

$$CMF_{10r} = \frac{e^{(-0.6869 + 0.0668 \times RHR)}}{e^{(-0.4865)}} \quad (10-20)$$

Where:

$CMF_{10r}$  = crash modification factor for the effect of roadside design; and

$RHR$  = roadside hazard rating.

This CMF applies to total roadway segment crashes. Photographic examples and quantitative definitions for each roadside hazard rating (1–7) as a function of roadside design features such as sideslope and clear zone width are presented in Appendix 13A.

#### **$CMF_{11r}$ —Lighting**

The base condition for lighting is the absence of roadway segment lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (2), as:

$$CMF_{11r} = 1.0 - \left[ (1.0 - 0.72 \times p_{mr} - 0.83 \times p_{pmr}) \times p_{nr} \right] \quad (10-21)$$

Where:

$CMF_{11r}$  = crash modification factor for the effect of lighting on total crashes;

$p_{mr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

$p_{pmr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

$p_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

This CMF applies to total roadway segment crashes. Table 10-12 presents default values for the nighttime crash proportions  $p_{mr}$ ,  $p_{pmr}$ , and  $p_{nr}$ . HSM users are encouraged to replace the estimates in Table 10-12 with locally derived values. If lighting installation increases the density of roadside fixed objects, the value of  $CMF_{10r}$  is adjusted accordingly.

**Table 10-12.** Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury $p_{mr}$	PDO $p_{pmr}$	$p_{nr}$
2U	0.382	0.618	0.370

Note: Based on HSIS data for Washington (2002–2006)

#### **$CMF_{12r}$ —Automated Speed Enforcement**

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The base condition for automated speed enforcement is that it is absent.

The value of  $CMF_{12r}$  for the effect of automated speed enforcement for total crashes on rural two-lane, two-way highways is derived as 0.93 from the CMF value presented in Chapter 17 and crash type percentages found in Chapter 10. Details of this derivation are not provided.

### **10.7.2. Crash Modification Factors for Intersections**

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by CMFs. The CMFs for intersection skew angle, left-turn lanes, right-turn lanes, and lighting are presented below. Each of the CMFs applies to total crashes.

#### **$CMF_{1t}$ —Intersection Skew Angle**

The base condition for intersection skew angle is zero degrees of skew (i.e., an intersection angle of 90 degrees). The skew angle for an intersection was defined as the absolute value of the deviation from an intersection angle of 90 degrees. The absolute value is used in the definition of skew angle because positive and negative skew angles are considered to have similar detrimental effect (4). This is illustrated in Section 14.6.2.

#### **Three-Leg Intersections with Stop-Control on the Minor Approach**

The CMF for intersection angle at three-leg intersections with stop-control on the minor approach is:

$$CMF_{1i} = e^{(0.004 \times skew)} \quad (10-22)$$

Where:

$CMF_{li}$  = crash modification factor for the effect of intersection skew on total crashes; and

$skew$  = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

This CMF applies to total intersection crashes.

***Four-Leg Intersections with Stop-Control on the Minor Approaches***

The CMF for intersection angle at four-leg intersection with stop-control on the minor approaches is:

$$CMF_{li} = e^{(0.0054 \times skew)} \quad (10-23)$$

Where:

$CMF_{li}$  = crash modification factor for the effect of intersection skew on total crashes; and

$skew$  = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

This CMF applies to total intersection crashes.

If the skew angle differs for the two minor road legs at a four-leg stop-controlled intersection, values of  $CMF_{li}$  is computed separately for each minor road leg and then averaged.

***Four-Leg Signalized Intersections***

Since the traffic signal separates most movements from conflicting approaches, the risk of collisions related to the skew angle between the intersecting approaches is limited at a signalized intersection. Therefore, the CMF for skew angle at four-leg signalized intersections is 1.00 for all cases.

***CMF<sub>2l</sub>—Intersection Left-Turn Lanes***

The base condition for intersection left-turn lanes is the absence of left-turn lanes on the intersection approaches. The CMFs for the presence of left-turn lanes are presented in Table 10-13. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to a stop-controlled intersection. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for the installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes. There is no indication of any safety effect of providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Table 10-13. The CMFs for installation of left-turn lanes are based on research by Harwood et al. (5) and are consistent with the CMFs presented in Chapter 14. A CMF of 1.00 is always be used when no left-turn lanes are present.

**Table 10-13.** Crash Modification Factors ( $CMF_{2l}$ ) for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes <sup>a</sup>			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg Intersection	Minor road stop control <sup>b</sup>	0.56	0.31	—	—
	Minor road stop control <sup>b</sup>	0.72	0.52	—	—
Four-leg Intersection	Traffic signal	0.82	0.67	0.55	0.45

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes

<sup>b</sup> Stop signs present on minor road approaches only.

#### **$CMF_{3r}$ —Intersection Right-Turn Lanes**

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMF for the presence of right-turn lanes is based on research by Harwood et al. (5) and is consistent with the CMFs in Chapter 14. These CMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to stop-controlled intersections. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes. There is no indication of any safety effect for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Table 10-14. The CMFs in the table apply to total intersection crashes. A CMF value of 1.00 is always be used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

**Table 10-14.** Crash Modification Factors ( $CMF_{3r}$ ) for Right-Turn Lanes on Approaches to an Intersection on Rural Two-Lane, Two-Way Highways

Intersection Type	Intersection Traffic Control	Number of Approaches with Right-Turn Lanes <sup>a</sup>			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-Leg Intersection	Minor road stop control <sup>b</sup>	0.86	0.74	—	—
	Minor road stop control <sup>b</sup>	0.86	0.74	—	—
Four-Leg Intersection	Traffic signal	0.96	0.92	0.88	0.85

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.

<sup>b</sup> Stop signs present on minor road approaches only.

#### **$CMF_{4l}$ —Lighting**

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (2), as:

$$CMF_{4l} = 1 - 0.38 \times p_{ni} \quad (10-24)$$

Where:

$CMF_{4l}$  = crash modification factor for the effect of lighting on total crashes; and

$p_{ni}$  = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersection crashes. Table 10-15 presents default values for the nighttime crash proportion  $p_{ni}$ . HSM users are encouraged to replace the estimates in Table 10-15 with locally derived values.

**Table 10-15.** Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
	$P_n$
3ST	0.260
4ST	0.244
4SG	0.286

Note: Based on HSIS data for California (2002–2006)

### 10.8. CALIBRATION OF THE SPFS TO LOCAL CONDITIONS

In Step 10 of the predictive method, presented in Section 10.4, the predictive model is calibrated to local state or geographic conditions. Crash frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes on rural two-lane, two-way roads than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments and intersections (defined as  $C_r$  and  $C_i$ , respectively) will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes on average than the roadways used in the development of the SPFs will have values less than 1.0. The calibration procedures are presented in Part C, Appendix A.

Calibration factors provide one method of incorporating local data to improve estimated crash frequencies for individual agencies or locations. Several other default values used in the predictive method, such as collision type and severity distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in Part C, Appendix A.

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### 10.9. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 10

This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 10.

Where rural two-lane, two-way roads intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the two-lane road within the interchange area, cannot be addressed with the predictive method for rural two-lane, two-way roads.

The SPFs developed for Chapter 10 do not include signalized three-leg intersection models. Such intersections are occasionally found on rural two-lane, two-way roads.

### 10.10. APPLICATION OF CHAPTER 10 PREDICTIVE METHOD

The predictive method presented in Chapter 10 applies to rural two-lane, two-way roads. The predictive method is applied to a rural two-lane, two-way facility by following the 18 steps presented in Section 10.4. Appendix 10A provides a series of worksheets for applying the predictive method and the predictive models detailed in this chapter. All computations within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed for consistency in computations. In the last stage of computations, rounding the final estimate of expected average crash frequency to one decimal place is appropriate.

### 10.11. SUMMARY

The predictive method can be used to estimate the expected average crash frequency for a series of contiguous sites (entire rural two-lane, two-way facility), or a single individual site. A rural two-lane, two-way facility is defined in Section 10.3, and consists of a two-lane, two-way undivided road which does not have access control and is outside of cities or towns with a population greater than 5,000 persons. Two-lane, two-way undivided roads that have occasional added lanes to provide additional passing opportunities can also be addressed with the Chapter 10 predictive method.

The predictive method for rural two-lane, two-way roads is applied by following the 18 steps of the predictive method presented in Section 10.4. Predictive models, developed for rural two-lane, two-way facilities, are applied in Steps 9, 10, and 11 of the method. These predictive models have been developed to estimate the predicted average crash frequency of an individual site which is an intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Each predictive model in Chapter 10 consists of a safety performance function (SPF), crash modification factors (CMFs), and a calibration factor. The SPF is selected in Step 9 and is used to estimate the predicted average crash frequency for a site with base conditions. The estimate can be for either total crashes or by crash-severity and crash types. In order to account for differences between the base conditions and the specific conditions of the site, CMFs are applied in Step 10, which adjust the prediction to account for the geometric design and traffic control features of the site. Calibration factors are also used to adjust the prediction to local conditions in the jurisdiction where the site is located. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 10.12 presents six sample problems which detail the application of the predictive method. Appendix 10A contains worksheets which can be used in the calculations for the predictive method steps.

### 10.12. SAMPLE PROBLEMS

In this section, six sample problems are presented using the predictive method for rural two-lane, two-way roads. Sample Problems 1 and 2 illustrate how to calculate the predicted average crash frequency for rural two-lane roadway segments. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for a stop-controlled intersection. Sample Problem 4 illustrates a similar calculation for a signalized intersection. Sample Problem 5 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are available (i.e., using the site-specific EB Method). Sample Problem 6 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are not available but project-level observed crash data are available (i.e., using the project-level EB Method).

**Table 10-16.** List of Sample Problems in Chapter 10

Problem No.	Page No.	Description
1	10-35	Predicted average crash frequency for a tangent roadway segment
2	10-42	Predicted average crash frequency for a curved roadway segment
3	10-49	Predicted average crash frequency for a three-leg stop-controlled intersection
4	10-55	Predicted average crash frequency for a four-leg signalized intersection
5	10-60	Expected average crash frequency for a facility when site-specific observed crash data are available
6	10-62	Expected average crash frequency for a facility when site-specific observed crash data are not available

#### 10.12.1. Sample Problem 1

The Site/Facility

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A rural two-lane tangent roadway segment.

#### The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

#### The Facts

- 1.5-mi length
- Tangent roadway segment
- 10,000 veh/day
- 2% grade
- 6 driveways per mi
- 10-ft lane width
- 4-ft gravel shoulder
- Roadside hazard rating = 4

#### Assumptions

Collision type distributions used are the default values presented in Table 10-4.

The calibration factor is assumed to be 1.10.

#### Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 6.1 crashes per year (rounded to one decimal place).

#### Steps

##### Step 1 through 8

To determine the predicted average crash frequency of the roadway segment in Sample Problem 1, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

##### Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

The SPF for a single roadway segment can be calculated from Equation 10-6 as follows:

$$N_{spr\ rf} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$

$$N_{spr\ rf} = 10,000 \times 1.5 \times 365 \times 10^{-6} \times e^{(-0.312)} = 4.008 \text{ crashes/year}$$

##### Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site-specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

*Lane Width (CMF<sub>lr</sub>)*

CMF<sub>lr</sub> can be calculated from Equation 10-11 as follows:

$$CMF_{lr} = (CMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For a 10-ft lane width and AADT of 10,000, CMF<sub>ra</sub> = 1.30 (see Table 10-8).

The proportion of related crashes,  $p_{ra}$ , is 0.574 (see discussion below Equation 10-11).

$$CMF_{lr} = (1.3 - 1.0) \times 0.574 + 1.0 = 1.17$$

*Shoulder Width and Type (CMF<sub>2r</sub>)*

$CMF_{2r}$  can be calculated from Equation 10-12, using values from Table 10-9, Table 10-10, and Table 10-4 as follows:

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0$$

For 4-ft shoulders and AADT of 10,000,  $CMF_{wra} = 1.15$  (see Table 10-9).

For 4-ft gravel shoulders,  $CMF_{tra} = 1.01$  (see Table 10-10).

The proportion of related crashes,  $p_{ra}$ , is 0.574 (see discussion below Equation 10-12).

$$CMF_{2r} = (1.15 \times 1.01 - 1.0) \times 0.574 + 1.0 = 1.09$$

*Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions (CMF<sub>3r</sub>)*

Since the roadway segment in Sample Problem 1 is a tangent,  $CMF_{3r} = 1.00$  (i.e., the base condition for  $CMF_{3r}$  is no curve).

*Horizontal Curves: Superelevation (CMF<sub>4r</sub>)*

Since the roadway segment in Sample Problem 1 is a tangent, and, therefore, has no superelevation,  $CMF_{4r} = 1.00$ .

*Grade (CMF<sub>5r</sub>)*

From Table 10-11, for a two percent grade,  $CMF_{5r} = 1.00$

*Driveway Density (CMF<sub>6r</sub>)*

The driveway density, DD, is 6 driveways per mile.  $CMF_{6r}$  can be calculated using Equation 10-17 as follows:

$$\begin{aligned} CMF_{6r} &= \frac{0.322 + DD \times [0.05 - 0.005 \times \ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(AADT)]} \\ &= \frac{0.322 + 6 \times [0.05 - 0.005 \times \ln(10,000)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(10,000)]} \\ &= 1.01 \end{aligned}$$

*Centerline Rumble Strips (CMF<sub>7r</sub>)*

Since there are no centerline rumble strips in Sample Problem 1,  $CMF_{7r} = 1.00$  (i.e., the base condition for  $CMF_{7r}$  is no centerline rumble strips).

*Passing Lanes (CMF<sub>8r</sub>)*

Since there are no passing lanes in Sample Problem 1,  $CMF_{8r} = 1.00$  (i.e., the base condition for  $CMF_{8r}$  is the absence of a passing lane).

*Two-Way Left-Turn Lanes (CMF<sub>9r</sub>)*

Since there are no two-way left-turn lanes in Sample Problem 1,  $CMF_{9r} = 1.00$  (i.e., the base condition for  $CMF_{9r}$  is the absence of a two-way left-turn lane).

*Roadside Design (CMF<sub>10r</sub>)*



The roadside hazard rating, RHR, in Sample Problem 1 is 4.  $CMF_{10r}$  can be calculated from Equation 10-20 as follows:

$$\begin{aligned} CMF_{10r} &= \frac{e^{(-0.6869 + 0.0668 \times RHR)}}{e^{(-0.4865)}} \\ &= \frac{e^{(-0.6869 + 0.0668 \times 4)}}{e^{(-0.4865)}} \\ &= 1.07 \end{aligned}$$

*Lighting ( $CMF_{11r}$ )*

Since there is no lighting in Sample Problem 1,  $CMF_{11r} = 1.00$  (i.e., the base condition for  $CMF_{11r}$  is the absence of roadway lighting).

*Automated Speed Enforcement ( $CMF_{12r}$ )*

Since there is no automated speed enforcement in Sample Problem 1,  $CMF_{12r} = 1.00$  (i.e., the base condition for  $CMF_{12r}$  is the absence of automated speed enforcement).

The combined CMF value for Sample Problem 1 is calculated below.

$$CMF_{comb} = 1.17 \times 1.09 \times 1.01 \times 1.07 = 1.38$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed a calibration factor,  $C_r$ , of 1.10 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 10-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } rs} &= N_{\text{spf } rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{12r}) \\ &= 4.008 \times 1.10 \times (1.38) = 6.084 \text{ crashes/year} \end{aligned}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1C (Corresponds to Worksheet 1C)*—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1D (Corresponds to Worksheet 1D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1E (Corresponds to Worksheet 1E)*—Summary Results for Rural Two-Lane, Two-Way Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

**Worksheet SP1A—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments**

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1.

**Worksheet SP1A. General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments**

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Length of segment, L (mi)		—	1.5
AADT (veh/day)		—	10,000
Lane width (ft)		12	10
Shoulder width (ft)		6	4
Shoulder type		paved	Gravel
Length of horizontal curve (mi)		0	not present
Radius of curvature (ft)		0	not present
Spiral transition curve (present/not present)		not present	not present
Superelevation variance (ft/ft)		<0.01	not present
Grade (%)		0	2
Driveway density (driveways/mi)		5	6
Centerline rumble strips (present/not present)		not present	not present
Passing lanes (present/not present)		not present	not present
Two-way left-turn lane (present/not present)		not present	not present
Roadside hazard rating (1–7 scale)		3	4
Segment lighting (present/not present)		not present	not present
Auto speed enforcement (present/not present)		not present	not present
Calibration factor, $C_r$		1.0	1.1

**Worksheet SP1B—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 13 of Worksheet SP1B which indicates the combined CMF value.

**Worksheet SP1B. Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Superelevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips	CMF for Passing Lanes	CMF for Two-Way Left-Turn Lane	CMF for Roadside Design	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{6r}$	$CMF_{7r}$	$CMF_{8r}$	$CMF_{9r}$	$CMF_{10r}$	$CMF_{11r}$	$CMF_{12r}$	$CMF_{comb}$
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	$(1)*(2)*\dots*(11)*(12)$
1.17	1.09	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.07	1.00	1.00	1.38

**Worksheet SP1C—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments**

The SPF for the roadway segment in Sample Problem 1 is calculated using Equation 10-6 and entered into Column 2 of Worksheet SP1C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-3. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined CMF (from Column 13 in Worksheet SP1B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

**Worksheet SP1C. Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{SPF}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{SPF}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_r$	Predicted Average Crash Frequency, $N_{predicted}$
	from Equation 10-6	from Equation 10-7	from Table 10-3	(2)total*(4)	(13) from Worksheet SP1B		(5)*(6)*(7)
Total	4.008	0.16	1.000	4.008	1.38	1.10	6.084
Fatal and injury (FI)	—	—	0.321	1.287	1.38	1.10	1.954
Property damage only (PDO)	—	—	0.679	2.721	1.38	1.10	4.131

**Worksheet SP1D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Roadway Segments**

Worksheet SP1D presents the default proportions for collision type (from Table 10-4) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Property-damage-only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet SP1C) by crash severity and collision type.

**Worksheet SP1D.** Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Proportion of Collision Type <sub>total</sub>	$N_{\text{predicted vs (total)}}$ (crashes/year)	Proportion of Collision Type <sub>FI</sub>	$N_{\text{predicted vs (FI)}}$ (crashes/year)	Proportion of Collision Type <sub>PDO</sub>	$N_{\text{predicted vs (PDO)}}$ (crashes/year)
Collision Type	from Table 10-4	(8) <sub>total</sub> from Worksheet SP1C	from Table 10-4	(8) <sub>FI</sub> from Worksheet SP1C	from Table 10-4	(8) <sub>PDO</sub> from Worksheet SP1C
Total	1.000	6.084	1.000	1.954	1.000	4.131
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>PDO</sub>
<b>SINGLE-VEHICLE</b>						
Collision with animal	0.121	0.736	0.038	0.074	0.184	0.760
Collision with bicycle	0.002	0.012	0.004	0.008	0.001	0.004
Collision with pedestrian	0.003	0.018	0.007	0.014	0.001	0.004
Overtuned	0.025	0.152	0.037	0.072	0.015	0.062
Ran off road	0.521	3.170	0.545	1.065	0.505	2.086
Other single-vehicle collision	0.021	0.128	0.007	0.014	0.029	0.120
Total single-vehicle crashes	0.693	4.216	0.638	1.247	0.735	3.036
<b>MULTIPLE-VEHICLE</b>						
Angle collision	0.085	0.517	0.100	0.195	0.072	0.297
Head-on collision	0.016	0.097	0.034	0.066	0.003	0.012
Rear-end collision	0.142	0.864	0.164	0.320	0.122	0.504
Sideswipe collision	0.037	0.225	0.038	0.074	0.038	0.157

Other multiple-vehicle collision	0.027	0.164	0.026	0.051	0.030	0.124
Total multiple-vehicle crashes	0.307	1.868	0.362	0.707	0.265	1.095

**Worksheet SP1E—Summary Results of Rural Two-Lane, Two-Way Roadway Segments**

Worksheet SP1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

**Worksheet SP1E. Summary Results for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(4) from Worksheet SP1C	(8) from Worksheet SP1C		(3)/(4)
Total	1.000	6.084	1.5	4.1
Fatal and injury (FI)	0.321	1.954	1.5	1.3
Property damage only (PDO)	0.679	4.131	1.5	2.8

**10.12.2. Sample Problem 2**

The Site/Facility

A rural two-lane curved roadway segment.

**The Question**

What is the predicted average crash frequency of the roadway segment for a particular year?

**The Facts**

- 0.1-mi length
- Curved roadway segment
- 8,000 veh/day
- 1% grade
- 1,200-ft horizontal curve radius
- No spiral transition
- 0 driveways per mi
- 11-ft lane width
- 2-ft gravel shoulder
- Roadside hazard rating = 5
- 0.1-mi horizontal curve length
- 0.04 superelevation rate

**Assumptions**

Collision type distributions have been adapted to local experience. The percentage of total crashes representing single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes is 78 percent.

The calibration factor is assumed to be 1.10.

Design speed = 60 mph

Maximum superelevation rate,  $e_{max}$  = 6 percent

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 0.5 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

The SPF for a single roadway segment can be calculated from Equation 10-6 as follows:

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \\ = 8,000 \times 0.1 \times 365 \times 10^{-6} \times e^{(-0.312)} = 0.214 \text{ crashes/year}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.**

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

*Lane Width (CMF<sub>1r</sub>)*

CMF<sub>1r</sub> can be calculated from Equation 10-11 as follows:

$$CMF_{1r} = (CMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For an 11-ft lane width and AADT of 8,000 veh/day, CMF<sub>ra</sub> = 1.05 (see Table 10-8)

The proportion of related crashes,  $p_{ra}$ , is 0.78 (see assumptions)

$$CMF_{1r} = (1.05 - 1.0) \times 0.78 + 1.0 = 1.04$$

*Shoulder Width and Type (CMF<sub>2r</sub>)*

CMF<sub>2r</sub> can be calculated from Equation 10-12, using values from Table 10-9, Table 10-10, and local data ( $p_{ra}$  = 0.78) as follows:

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0$$

For 2-ft shoulders and AADT of 8,000 veh/day, CMF<sub>wra</sub> = 1.30 (see Table 10-9)

For 2-ft gravel shoulders, CMF<sub>tra</sub> = 1.01 (see Table 10-10)

The proportion of related crashes,  $p_{rel}$ , is 0.78 (see assumptions)

$$CMF_{2r} = (1.30 \times 1.01 - 1.0) \times 0.78 + 1.0 = 1.24$$

*Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions ( $CMF_{3r}$ )*

For a 0.1 mile horizontal curve with a 1,200 ft radius and no spiral transition,  $CMF_{3r}$  can be calculated from Equation 10-13 as follows:

$$\begin{aligned} CMF_{3r} &= \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \\ &= \frac{(1.55 \times 0.1) + \left(\frac{80.2}{1200}\right) - (0.012 \times 0)}{(1.55 \times 0.1)} \\ &= 1.43 \end{aligned}$$

*Horizontal Curves: Superelevation ( $CMF_{4r}$ )*

$CMF_{4r}$  can be calculated from Equation 10-16 as follows:

$$CMF_{4r} = 1.06 + 3 \times (SV - 0.02)$$

For a roadway segment with an assumed design speed of 60 mph and an assumed maximum superelevation ( $e_{max}$ ) of six percent, AASHTO Green Book (1) provides for a 0.06 superelevation rate. Since the superelevation in Sample Problem 2 is 0.04, the superelevation variance is 0.02 ( $0.06 - 0.04$ ).

$$CMF_{4r} = 1.06 + 3 \times (0.02 - 0.02) = 1.06$$

*Grade ( $CMF_{5r}$ )*

From Table 10-11, for a one percent grade,  $CMF_{5r} = 1.00$ .

*Driveway Density ( $CMF_{6r}$ )*

Since the driveway density, DD, in Sample Problem 2 is less than 5 driveways per mile,  $CMF_{6r} = 1.00$  (i.e., the base condition for  $CMF_{6r}$  is five driveways per mile. If driveway density is less than five driveways per mile,  $CMF_{6r}$  is 1.00).

*Centerline Rumble Strips ( $CMF_{7r}$ )*

Since there are no centerline rumble strips in Sample Problem 2,  $CMF_{7r} = 1.00$  (i.e., the base condition for  $CMF_{7r}$  is no centerline rumble strips).

*Passing Lanes ( $CMF_{8r}$ )*

Since there are no passing lanes in Sample Problem 2,  $CMF_{8r} = 1.00$  (i.e., the base condition for  $CMF_{8r}$  is the absence of a passing lane).

*Two-Way Left-Turn Lanes ( $CMF_{9r}$ )*

Since there are no two-way left-turn lanes in Sample Problem 2,  $CMF_{9r} = 1.00$  (i.e., the base condition for  $CMF_{9r}$  is the absence of a two-way left-turn lane).

*Roadside Design ( $CMF_{10r}$ )*

The roadside hazard rating, RHR, is 5. Therefore,  $CMF_{10r}$  can be calculated from Equation 10-20 as follows:

$$\begin{aligned}
 CMF_{10r} &= \frac{e^{(-0.6869 + 0.0668 \times RHR)}}{e^{(-0.4865)}} \\
 &= \frac{e^{(-0.6869 + 0.0668 \times 5)}}{e^{(-0.4865)}} \\
 &= 1.14
 \end{aligned}$$

*Lighting ( $CMF_{11r}$ )*

Since there is no lighting in Sample Problem 2,  $CMF_{11r} = 1.00$  (i.e., the base condition for  $CMF_{11r}$  is the absence of roadway lighting).

*Automated Speed Enforcement ( $CMF_{12r}$ )*

Since there is no automated speed enforcement in Sample Problem 2,  $CMF_{12r} = 1.00$  (i.e., the base condition for  $CMF_{12r}$  is the absence of automated speed enforcement).

The combined CMF value for Sample Problem 2 is calculated below.

$$CMF_{comb} = 1.04 \times 1.24 \times 1.43 \times 1.06 \times 1.14 = 2.23$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed that a calibration factor,  $C_r$ , of 1.10 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

*Calculation of Predicted Average Crash Frequency*

The predicted average crash frequency is calculated using Equation 10-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned}
 N_{\text{predicted } rs} &= N_{\text{spf } rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{12r}) \\
 &= 0.214 \times 1.10 \times (2.23) = 0.525 \text{ crashes/year}
 \end{aligned}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2C (Corresponds to Worksheet 1C)*—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Summary Results for Rural Two-Lane, Two-Way Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

### Worksheet SP2A—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments



Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2.

**Worksheet SP2A.** General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Length of segment, L (mi)		—	0.1
AADT (veh/day)		—	8,000
Lane width (ft)		12	11
Shoulder width (ft)		6	2
Shoulder type		paved	gravel
Length of horizontal curve (mi)		0	0.1
Radius of curvature (ft)		0	1,200
Spiral transition curve (present/not present)		not present	not present
Superelevation variance (ft/ft)		<0.01	0.02 (0.06–0.04)
Grade (%)		0	1
Driveway density (driveways/mi)		5	0
Centerline rumble strips (present/not present)		not present	not present
Passing lanes (present/not present)		not present	not present
Two-way left-turn lane (present/not present)		not present	not present
Roadside hazard rating (1–7 scale)		3	5
Segment lighting(present/not present)		not present	not present
Auto speed enforcement (present/not present)		not present	not present
Calibration factor, C <sub>r</sub>		1.0	1.1

**Worksheet SP2B—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 13 of Worksheet SP2B which indicates the combined CMF value.

**Worksheet SP2B. Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Superelevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips	CMF for Passing Lanes	CMF for Two-Way Left-Turn Lane	CMF for Roadside Design	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{6r}$	$CMF_{7r}$	$CMF_{8r}$	$CMF_{9r}$	$CMF_{10r}$	$CMF_{11r}$	$CMF_{12r}$	$CMF_{comb}$
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	$(1)*(2)*\dots*(11)*(12)$
1.04	1.24	1.43	1.06	1.00	1.00	1.00	1.00	1.00	1.14	1.00	1.00	2.23

**Worksheet SP2C—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments**

The SPF for the roadway segment in Sample Problem 2 is calculated using Equation 10-6 and entered into Column 2 of Worksheet SP2C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 2. Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-3 (as the EB Method is not utilized). These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined CMF (from Column 13 in Worksheet SP2B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

**Worksheet SP2C. Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{SPF}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{SPF}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_r$	Predicted Average Crash Frequency, $N_{predicted}$
	from Equation 10-6	from Equation 10-7	from Table 10-3	$(2)_{total}*(4)$	(13) from Worksheet SP2B		$(5)*(6)*(7)$
Total	0.214	2.36	1.000	0.214	2.23	1.10	0.525
Fatal and injury (FI)	—	—	0.321	0.069	2.23	1.10	0.169
Property damage only (PDO)	—	—	0.679	0.145	2.23	1.10	0.356

**Worksheet SP2D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Roadway Segments**

Worksheet SP2D presents the default proportions for collision type (from Table 10-3) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Property-damage-only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet SP2C) by crash severity and collision type.

**Worksheet SP2D. Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	Proportion of Collision Type <sub>(total)</sub>	$N_{\text{predicted } rs \text{ (total)}}$ (crashes/year)	Proportion of Collision Type <sub>(FI)</sub>	$N_{\text{predicted } rs \text{ (FI)}}$ (crashes/year)	Proportion of Collision Type <sub>(PDO)</sub>	$N_{\text{predicted } rs \text{ (PDO)}}$ (crashes/year)
	from Table 10-4	(8) <sub>total</sub> from Worksheet SP2C	from Table 10-4	(8) <sub>FI</sub> from Worksheet SP2C	from Table 10-4	(8) <sub>PDO</sub> from Worksheet SP2C
Total	1.000	0.525	1.000	0.169	1.000	0.356
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>PDO</sub>
<b>SINGLE-VEHICLE</b>						
Collision with animal	0.121	0.064	0.038	0.006	0.184	0.066
Collision with bicycle	0.002	0.001	0.004	0.001	0.001	0.000
Collision with pedestrian	0.003	0.002	0.007	0.001	0.001	0.000
Overtuned	0.025	0.013	0.037	0.006	0.015	0.005
Ran off road	0.521	0.274	0.545	0.092	0.505	0.180
Other single-vehicle collision	0.021	0.011	0.007	0.001	0.029	0.010
Total single-vehicle crashes	0.693	0.364	0.638	0.108	0.735	0.262
<b>MULTIPLE-VEHICLE</b>						
Angle collision	0.085	0.045	0.100	0.017	0.072	0.026
Head-on collision	0.016	0.008	0.034	0.006	0.003	0.001
Rear-end collision	0.142	0.075	0.164	0.028	0.122	0.043
Sideswipe collision	0.037	0.019	0.038	0.006	0.038	0.014
Other multiple-vehicle collision	0.027	0.014	0.026	0.004	0.030	0.011

Total multiple-vehicle crashes	0.307	0.161	0.362	0.061	0.265	0.094
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**Worksheet SP2E—Summary Results for Rural Two-Lane, Two-Way Roadway Segments**

Worksheet SP2E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

**Worksheet SP2E. Summary Results for Rural Two-Lane, Two-Way Roadway Segments**

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(4) from Worksheet SP2C	(8) from Worksheet SP2C		(3)/(4)
Total	1.000	0.525	0.1	5.3
Fatal and injury (FI)	0.321	0.169	0.1	1.7
Property damage only (PDO)	0.679	0.356	0.1	3.6

**10.12.3. Sample Problem 3**

The Site/Facility

A three-leg stop-controlled intersection located on a rural two-lane roadway.

**The Question**

What is the predicted average crash frequency of the stop-controlled intersection for a particular year?

**The Facts**

- 3 legs
- Minor-road stop control
- No right-turn lanes on major road
- No left-turn lanes on major road
- 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- Intersection lighting is present

**Assumptions**

- Collision type distributions used are the default values from Table 10-6.
- The proportion of crashes that occur at night are not known, so the default proportion for nighttime crashes is assumed.
- The calibration factor is assumed to be 1.50.

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem 3 is determined to be 2.9 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the intersection in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

The SPF for a single three-leg stop-controlled intersection can be calculated from Equation 10-8 as follows:

$$N_{spf\ ST} = \exp \left[ -9.86 + 0.79 \times \ln(AADT_{maj}) + 0.49 \times \ln(AADT_{min}) \right]$$

$$= \exp \left[ -9.86 + 0.79 \times \ln(8,000) + 0.49 \times \ln(1,000) \right] = 1.867 \text{ crashes/year}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.**

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

*Intersection Skew Angle (CMF<sub>1i</sub>)*

CMF<sub>1i</sub> can be calculated from Equation 10-22 as follows:

$$CMF_{1i} = e^{(0.004 \times skew)}$$

The intersection skew angle for Sample Problem 3 is 30 degrees.

$$CMF_{1i} = e^{(0.004 \times 30)} = 1.13$$

*Intersection Left-Turn Lanes (CMF<sub>2i</sub>)*

Since no left-turn lanes are present in Sample Problem 3, CMF<sub>2i</sub> = 1.00 (i.e., the base condition for CMF<sub>2i</sub> is the absence of left-turn lanes on the intersection approaches).

*Intersection Right-Turn Lanes (CMF<sub>3i</sub>)*

Since no right-turn lanes are present, CMF<sub>3i</sub> = 1.00 (i.e., the base condition for CMF<sub>3i</sub> is the absence of right-turn lanes on the intersection approaches).

*Lighting (CMF<sub>4i</sub>)*

CMF<sub>4i</sub> can be calculated from Equation 10-24 using Table 10-15.

$$CMF_{4i} = 1 - 0.38 \times p_{ni}$$

From Table 10-15, for a three-leg stop-controlled intersection, the proportion of total crashes that occur at night (see assumption),  $p_{ni}$ , is 0.26.

$$CMF_{4i} = 1 - 0.38 \times 0.26 = 0.90$$

The combined CMF value for Sample Problem 3 is calculated below.

$$CMF_{comb} = 1.13 \times 0.90 = 1.02$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed that a calibration factor,  $C_i$ , of 1.50 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 10-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted int}} = N_{\text{spf int}} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{4i})$$

$$= 1.867 \times 1.50 \times (1.02) = 2.857 \text{ crashes/year}$$

**WORKSHEETS**

The step-by-step instructions above are the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

**Worksheet SP3A—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections**

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 3.

**Worksheet SP3A. General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections**

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		—	3ST
AADT <sub>maj</sub> (veh/day)		—	8,000
AADT <sub>min</sub> (veh/day)		—	1,000

Intersection skew angle (degrees)		0	30
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	0
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)		0	0
Intersection lighting (present/not present)		not present	present
Calibration factor, $C_i$		1.0	1.50

### Worksheet SP3B—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SP3B which indicates the combined CMF value.

#### Worksheet SP3B. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
$CMF_{ii}$	$CMF_{2i}$	$CMF_{3i}$	$CMF_{4i}$	$CMF_{comb}$
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	$(1)*(2)*(3)*(4)$
1.13	1.00	1.00	0.90	1.02

### Worksheet SP3C—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

The SPF for the intersection in Sample Problem 3 is calculated using Equation 10-8 and entered into Column 2 of Worksheet SP3C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-5. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined CMF (from Column 13 in Worksheet SP3B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

**Worksheet SP3C.** Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{adj\ 3ST, 4ST\ or\ 4SG}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{adj\ 3ST, 4ST\ or\ 4SG}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_i$	Predicted Average Crash Frequency, $N_{predicted\ int}$
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total} \times (4)$	from (5) of Worksheet SP3B		$(5) \times (6) \times (7)$
Total	1.867	0.54	1.000	1.867	1.02	1.50	2.857
Fatal and injury (FI)	—	—	0.415	0.775	1.02	1.50	1.186
Property damage only (PDO)	—	—	0.585	1.092	1.02	1.50	1.671

**Worksheet SP3D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections**

Worksheet SP3D presents the default proportions for collision type (from Table 10-6) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Property-damage-only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet SP3C) by crash severity and collision type.

**Worksheet SP3D.** Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	Proportion of Collision Type <sub>(total)</sub>	$N_{predicted\ int\ (total)}$ (crashes/year)	Proportion of Collision Type <sub>(FI)</sub>	$N_{predicted\ int\ (FI)}$ (crashes/year)	Proportion of Collision Type <sub>(PDO)</sub>	$N_{predicted\ int\ (PDO)}$ (crashes/year)
	from Table 10-6	$(8)_{total}$ from Worksheet SP3C	from Table 10-6	$(8)_{FI}$ from Worksheet SP3C	from Table 10-6	$(8)_{PDO}$ from Worksheet SP3C
Total	1.000	2.857	1.000	1.186	1.000	1.671
		$(2) \times (3)_{total}$		$(4) \times (5)_{FI}$		$(6) \times (7)_{PDO}$
<b>SINGLE-VEHICLE</b>						
Collision with animal	0.019	0.054	0.008	0.009	0.026	0.043
Collision with bicycle	0.001	0.003	0.001	0.001	0.001	0.002



Collision with pedestrian	0.001	0.003	0.001	0.001	0.001	0.002
Overturned	0.013	0.037	0.022	0.026	0.007	0.012
Ran off road	0.244	0.697	0.240	0.285	0.247	0.413
Other single-vehicle collision	0.016	0.046	0.011	0.013	0.020	0.033
Total single-vehicle crashes	0.294	0.840	0.283	0.336	0.302	0.505
<b>MULTIPLE-VEHICLE</b>						
Angle collision	0.237	0.677	0.275	0.326	0.210	0.351
Head-on collision	0.052	0.149	0.081	0.096	0.032	0.053
Rear-end collision	0.278	0.794	0.260	0.308	0.292	0.488
Sideswipe collision	0.097	0.277	0.051	0.060	0.131	0.219
Other multiple-vehicle collision	0.042	0.120	0.050	0.059	0.033	0.055
Total multiple-vehicle crashes	0.706	2.017	0.717	0.850	0.698	1.166

#### Worksheet SP3E—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP3E presents a summary of the results.

#### Worksheet SP3E. Summary Results for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)
	(4) from Worksheet SP3C	(8) from Worksheet SP3C
Total	1.000	2.857
Fatal and injury (FI)	0.415	1.186
Property damage only (PDO)	0.585	1.671

#### 10.12.4. Sample Problem 4

A four-leg signalized intersection located on a rural two-lane roadway.

##### The Question

What is the predicted average crash frequency of the signalized intersection for a particular year?

##### The Facts

- 4 legs
- 1 right-turn lane on one approach
- Signalized intersection
- 90-degree intersection angle

- No lighting present
- AADT of major road = 10,000 veh/day
- AADT of minor road = 2,000 veh/day
- 1 left-turn lane on each of two approaches

#### Assumptions

- Collision type distributions used are the default values from Table 10-6.
- The calibration factor is assumed to be 1.30.

#### Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem 4 is determined to be 5.7 crashes per year (rounded to one decimal place).

#### Steps

##### Step 1 through 8

To determine the predicted average crash frequency of the intersection in Sample Problem 4, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

##### Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

The SPF for a signalized intersection can be calculated from Equation 10-10 as follows:

$$N_{spf, 4SG} = \exp \left[ -5.13 + 0.60 \times \ln(AADT_{maj}) + 0.20 \times \ln(AADT_{min}) \right]$$

$$= \exp \left[ -5.13 + 0.60 \times \ln(10,000) + 0.20 \times \ln(2,000) \right] = 6.796 \text{ crashes/year}$$

##### Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

##### Intersection Skew Angle ( $CMF_{I1}$ )

The CMF for skew angle at four-leg signalized intersections is 1.00 for all cases.

##### Intersection Left-Turn Lanes ( $CMF_{21}$ )

From Table 10-13 for a signalized intersection with left-turn lanes on two approaches,  $CMF_{21} = 0.67$ .

##### Intersection Right-Turn Lanes ( $CMF_{31}$ )

From Table 10-14 for a signalized intersection with a right-turn lane on one approach,  $CMF_{31} = 0.96$ .

##### Lighting ( $CMF_{41}$ )

Since there is no intersection lighting present in Sample Problem 4,  $CMF_{41} = 1.00$  (i.e., the base condition for  $CMF_{41}$  is the absence of intersection lighting).

The combined CMF value for Sample Problem 4 is calculated below.

$$CMF_{comb} = 0.67 \times 0.96 = 0.64$$

##### Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed that a calibration factor,  $C_i$ , of 1.30 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted int}} = N_{\text{spf int}} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{4i})$$

$$= 6.796 \times 1.30 \times (0.64) = 5.654 \text{ crashes/year}$$

**WORKSHEETS**

The step-by-step instructions above are the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4D (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4E (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

**Worksheet SP4A—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections**

Worksheet SP4A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4.

**Worksheet SP4A. General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections**

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		—	4SG
AADT <sub>maj</sub> (veh/day)		—	10,000
AADT <sub>min</sub> (veh/day)		—	2,000
Intersection skew angle (degrees)		0	0
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	2
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)		0	1

Intersection lighting (present/not present)	not present	not present
Calibration factor, $C_i$	1.0	1.3

#### Worksheet SP4B—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SP4B which indicates the combined CMF value.

#### Worksheet SP4B. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
$CMF_{I1}$	$CMF_{21}$	$CMF_{31}$	$CMF_{41}$	$CMF_{comb}$
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	$(1)*(2)*(3)*(4)$
1.00	0.67	0.96	1.00	0.64

#### Worksheet SP4C—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

The SPF the intersection in Sample Problem 4 is calculated using Equation 10-8 and entered into Column 2 of Worksheet SP4C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-5. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined CMF (from Column 13 in Worksheet SP4B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

**Worksheet SP4C. Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{adj\ 3ST, 4ST, \text{ or } 4SG}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{adj\ 3ST, 4ST, \text{ or } 4SG}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_i$	Predicted Average Crash Frequency, $N_{predicted\ tot}$
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total} \times (4)$	from (5) of Worksheet SP4B		$(5) \times (6) \times (7)$
Total	6.796	0.11	1.000	6.796	0.64	1.30	5.654
Fatal and injury (FI)	—	—	0.340	2.311	0.64	1.30	1.923
Property damage only (PDO)	—	—	0.660	4.485	0.64	1.30	3.732

**Worksheet SP4D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections**

Worksheet SP4D presents the default proportions for collision type (from Table 10-6) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Property-damage-only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet SP4C) by crash severity and collision type.

**Worksheet SP4D.** Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	Proportion of Collision Type (total)	$N_{\text{predicted int (total)}}$ (crashes/year)	Proportion of Collision Type (FI)	$N_{\text{predicted int (FI)}}$ (crashes/year)	Proportion of Collision Type (PDO)	$N_{\text{predicted int (PDO)}}$ (crashes/year)
	from Table 10-6	(8) <sub>total</sub> from Worksheet SP4C	from Table 10-6	(8) <sub>FI</sub> from Worksheet SP4C	from Table 10-6	(8) <sub>PDO</sub> from Worksheet SP4C
Total	1.000	5.654	1.000	1.923	1.000	3.732
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>PDO</sub>
<b>SINGLE-VEHICLE</b>						
Collision with animal	0.002	0.011	0.000	0.000	0.003	0.011
Collision with bicycle	0.001	0.006	0.001	0.002	0.001	0.004
Collision with pedestrian	0.001	0.006	0.001	0.002	0.001	0.004
Overtuned	0.003	0.017	0.003	0.006	0.003	0.011
Ran off road	0.064	0.362	0.032	0.062	0.081	0.302
Other single-vehicle collision	0.005	0.028	0.003	0.006	0.018	0.067
Total single-vehicle crashes	0.076	0.430	0.040	0.077	0.107	0.399
<b>MULTIPLE-VEHICLE</b>						
Angle collision	0.274	1.549	0.336	0.646	0.242	0.903
Head-on collision	0.054	0.305	0.080	0.154	0.040	0.149
Rear-end collision	0.426	2.409	0.403	0.775	0.438	1.635
Sideswipe collision	0.118	0.667	0.051	0.098	0.153	0.571
Other multiple-vehicle collision	0.052	0.294	0.090	0.173	0.020	0.075
Total multiple-vehicle crashes	0.924	5.224	0.960	1.846	0.893	3.333

**Worksheet SP4E—Summary Results for Rural Two-Lane, Two-Way Road Intersections**

Worksheet SP4E presents a summary of the results.

**Worksheet SP4E. Summary Results for Rural Two-Lane, Two-Way Road Intersections**

(1)	(2)	(3)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)
	(4) from Worksheet SP4C	(8) from Worksheet SP4C
Total	1.000	5.654
Fatal and injury (FI)	0.340	1.923
Property damage only (PDO)	0.660	3.732

**10.12.5. Sample Problem 5****The Project**

A project of interest consists of three sites: a rural two-lane tangent segment, a rural two-lane curved segment, and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2, and 3.)

**The Question**

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2, and 3 and the observed crash frequencies using the site-specific EB Method?

**The Facts**

- 2 roadway segments (2U tangent segment, 2U curved segment)
- 1 intersection (3ST intersection)
- 15 observed crashes (2U tangent segment: 10 crashes; 2U curved segment: 2 crashes; 3ST intersection: 3 crashes)

**Outline of Solution**

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted average crash frequencies for the project using the site-specific EB Method (i.e., observed crashes are assigned to specific intersections or roadway segments) presented in Part C, Appendix A.2.4.

**Results**

The expected average crash frequency for the project is 12.3 crashes per year (rounded to one decimal place).

**WORKSHEETS**

To apply the site-specific EB Method to multiple roadway segments and intersections on a rural two-lane, two-way road combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- *Worksheet SP5A (Corresponds to Worksheet 3A)*—Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways
- *Worksheet SP5B (Corresponds to Worksheet 3B)*—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

**Worksheets SP5A—Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways**

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered into Columns 2 through 4 of Worksheet SP5A. Column 5 presents the observed crash frequencies by site type, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from Part C, Appendix A is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8. Detailed calculation of Columns 7 and 8 are provided below.

**Worksheet SP5A.** Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	Weighted Adjustment, $w$	Expected average crash frequency, $N_{\text{expected}}$
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FI)}}$	$N_{\text{predicted (PDO)}}$			Equation A-5	Equation A-4
	ROADWAY SEGMENTS						
Segment 1	6.084	1.954	4.131	10	0.16	0.507	8.015
Segment 2	0.525	0.169	0.356	2	2.36	0.447	1.341
INTERSECTIONS							
Intersection 1	2.857	1.186	1.671	3	0.54	0.393	2.944
Combined (Sum of Column)	9.466	3.309	6.158	15	—	—	12.300

**Column 7—Weighted Adjustment**

The weighted adjustment,  $w$ , to be placed on the predictive model estimate is calculated using Equation A-5 as follows:

$$w = \frac{1}{1 + k \times \left( \sum_{\text{all study years}} N_{\text{predicted}} \right)}$$

Segment 1

$$w = \frac{1}{1 + 0.16 \times (6.084)} = 0.507$$

Segment 2



$$w = \frac{1}{1 + 2.36 \times (0.525)} = 0.447$$

Intersection 1

$$w = \frac{1}{1 + 0.54 \times (2.857)} = 0.393$$

**Column 8—Expected Average Crash Frequency**

The estimate of expected average crash frequency,  $N_{\text{expected}}$ , is calculated using Equation A-4 as follows:

$$N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}}$$

Segment 1

$$N_{\text{expected}} = 0.507 \times 6.084 + (1 - 0.507) \times 10 = 8.015$$

Segment 2

$$N_{\text{expected}} = 0.447 \times 0.525 + (1 - 0.447) \times 2 = 1.341$$

Intersection 1

$$N_{\text{expected}} = 0.393 \times 2.857 + (1 - 0.393) \times 3 = 2.944$$

**Worksheet SP5B—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways**

Worksheet SP5B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

**Worksheet SP5B.** Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	$N_{\text{expected}}$
Total	(2) <sub>comb</sub> from Worksheet SP5A	(8) <sub>comb</sub> from Worksheet SP5A
	9.466	12.3
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet SP5A	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub>
	3.309	4.3
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet SP5A	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub>
	6.158	8.0

**10.12.6. Sample Problem 6**

The Project

A project of interest consists of three sites: a rural two-lane tangent segment; a rural two-lane curved segment; and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2, and 3.)

#### The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2, and 3 and the observed crash frequencies using the project-level EB Method?

#### The Facts

- 2 roadway segments (2U tangent segment, 2U curved segment)
- 1 intersection (3ST intersection)
- 15 observed crashes (but no information is available to attribute specific crashes to specific sites within the project)

#### Outline of Solution

Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e., observed crash data for individual roadway segments and intersections are not available, but observed crashes are assigned to a facility as a whole) presented in Part C, Appendix A.2.5.

#### Results

The expected average crash frequency for the project is 11.7 crashes per year (rounded to one decimal place).

## WORKSHEETS

To apply the project-level EB Method to multiple roadway segments and intersections on a rural two-lane, two-way road combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- *Worksheet SP6A (Corresponds to Worksheet 4A)*—Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways
- *Worksheet SP6B (Corresponds to Worksheet 4B)*—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

#### Worksheets SP6A—Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered in Columns 2 through 4 of Worksheet SP6A. Column 5 presents the total observed crash frequencies combined for all sites, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates  $N_{w0}$  and Column 8  $N_{w1}$ . Equations A-10 through A-14 from Part C, Appendix A are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

**Worksheet SP6A.** Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	$N_{\text{predicted } w=0}$	$N_{\text{predicted } w=1}$	$W_0$	$N_0$	$U_1$	$N_1$	$N_{\text{expected } \text{combined}}$
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FI)}}$	$N_{\text{predicted (PDO)}}$			Equation A-8 (6)*(2) <sup>2</sup>	Equation A-9 sqrt((6)*(2))	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
	ROADWAY SEGMENTS											
Segment 1	6.084	1.954	4.131	—	0.16	5.922	0.987	—	—	—	—	—
Segment 2	0.525	0.169	0.356	—	2.36	0.651	1.113	—	—	—	—	—
INTERSECTIONS												
Intersection 1	2.857	1.186	1.671	—	0.54	4.408	1.242	—	—	—	—	—
Combined (Sum of Column)	9.466	3.309	6.158	15	—	10.981	3.342	0.463	12.438	0.739	10.910	11.674

Note:  $N_{\text{predicted } w0}$  = Predicted number of total crashes assuming that crash frequencies are statistically independent

$$N_{\text{predicted } w0} = \sum_{j=1}^5 k_{rmj} N_{rmj}^2 + \sum_{j=1}^5 k_{rsj} N_{rsj}^2 + \sum_{j=1}^5 k_{rdj} N_{rdj}^2 + \sum_{j=1}^4 k_{imj} N_{imj}^2 + \sum_{j=1}^4 k_{isj} N_{isj}^2 \quad (\text{A-8})$$

$N_{\text{predicted } w1}$  = Predicted number of total crashes assuming that crash frequencies are perfectly correlated

$$N_{\text{predicted } w1} = \sum_{i=1}^5 \sqrt{k_{rmj} N_{rmj}} + \sum_{i=1}^5 \sqrt{k_{rsj} N_{rsj}} + \sum_{i=1}^5 \sqrt{k_{rdj} N_{rdj}} + \sum_{i=1}^4 \sqrt{k_{imj} N_{imj}} + \sum_{i=1}^4 \sqrt{k_{isj} N_{isj}} \quad (\text{A-9})$$

#### Column 9— $w_0$

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent,  $w_0$ , is calculated using Equation A-10 as follows:

$$\begin{aligned} w_0 &= \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} \\ &= \frac{1}{1 + \frac{10.981}{9.466}} \\ &= 0.463 \end{aligned} \quad (\text{A-10})$$

#### Column 10— $N_0$

The expected crash frequency based on the assumption that different roadway elements are statistically independent,  $N_0$ , is calculated using Equation A-11 as follows:

$$\begin{aligned}
 N_0 &= w_0 \times N_{\text{predicted}(\text{total})} + (1 - w_0) \times N_{\text{observed}(\text{total})} \\
 &= 0.463 \times 9.466 + (1 - 0.463) \times 15 = 12.438
 \end{aligned}
 \tag{A-11}$$

**Column 11— $w_1$** 

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated,  $w_1$ , is calculated using Equation A-12 as follows:

$$\begin{aligned}
 w_1 &= \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted}(\text{total})}}} \\
 &= \frac{1}{1 + \frac{3.342}{9.466}} \\
 &= 0.739
 \end{aligned}
 \tag{A-12}$$

**Column 12— $N_1$** 

The expected crash frequency based on the assumption that different roadway elements are perfectly correlated,  $N_1$ , is calculated using Equation A-13 as follows:

$$\begin{aligned}
 N_1 &= w_1 \times N_{\text{predicted}(\text{total})} + (1 - w_1) \times N_{\text{observed}(\text{total})} \\
 &= 0.739 \times 9.466 + (1 - 0.739) \times 15 = 10.910
 \end{aligned}
 \tag{A-13}$$

**Column 13— $N_{\text{expected/comb}}$** 

The expected average crash frequency based of combined sites,  $N_{\text{expected/comb}}$ , is calculated using Equation A-14 as follows:

$$\begin{aligned}
 N_{\text{expected/comb}} &= \frac{N_0 + N_1}{2} \\
 &= \frac{12.438 + 10.910}{2} \\
 &= 11.674
 \end{aligned}
 \tag{A-14}$$

**Worksheet SP6B—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways**

Worksheet SP6B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

**Worksheet SP6B. Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways**

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	$N_{\text{expected/comb}}$
Total	(2) <sub>comb</sub> from Worksheet SP6A	(13) <sub>comb</sub> from Worksheet SP6A
	9.466	11.7
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet SP6A	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub>
	3.309	4.1
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet SP6A	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub>
	6.158	7.6

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## APPENDIX 10A. WORKSHEETS FOR PREDICTIVE METHOD FOR RURAL TWO-LANE, TWO-WAY ROADS

Commented [IJ43]: 17-71: these need to be updated by another party.

### Worksheet 1A. General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Length of segment, L (mi)		—	
AADT (veh/day)		—	
Lane width (ft)		12	
Shoulder width (ft)		6	
Shoulder type		paved	
Length of horizontal curve (mi)		0	
Radius of curvature (ft)		0	
Spiral transition curve (present/not present)		not present	
Superelevation variance (ft/ft)		<0.01	
Grade (%)		0	
Driveway density (driveways/mile)		5	
Centerline rumble strips (present/not present)		not present	
Passing lanes (present/not present)		not present	
Two-way left-turn lane (present/not present)		not present	
Roadside hazard rating (1–7 scale)		3	
Segment lighting (present/not present)		not present	
Auto speed enforcement (present/not present)		not present	
Calibration factor, $C_r$		1.0	

**Worksheet 1B.** Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Superelevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips	CMF for Passing Lanes	CMF for Two-Way Left-Turn Lane	CMF for Roadside Design	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{6r}$	$CMF_{7r}$	$CMF_{8r}$	$CMF_{9r}$	$CMF_{10r}$	$CMF_{11r}$	$CMF_{12r}$	$CMF_{comb}$
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	$(1)*(2)*\dots*(11)*(12)$

**Worksheet 1C.** Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{obs}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{obs}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_r$	Predicted Average Crash Frequency, $N_{predicted}$
	from Equation 10-6	from Equation 10-7	from Table 10-3	$(2)_{total}*(4)$	(13) from Worksheet 1B		$(5)*(6)*(7)$
Total			1.000				
Fatal and injury (FI)	—	—	0.321				
Property damage only (PDO)	—	—	0.679				



**Worksheet 1D.** Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Proportion of Collision Type <sub>(total)</sub>	$N_{\text{predicted } rs \text{ (total)}}$ (crashes/year)	Proportion of Collision Type <sub>(FI)</sub>	$N_{\text{predicted } rs \text{ (FI)}}$ (crashes/year)	Proportion of Collision Type <sub>(PDO)</sub>	$N_{\text{predicted } rs \text{ (PDO)}}$ (crashes/year)
Collision Type	from Table 10-4	(8)total from Worksheet 1C	from Table 10-4	(8)FI from Worksheet 1C	from Table 10-4	(8)PDO from Worksheet 1C
Total	1.000		1.000		1.000	
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>PDO</sub>
<b>SINGLE-VEHICLE</b>						
Collision with animal	0.121		0.038		0.184	
Collision with bicycle	0.002		0.004		0.001	
Collision with pedestrian	0.003		0.007		0.001	
Overtuned	0.025		0.037		0.015	
Ran off road	0.521		0.545		0.505	
Other single-vehicle collision	0.021		0.007		0.029	
Total single-vehicle crashes	0.693		0.638		0.735	
<b>MULTIPLE-VEHICLE</b>						
Angle collision	0.085		0.100		0.072	
Head-on collision	0.016		0.034		0.003	
Rear-end collision	0.142		0.164		0.122	
Sideswipe collision	0.037		0.038		0.038	
Other multiple-vehicle collision	0.027		0.026		0.03	
Total multiple-vehicle crashes	0.307		0.362		0.265	

**Worksheet 1E.** Summary Results for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total				
Fatal and injury (FI)				
Property damage only (PDO)				

**Worksheet 2A.** General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		—	
AADT <sub>maj</sub> (veh/day)		—	
AADT <sub>min</sub> (veh/day)		—	
Intersection skew angle (degrees)		0	
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)		0	
Intersection lighting (present/not present)		not present	
Calibration factor, C <sub>i</sub>		1.0	

**Worksheet 2B.** Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
CMF <sub>fi</sub>	CMF <sub>2i</sub>	CMF <sub>3i</sub>	CMF <sub>4i</sub>	CMF <sub>comb</sub>
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	(1)*(2)*(3)*(4)

**Worksheet 2C.** Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{off\ 3ST, 4ST\ or\ 4SG}$	Overdispersion Parameter, $k$	Crash Severity Distribution	$N_{off\ 3ST, 4ST\ or\ 4SG}$ by Severity Distribution	Combined CMFs	Calibration Factor, $C_i$	Predicted Average Crash Frequency, $N_{predicted\ int}$
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total} * (4)$	from (5) of Worksheet 2B		$(5) * (6) * (7)$
Total							
Fatal and injury (FI)	—	—					
Property damage only (PDO)	—	—					

**Worksheet 2D.** Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	Proportion of Collision Type $(total)$	$N_{predicted\ int\ (total)}$ (crashes/year)	Proportion of Collision Type $(FI)$	$N_{predicted\ int\ (FI)}$ (crashes/year)	Proportion of Collision Type $(PDO)$	$N_{predicted\ int\ (PDO)}$ (crashes/year)
	from Table 10-6	$(8)_{total}$ from Worksheet 2C	from Table 10-6	$(8)_{FI}$ from Worksheet 2C	from Table 10-6	$(8)_{PDO}$ from Worksheet 2C
Total	1.000		1.000		1.000	
		$(2) * (3)_{total}$		$(4) * (5)_{FI}$		$(6) * (7)_{PDO}$

**SINGLE-VEHICLE**

Collision with animal						
Collision with bicycle						
Collision with pedestrian						
Overtuned						
Ran off road						
Other single-vehicle collision						
Total single-vehicle crashes						

**MULTIPLE-VEHICLE**

Angle collision						
Head-on collision						
Rear-end collision						

Sideswipe collision						
Other multiple-vehicle collision						
Total multiple-vehicle crashes						

**Worksheet 2E.** Summary Results for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)
Crash Severity Level	Crash Severity Distribution	Predicted Average Crash Frequency (crashes/year)
	(4) from Worksheet 2C	(8) from Worksheet 2C
Total		
Fatal and injury (FI)		
Property damage only (PDO)		

**Worksheet 3A.** Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	Weighted Adjustment, $w$	Expected Average Crash Frequency, $N_{\text{expected}}$
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FI)}}$	$N_{\text{predicted (PDO)}}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Segment 5							
Segment 6							
Segment 7							
Segment 8							
INTERSECTIONS							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Intersection 5							
Intersection 6							
Intersection 7							

Intersection 8							
Combined (Sum of Column)					—	—	

**Worksheet 3B.** Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	$N_{\text{expected}}$
Total	(2) <sub>comb</sub> from Worksheet 3A	(8) <sub>comb</sub> from Worksheet 3A
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet 3A	(3) <sub>total</sub> *(2) <sub>FI</sub> /(2) <sub>total</sub>
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet 3A	(3) <sub>total</sub> *(2) <sub>PDO</sub> /(2) <sub>total</sub>

**Worksheet 4A.** Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter $\tau, k$	$N_{\text{predicted } w0}$	$N_{\text{predicted } w1}$	$w0$	$N0$	$w1$	$N1$	$N_{\text{expected } /comb}$
	$N_{\text{predicted } d}$ (total)	$N_{\text{predicted } d}$ (FI)	$N_{\text{predicted } d}$ (PDO)									
						Equation A-8 (6)*(2) <sup>2</sup>	Equation A-9 $\sqrt{\text{rt}((6)*}$ (2))	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
<b>ROADWAY SEGMENTS</b>												
Segment 1				—				—	—	—	—	—
Segment 2				—				—	—	—	—	—
Segment 3				—				—	—	—	—	—
Segment 4				—				—	—	—	—	—
Segment 5				—				—	—	—	—	—
Segment 6				—				—	—	—	—	—
Segment 7				—				—	—	—	—	—
Segment 8				—				—	—	—	—	—
<b>INTERSECTIONS</b>												
Intersection 1				—				—	—	—	—	—
Intersection 2				—				—	—	—	—	—
Intersection 3				—				—	—	—	—	—
Intersection 4				—				—	—	—	—	—
Intersection 5				—				—	—	—	—	—

Intersection 6				—				—	—	—	—	—
Intersection 7				—				—	—	—	—	—
Intersection 8				—				—	—	—	—	—
Combined (Sum of Column)					—							

**Worksheet 4B.** Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	$N_{\text{expected/comb}}$
Total	(2) <sub>comb</sub> from Worksheet 4A	(13) <sub>comb</sub> from Worksheet 4A
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet 4A	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub>
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet 4A	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub>

## CHAPTER 11. PREDICTIVE METHOD FOR RURAL MULTILANE HIGHWAYS

### 11.1. INTRODUCTION

This chapter presents the predictive method for rural multilane highways. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in Part C—Introduction and Applications Guidance.

The predictive method for rural multilane highways provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for a rural multilane highway facility with known characteristics. All types of crashes involving vehicles of all types are included. Pedestrian, bicycle, and animal crashes are excluded. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the predictive models in Chapter 11 is documented in Ivan et al. (5). The CMFs used in the predictive models have been reviewed and updated by Harkey et al. (3) and in related work by Srinivasan et al. (6).

This chapter presents the following information about the predictive method for rural multilane highways:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 11 and site types for which predictive models have been developed for Chapter 11.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing a rural multilane facility into individual sites, consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for rural multilane highways.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 11.
- Guidance for the application of Chapter 11 predictive method and limitations of the predictive method specific to Chapter 11.
- Sample problems illustrating the application of Chapter 11 predictive method for rural multilane highways.

**Commented [ATAF1]:** We are not including pedestrian, bicycle and animal crashes

**Commented [ATAF2]:** Reference updated

**Commented [U3]:** This needs to be updated pending what is decided to do about CMFs for these models.

## 11.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the “expected average crash frequency,”  $N_{\text{expected}}$  (by total crashes, crash severity, or collision type), of a roadway network, facility, or site. In the predictive method, the roadway is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as “sites.” Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type, a number of different site types may exist, such as divided and undivided roadway segments, and signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities.

The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The estimate relies on estimates made using predictive models which are combined with observed crash data using the Empirical Bayes (EB) Method.

The predictive models used in Chapter 11 to determine the predicted average crash frequency,  $N_{\text{predicted}}$ , are of the general form shown in Equation 11-1.

$$N_{\text{predicted}} = N_{\text{spf } x} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) \times C_x \quad (11-1)$$

Where:

$N_{\text{predicted}}$  = predicted average crash frequency for a specific year on site type  $x$ ;

$N_{\text{spf } x}$  = predicted average crash frequency determined for base conditions of the SPF developed for site type  $x$ ;

$CMF_{yx}$  = crash modification factors specific to site type  $x$  and specific geometric design and traffic control features  $y$ ; and

$C_x$  = calibration factor to adjust SPF for local conditions for site type  $x$ .

The predictive models in Chapter 11 provide estimates of the crash severity for roadway segments and intersections. The SPFs in Chapter 11 address all levels of injury severity including fatalities (K), incapacitating injuries (A), non-incapacitating injuries (B), possible injuries (C), and no injury (O). For each individual site type, models were estimated for KABCO, KABC, KAB, and KA severity levels. The default estimates of the models for roadway segments and intersections are provided in Section 11.6. Supplementary models for same direction, intersecting direction and opposite direction crashes by severity level for segments and intersections are provided in Appendix 11B.

## 11.3. RURAL MULTILANE HIGHWAYS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 11

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 11. These predictive models are applied following the steps of the predictive method presented in Section 11.4.



### 11.3.1. Definition of Chapter 11 Facility and Site Types

Chapter 11 applies to rural multilane highway facilities. The term “multilane” refers to facilities with four through lanes. Rural multilane highway facilities may have occasional grade-separated interchanges, but these are not to be the primary form of access and egress. The predictive method does not apply to any section of a multilane highway within the limits of an interchange which has free-flow ramp terminals on the multilane highway of interest. Facilities with six or more lanes are not covered in Chapter 11.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all rural multilane facilities independent of official state or local highway designation.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas are based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas which have a population less than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area.

Table 11-1 identifies the specific site types on rural multilane highways for which predictive models have been developed for estimating the expected average crash frequency by severity, and collision type. In Chapter 11, separate SPFs are used for each individual site to predict multiple-vehicle crashes (including same direction crashes, intersecting direction crashes, and opposite direction crashes) and single-vehicle crashes for both roadway segments and intersections. No predictive models are available for roadway segments with more than four lanes or for other intersection types such as all-way stop-controlled intersections, yield-controlled intersections, or uncontrolled intersections.

**Table 11-1.** Rural Multilane Highway Site Type with SPFs in Chapter 11

Site Type	Site Types with SPFs in Chapter 11
Roadway Segments	Rural four-lane undivided segments (4U) Rural four-lane divided segments (4D)
Intersections	<u>Unsignalized three-leg (Stop control on minor-road approaches) (3ST)</u> <u>Unsignalized four-leg (Stop control on minor-road approaches) (4ST)</u> Signalized four-leg (4SG)

**Deleted:** No predictive models are available for roadway segments with more than four lanes or for other intersection types such as yield-controlled intersections, or uncontrolled intersections.

**Deleted:** All-way stop-controlled three-leg (3ST)

**Deleted:** All-way stop-controlled four-leg (4ST)

These specific site types are defined as follows:

- *Undivided four-lane roadway segment (4U)*—a roadway consisting of four lanes with a continuous cross-section which provides two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Divided four-lane roadway segment (4D)*—Divided highways are non-freeway facilities (i.e., facilities without full control of access) that have the lanes in the two directions of travel separated by a raised, depressed, or flush median which is not designed to be traversed by a vehicle. The median may include or exclude a physical barrier.
- *Three-leg intersection with stop control (3ST)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and a minor road. A stop sign is provided on the minor-road approach to the intersection only.
- *Four-leg intersection with stop control (4ST)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and two minor roads. A stop sign is provided on both minor-road approaches to the intersection.

**Deleted:** *Three-leg intersection with all-way stop control (3ST)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and a minor road. Stop signs are provided on all intersection approaches.

**Deleted:** *Four-leg intersection with all-way stop control (4ST)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and two minor roads. On all approaches, stop signs are provided.

- *Four-leg signalized intersection (4SG)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and two other rural roads which may be two lane or four lane rural highways. Signalized control is provided at the intersection by traffic lights.

### 11.3.2. Predictive Models for Rural Multilane Roadway Segments

The predictive models can be used to estimate total crashes (i.e., all crash severities and collision types) or can be used to estimate the expected average frequency of specific crash severity levels or specific collision types. The predictive model for an individual roadway segment or intersection combines a SPF with CMFs and a calibration factor.

The predictive models for roadway segments estimate the predicted average crash frequency of non-intersection-related crashes. The predictive models for undivided roadway segments, divided roadway segments and intersections are presented in Equations 11-2, 11-3, and 11-4.

For undivided roadway segments the predictive model is:

$$N_{\text{predicted } rs} = N_{\text{spf } ru} \times (CMF_{1ru} \times CMF_{2ru} \times K \times CMF_{5ru}) \times C_{ru} \quad (11-2)$$

For divided roadway segments the predictive model is:

$$N_{\text{predicted } rs} = N_{\text{spf } rd} \times (CMF_{1rd} \times CMF_{2rd} \times K \times CMF_{5rd}) \times C_{rd} \quad (11-3)$$

Where:

- $N_{\text{predicted } rs}$  = predictive model estimate of expected average crash frequency for an individual roadway segment for the selected year;
- $N_{\text{spf } ru}$  = expected average crash frequency for an undivided roadway segment with base conditions;
- $C_{ru}$  = calibration factor for undivided roadway segments developed for a particular jurisdiction or geographical area;
- $CMF_{1ru} \dots CMF_{5ru}$  = crash modification factors for undivided roadway segments;
- $N_{\text{spf } rd}$  = expected average crash frequency for a divided roadway segment with base conditions; and
- $CMF_{1rd} \dots CMF_{5rd}$  = crash modification factors for divided roadway segments.
- $C_{rd}$  = calibration factor for divided roadway segments developed for a particular jurisdiction or geographical area;

### 11.3.3. Predictive Models for Rural Multilane Highway Intersections

The predictive models for intersections estimate the predicted average crash frequency of crashes within the limits of an intersection, or crashes that occur on the intersection legs, and are a result of the presence of the intersection (i.e., intersection-related crashes).

For all intersection types in Chapter 11 the predictive model is:

$$N_{\text{predicted int}} = N_{\text{spf int}} \times (CMF_{1\text{int}} \times CMF_{2\text{int}} \times K \times CMF_{5\text{int}}) \times C_{\text{int}} \quad (11-4)$$

Where:

$N_{\text{predicted int}}$  = predicted average crash frequency for an individual intersection for the selected year;

$N_{\text{spf int}}$  = predicted average crash frequency for an intersection with base conditions;

$CMF_{1\text{int}} \dots CMF_{5\text{int}}$  = crash modification factors for intersections; and

$C_{\text{int}}$  = calibration factor for intersections of a specific type developed for use for a particular jurisdiction of geographical area.

The SPFs for rural multilane highways are presented in Section 11.6. The associated CMFs for each of the SPFs are presented in Section 11.7, and summarized in Table 11-10. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors, are determined in Part C, Appendix A.1.1. Due to continual change in the crash frequency with time, the value of the calibration factors may change for the selected year of the study period.

**Commented [A4]:** If there are no CMFs developed for 4SG intersections, we need to mention that here.

**Commented [A5]:** CMFs section is not in our scope. Table numbers are expected to change. When the chapter is finalized, the table number needs to be updated.

**Commented [J6]:** Update according to where the calibration procedures end up

## 11.4. PREDICTIVE METHOD FOR RURAL MULTILANE HIGHWAYS

The predictive method for rural multilane highways is shown in Figure 11-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or by crash severity and collision types) for a rural multilane highway facility. The components of the predictive models in Chapter 11 are determined and applied in Steps 9, 10, and 11 of the predictive method. Further information needed to apply each step is provided in the following sections and in Part C, Appendix A.

There are 18 steps in the predictive method. In some situations, certain steps will not be needed because the data are not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario or proposed treatment option (within the same period to allow for comparison).

The following explains the details of each step of the method as applied to rural multilane highways.

**Commented [J7]:** 17-71 Contractor – update as necessary.

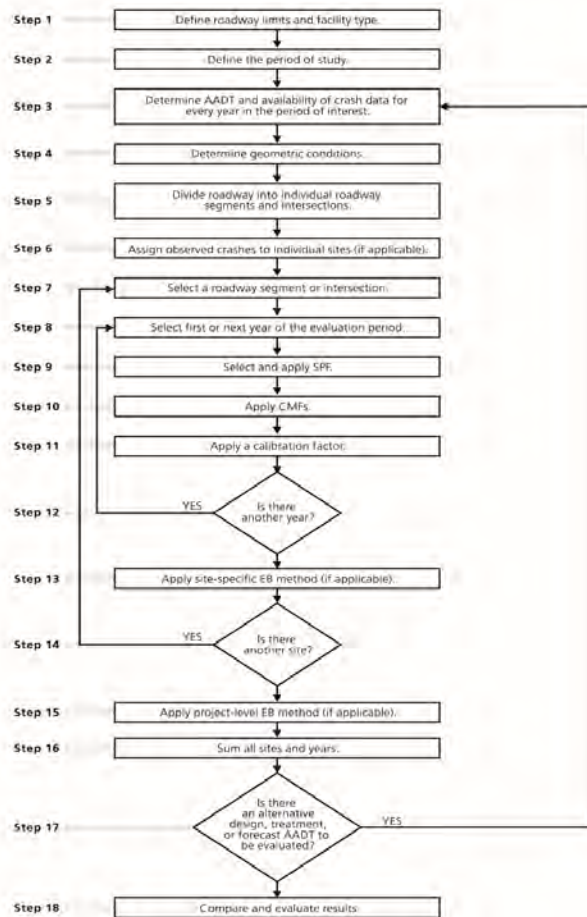


Figure 11-1. The HSM Predictive Method

**Step 1—Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency by severity, and collision types are to be estimated.**

The predictive method can be undertaken for a roadway network, a facility, or an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and unsignalized intersections. The definitions of a rural multilane highway, an intersection and roadway segments, and the specific site types included in Chapter 11 are provided in Section 11.3.

**Deleted:** all-way stop-controlled intersections

The predictive method can be undertaken for an existing roadway, a design alternative for an existing, or a new roadway (which may be either unconstructed or yet to experience enough traffic to have observed crash data). The limits of the roadway of interest will depend on the nature of the study. The study may be limited to only one specific site or a group of contiguous sites. Alternatively, the predictive method can be applied to a very long corridor for the purposes of network screening (determining which sites require upgrading to reduce crashes) which is discussed in Chapter 4, Network Screening.

**Commented [A8]:** This needs to be updated if necessary

**Step 2—Define the period of interest.**

The predictive method can be undertaken for either a past or future period measured in years. Years of interest will be determined by the availability of observed or forecast average annual daily traffic (AADT) volumes, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

- A past period (based on observed AADTs) for:
  - An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features, and traffic volumes are known.
  - An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).
- A future period (based on forecast AADTs) for:
  - An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
  - An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
  - A new roadway network, facility, or site that does not currently exist, but is proposed for construction during some future period.

**Step 3—For the study period, determine the availability of an annual average daily traffic volumes and, for an existing roadway network, the availability of observed crash data to determine whether the EB Method is applicable.**

***Determining Traffic Volumes***

The SPFs used in Step 9 (and some CMFs in Step 10), include AADT volumes (vehicles per day) as a variable. For a past period, the AADT may be determined by automated recording or estimated from a sample survey. For a future period, the AADT may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models, or based on the assumption that current traffic volumes will remain relatively constant.

For each roadway segment, the AADT is the average daily two-way, 24-hour traffic volume on that roadway segment in each year of the period to be evaluated selected in Step 8.

For each intersection, two values are required in each predictive model. These are the AADT of the major street,  $AADT_{maj}$ , and the two-way AADT of the minor street,  $AADT_{min}$ .

In Chapter 11,  $AADT_{maj}$  and  $AADT_{min}$  are determined as follows: if the AADTs on the two major-road legs of an intersection differ, the larger of the two AADT values is used for  $AADT_{maj}$ . For a three-leg intersection, the AADT of the minor-road leg is used for  $AADT_{min}$ . For a four-leg intersection, the larger of the AADTs for the two minor-road legs should be used for  $AADT_{min}$ . If a highway agency lacks data on the entering traffic volumes, but has two-way AADT data for the major and minor-road legs of the intersection, these may be used as a substitute for the entering volume data. Where needed, the total entering volume (TEV) can be estimated as the sum of  $AADT_{maj}$  and  $AADT_{min}$  for four-leg intersections and the sum of  $AADT_{maj}$  and half of  $AADT_{min}$  for three-leg intersections.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated, as appropriate. If there is no established procedure for doing this, the following may be applied within the predictive method to estimate the AADTs for years for which data are not available.

- If AADT data are available for only a single year, that same value is assumed to apply to all years of the before period.
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation.

- The AADTs for years before the first year for which data are available are assumed to be equal to the AADT for that first year.
- The AADTs for years after the last year for which data are available are assumed to be equal to the last year's AADT.

If the EB Method is used (discussed below), AADT data are needed for each year of the period for which observed crash frequency data are available. If the EB Method will not be used, AADTs for the appropriate time period—past, present, or future—determined in Step 2 are used.

#### ***Determining Availability of Observed Crash Data***

Where an existing site or alternative conditions to an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable observed crash data are available for the specific study roadway network, facility, or site. Observed data may be obtained directly from the jurisdiction's crash report system. At least two years of observed crash frequency data are desirable to apply the EB Method. The EB Method and criteria to determine whether the EB Method is applicable are presented in [Part C, Appendix A.2.1](#).

**Commented [A9]:** This needs to be updated if necessary.

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but cannot be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash data are not available, then Steps 6, 13, and 15 of the predictive method are not conducted. In this case, the estimate of expected average crash frequency is limited to using a predictive model (i.e., the predicted average crash frequency).

#### **Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the study network.**

In order to determine the relevant data needs and to avoid unnecessary data collection, it is necessary to understand the base conditions of the SPFs in Step 9 and the CMFs in Step 10. The base conditions are defined in Sections 11.6.1 and 11.6.2 for roadway segments and in Section 11.6.3 for intersections.

The following geometric design and traffic control features are used to select a SPF and to determine whether the site specific conditions vary from the base conditions and, therefore, whether a CMF is applicable:

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Presence of median and median width (feet) (for divided roadway segments)
- Sideslope (for undivided roadway segments)
- Shoulder type
- Shoulder width (feet)
- Lane width (feet)
- Presence of lighting
- Presence of automated speed enforcement

For each intersection in the study area, the following geometric design and traffic control features are identified:

- Number of intersection legs (3 or 4)
- ~~Type of traffic control (minor-road stop or signalized)~~
- ~~Intersection skew angle (stop-controlled and signalized intersections)~~
- Presence of left-turn and right-turn lanes

**Deleted:** Type of traffic control (all-way stop or signalized)

**Deleted:** Intersection skew angle (all-way stop-controlled and signalized intersections)

- Presence or absence of lighting

**Step 5—Divide the roadway network or facility under consideration into individual homogenous roadway segments and intersections, which are referred to as sites.**

Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 11 predictive models are provided in Section 11.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results.

**Step 6—Assign observed crashes to the individual sites (if applicable).**

Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, proceed to Step 7. In Step 3, the availability of observed data and whether the data could be assigned to specific locations was determined. The specific criteria for assigning crashes to individual roadway segments or intersections are presented in [Part C, Appendix A.2.3](#).

**Commented [A10]:** This needs to be updated if necessary.

Crashes that occur at an intersection or on an intersection leg, and are related to the presence of an intersection, are assigned to the intersection and used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections and are not related to the presence of an intersection are assigned to the roadway segment on which they occur; such crashes are used in the EB Method together with the predicted average crash frequency for the roadway segment.

**Step 7—Select the first or next individual site in the study network. If there are no more sites to be evaluated, proceed to Step 15.**

In Step 5, the roadway network within the study limits has been divided into a number of individual homogenous sites (intersections and roadway segments).

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, which is the sum of all of the individual sites, for each year in the study. Note that this value will be the total number of crashes expected to occur over all sites during the period of interest. If a crash frequency is desired (crashes per year), the total can be divided by the number of years in the period of interest.

The estimation for each site (roadway segment or intersection) is conducted one at a time. Steps 8 through 14, described below, are repeated for each site.

**Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 14.**

Steps 8 through 14 are repeated for each site in the study and for each year in the study period.

The individual years of the evaluation period may have to be analyzed one year at a time for any particular roadway segment or intersection because SPFs and some CMFs (e.g., lane and shoulder widths) are dependent on AADT, which may change from year to year.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

Steps 9 through 13, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 11 follow the general form shown in Equation 11-1. Each predictive model consists of a SPF, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor ( $C$ ). The SPFs, CMFs and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predictive model estimate of predicted average crash frequency for the selected year of the selected site. The SPFs available for rural multilane highways are presented in Section 11.6.

The SPF (which is a statistical regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 11.6. A detailed explanation and overview of the SPFs in Part C is provided in [Section C.6.3](#).

**Commented [A11]:** This needs to be updated if necessary.

The SPFs (and base conditions) developed for Chapter 11 are summarized in Table 11-2. For the selected site, determine the appropriate SPF for the site type (intersection or roadway segment) and geometric and traffic control features (undivided roadway, divided roadway, ~~stop-controlled intersection~~, signalized intersection). The SPF for the selected site is calculated using the AADT determined in Step 3 (or  $AADT_{maj}$  and  $AADT_{min}$  for intersections) for the selected year.

**Deleted:**, all-way stop-controlled

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.**

In order to account for differences between the base conditions (Section 11.6) and the site specific conditions, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

**Commented [A12]:** This needs to be updated if necessary.

All CMFs used in Chapter 11 have the same base conditions as the SPFs used in Chapter 11 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 11.7 may be used as part of the Chapter 11 predictive method. Table 11-10 indicates which CMFs are applicable to the SPFs in Section 11.6.

**Commented [A13]:** This needs to be updated if necessary.

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods in the data sets. Calibration of the SPFs to local conditions will account for differences in the data set. A calibration factor ( $C_{rd}$  for undivided roadway segments,  $C_{rd}$  for divided roadway segments or  $C_{int}$  for intersections) is applied to each SPF in the predictive method. An overview of the use of calibration factors is provided in Section C.6.5. Detailed guidance for the development of calibration factors is included in Part C, Appendix A.1.1.

**Commented [A14]:** This needs to be updated if necessary.

**Commented [A15]:** This needs to be updated if necessary.

Steps 9, 10, and 11 together implement the predictive models in Equations 11-2, 11-3, and 11-4 to determine predicted average crash frequency.

**Step 12—If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 13.**

This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

**Step 13—Apply site-specific EB Method (if applicable).**

Whether the site-specific EB Method is applicable is determined in Step 3. The site-specific EB Method combines the Chapter 11 predictive model estimate of predicted average crash frequency,  $N_{predicted}$ , with the observed crash frequency of the specific site,  $N_{observed}$ . This provides a more statistically reliable estimate of the expected average crash frequency of the selected site.

In order to apply the site-specific EB Method, overdispersion parameter,  $k$ , for the SPF is used. This is in addition to the material in Part C, Appendix A.2.4. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to  $N_{predicted}$  and  $N_{observed}$ . Overdispersion parameters are provided for each SPF in Section 11.6.

**Commented [A16]:** This needs to be updated if necessary.

*Apply the site-specific EB Method to a future time period, if appropriate.*

The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period to a future time period.

**Commented [A17]:** This needs to be updated if necessary.



**Step 14—If there is another site to be evaluated, return to Step 7, otherwise, proceed to Step 15.**

This step creates a loop through Steps 7 to 13 that is repeated for each roadway segment or intersection within the facility.

**Step 15—Apply the project level EB Method (if the site specific EB Method is not applicable).**

This step is only applicable to existing conditions when observed crash data are available but cannot be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in [Part C, Appendix A.2.5](#).

**Commented [A18]:** This needs to be updated if necessary.

**Step 16—Sum all sites and years in the study to estimate total crash frequency.**

The total estimated number of crashes within the network or facility limits during a study period of  $n$  years is calculated using Equation 11-5:

$$N_{total} = \sum_{\substack{\text{all} \\ \text{roadway} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int} \quad (11-5)$$

Where:

$N_{total}$  = total expected number of crashes within the limits of a rural multilane highway for the period of interest. Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits within the study period;

$N_{rs}$  = expected average crash frequency for a roadway segment using the predictive method for one specific year; and

$N_{int}$  = expected average crash frequency for an intersection using the predictive method for one specific year.

Equation 11-5 represents the total expected number of crashes estimated to occur during the study period. Equation 11-6 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{total\ average} = \frac{N_{total}}{n} \quad (11-6)$$

Where:

$N_{total\ average}$  = total expected average crash frequency estimated to occur within the defined network or facility limits during the study period; and

$n$  = number of years in the study period.

**Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.**

Steps 3 through 16 of the predictive method are repeated as appropriate for the same roadway limits but for alternative conditions, treatments, periods of interest, or forecast AADTs.

**Step 18—Evaluate and compare results.**

The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time, for given geometric design and traffic control features, and known or estimated AADT. In addition to estimating total crashes, the estimate can be made for different crash severity levels and different collision types. Default SPF by crash severity and collision type are provided in Appendix 11B.

## 11.5. ROADWAY SEGMENTS AND INTERSECTIONS

Section 11.4 provides an explanation of the predictive method. Sections 11.5 through 11.8 provide the specific detail necessary to apply the predictive method steps on rural multilane roads. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in [Part C, Appendix A.1]. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in [Part C, Appendix A.2].

**Commented [A19]:** This needs to be updated.

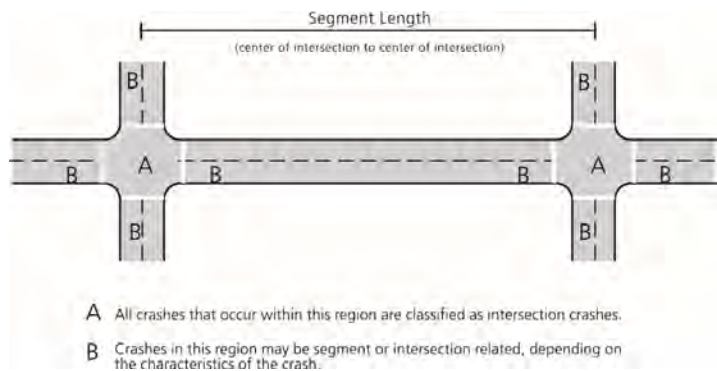
**Commented [A20]:** This needs to be updated.

In Step 5 of the predictive method, the roadway within the defined roadway limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as “sites.” A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA *Interactive Highway Safety Design Model* (IHSDM) (2).

Roadway segments begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Figure 11-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 11 provides predictive models for stop-controlled (three- and four-leg) and signalized (four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the curblane limits of an intersection (Region A of Figure 11-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 11-2).

**Deleted:** for all-way stop-controlled



**Figure 11-2.** Definition of Segments and Intersections

The segmentation process produces a set of roadway segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes, key roadway design characteristics, and traffic control features. Figure 11-2 shows the segment length,  $L$ , for a single homogenous roadway segment occurring between two intersections. However, it is likely that several homogenous roadway segments will occur between two intersections. A new (unique) homogeneous segment begins 250 ft from the center of an intersection or where there is a change in at least one of the following characteristics of the roadway:

- Average annual daily traffic (vehicles per day)
- Presence of median and median width (feet)
- Sideslope (for undivided roadway segments)
- Shoulder type

**Commented [ATAF21]:** Tables that include rounded numbers (lane widths, shoulder widths etc) removed

- Shoulder width (feet) Lane width (feet)
- Presence of lighting
- Presence of automated speed enforcement

In addition, each individual intersection is treated as a separate site for which the intersection-related crashes are estimated using the predictive method.

There is no minimum roadway segment length,  $L$ , for application of the predictive models for roadway segments. However, as a practical matter, when dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results.

In order to apply the site-specific EB Method, observed crashes are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway-segment related depending on whether the crashes occurred 250 feet from the intersection centers. The methodology for assignment of crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3.

**Commented [A22]:** This needs to be updated if necessary.

## 11.6. SAFETY PERFORMANCE FUNCTIONS

In Step 9 of the predictive method, the appropriate safety performance functions (SPFs) are used to predict average crash frequency for the selected year for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for the HSM, the dependent variable estimated is the predicted average crash frequency for a roadway segment or intersection under base conditions, and the independent variables are the AADTs of the roadway segment or intersection legs (and, for roadway segments, the length of the roadway segment).

The predicted crash frequencies for base conditions are calculated from the predictive method in Equations 11-2, 11-3, and 11-4. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3.

**Commented [A23]:** This needs to be updated if necessary.

Each SPF also has an associated overdispersion parameter,  $k$ . The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the EB Method discussed in Part C, Appendix A. The SPFs in Chapter 11 are summarized in Table 11-2. [Note that SPFs are not provided for some combinations of crash type and severity level due to an insufficient number of observed crashes of that combination, failure of the estimated SPF to converge in the estimation process, estimated parameters failing modest significance tests, estimated parameters taking unrealistic values, or a combination of these reasons.](#)

**Commented [A24]:** This needs to be updated if necessary.

**Table 11-2.** Safety Performance Functions included in Chapter 11

Chapter 11 SPFs for Rural Multilane Highways	SPF Equations and Exhibits
Undivided rural four-lane roadway segments	Equations 11-7 and 11-8, Table 11-3, Figure 11-3
Divided roadway segments	Equations 11-9 and 11-10, Table 11-4, Figure 11-4
<del>Three- and four-leg stop-controlled intersections</del>	Equation 11-11, Table 11-5
Four-leg signalized intersections	Equation 11-12, Table 11-6

**Deleted:** Three- and four-leg all-way stop-controlled intersections

Some highway agencies may have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience. These models may be substituted for models presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Part C, Appendix A.

**Commented [A25]:** This needs to be updated if necessary.

### 11.6.1. Safety Performance Functions for Undivided Roadway Segments

The predictive model for estimating predicted average crash frequency on a particular undivided rural multilane roadway segment was presented in Equation 11-2. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs.

The base conditions of the SPF for undivided roadway segments on rural multilane highways are:

- Lane width (LW) 12 feet
- Shoulder width  $\geq 6$  feet
- Shoulder type Paved
- Sideslopes 1V:7H or flatter
- Lighting None
- Automated speed enforcement None

The SPF for undivided roadway segments on a rural multilane highway is shown in Equation 11-7 and presented graphically in Figure 11-3. Note that Figure 11-3 is plotted for a segment length of 1 mile.

$$N_{spf\ ru} = e^{(a+b \times \ln(AADT) + \ln(L))} \quad (11-7)$$

Where:

$N_{spf\ ru}$  = base total expected average crash frequency for a roadway segment;

AADT = annual average daily traffic (vehicles per day) on roadway segment;

$L$  = length of roadway segment (miles); and

$a, b$  = regression coefficients used to determine  $N_{spf\ ru}$ .

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 11.4. The SPFs for undivided roadway segments on rural multilane highways are applicable to the AADT range from 250 to 21,665 vehicles per day. Application to sites with AADTs substantially outside this range may not provide accurate results.

The value of the overdispersion parameter associated with  $N_{spf\ ru}$  is determined as a function of segment length. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. The value is determined as:

$$k = \frac{1}{e^{(c + \ln(L))}} \quad (11-8)$$

Where:

$k$  = overdispersion parameter associated with the roadway segment;

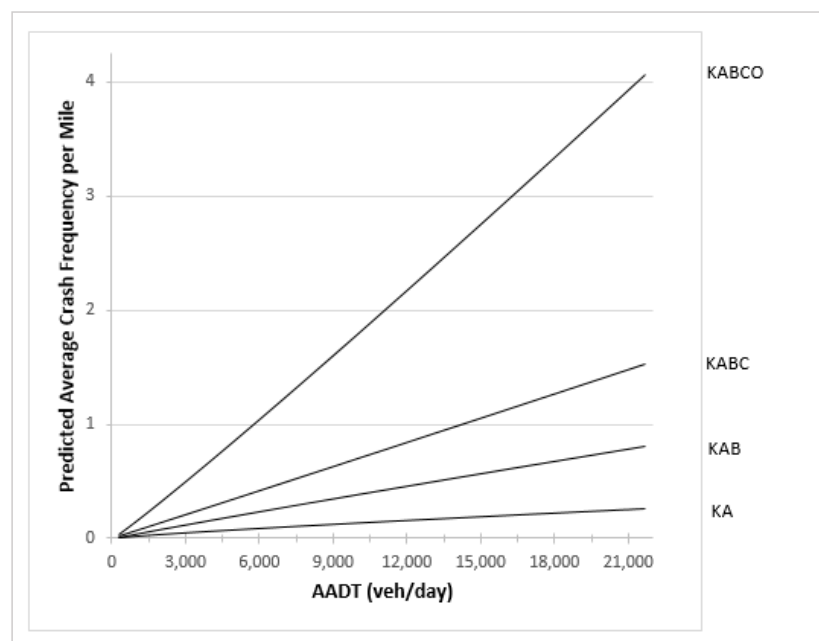
$L$  = length of roadway segment (miles); and

$c$  = a regression coefficient used to determine the overdispersion parameter.

Table 11-3 presents the values of the coefficients used for applying Equations 11-7 and 11-8 to determine the SPF for expected average crash frequency by total crashes (KABCO crashes), fatal-and-injury crashes (KABC crashes), fatal-and-injury crashes excluding possible injury crashes (KAB crashes) and fatal-and-injury crashes excluding both possible and non-incapacitating injury crashes (KA crashes).

**Table 11-3.** SPF Coefficients for Total and Fatal-and-Injury Crashes on Undivided Roadway Segments (for use in Equations 11-7 and 11-8)

Severity Level	a	b	c
KABCO	-9.129	1.055	0.476
KABC	-9.652	1.009	0.611
KAB	-9.704	0.950	0.783
KA	-9.799	0.847	-0.216

**Figure 11-3.** Graphical Form of the SPF for Undivided Roadway Segments (from Equation 11-7 and Table 11-3)

Appendix 11B presents alternative SPFs that can be applied to predict crash frequencies for selected collision types for undivided roadway segments on rural multilane highways. The collision types are single vehicle, same direction, intersecting direction and opposite direction collisions. Use of these alternative models may be considered when estimates are needed for a specific collision type rather than for all crash types combined. It should be noted that the alternative SPFs in Appendix 11B do not address all potential collision types of interest and there is no assurance that the estimates for individual collision types would sum to the estimate for all collision types combined provided by the models in Table 11-3.

### 11.6.2. Safety Performance Functions for Divided Roadway Segments

The predictive model for estimating predicted average crash frequency on a particular divided rural multilane roadway segment was presented in Equation 11-3. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPF for divided rural multilane highway segments is presented in this section. Divided rural multilane highway roadway segments are defined in Section 11.3.

Some divided highways have two roadways, built at different times, with independent alignments and distinctly different roadway characteristics, separated by a wide median. In this situation, it may be appropriate to apply the divided highway methodology twice, separately for the characteristics of each roadway but using the combined traffic volume, and then average the predicted crash frequencies.

The base conditions for the SPF for divided roadway segments on rural multilane highways are:

- Lane width (LW)                      12 feet
- Shoulder Type                          Paved
- Right shoulder width                   $\geq 8$  feet
- Median width                            $\geq 30$  feet
- Lighting                                  None
- Automated speed enforcement      None

The SPF for expected average crash frequency for divided roadway segments on rural multilane highways is shown in Equation 11-9 and presented graphically in Figure 11-4. The graph is generated for a segment length of 1 mile.

$$N_{spf\ rd} = e^{(a+b \times \ln(AADT) + \ln(L))} \quad (11-9)$$

Where:

- $N_{spf\ rd}$                       = base total number of roadway segment crashes per year;
- $AADT$                         = annual average daily traffic (vehicles/day) on roadway segment;
- $L$                               = length of roadway segment (miles); and
- $a, b$                          = regression coefficients used to determine  $N_{spf\ rd}$ .

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 11.4. The SPFs for divided roadway segments on rural multilane highways are applicable to the AADT range from 2,325 to 66,500 vehicles per day. Application to sites with AADTs substantially outside this range may not provide reliable results.

The value of the overdispersion parameter is determined as a function of segment length as:

$$k = \frac{1}{e^{(c + \ln(L))}} \quad (11-10)$$

Where:

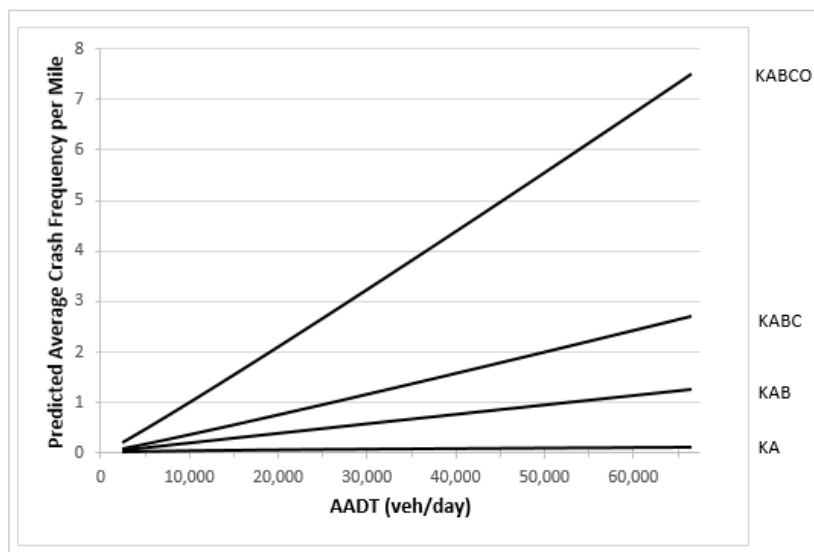
- $k$                               = overdispersion parameter associated with the roadway segment;
- $L$                               = length of roadway segment (miles); and

$c$  = a regression coefficient used to determine the overdispersion parameter.

Table 11-4 presents the values for the coefficients used in applying Equations 11-9 and 11-10.

**Table 11-4.** SPF Coefficients for Total and Fatal-and-Injury Crashes on Divided Roadway Segments (for use in Equations 11-9 and 11-10)

Severity Level	a	b	c
KABCO	-9.644	1.050	0.669
KABC	-10.817	1.064	1.023
KAB	-10.690	0.983	2.090
KA	-7.690	0.508	11.238



**Figure 11-4.** Graphical Form of SPF for Rural Multilane Divided Roadway Segments (from Equation 11-9 and Table 11-4)

Appendix 11B presents alternative SPFs that can be applied to predict crash frequencies for selected collision types (single vehicle, same direction and opposite direction) for divided roadway segments on rural multilane highways. Use of these alternative models may be considered when estimates are needed for a specific collision type rather than for all crash types combined. It should be noted that the alternative SPFs in Appendix 11B do not address all potential collision types of interest and there is no assurance that the estimates for individual collision types would sum to the estimate for all collision types combined provided by the models in Table 11-4.

### 11.6.3. Safety Performance Functions for Intersections

The predictive model for estimating predicted average crash frequency at a particular rural multilane intersection was presented in Equation 11-4. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPFs for rural multilane highway intersections are presented in this section. ~~Three- and four-leg stop-controlled~~ intersections and four-leg signalized rural multilane highway intersections are defined in Section 11.3.

SPFs have been developed for three types of intersections on rural multilane highways. These models can be used for intersections located on both divided and undivided rural four-lane highways. The three types of intersections are:

- ~~Three-leg intersections with minor-road stop control (3ST)~~
- ~~Four-leg intersections with minor-road stop control (4ST)~~
- Four-leg signalized intersections (4SG)

Models for three-leg signalized intersections on rural multilane roads are not available.

The SPFs for ~~three- and four-leg stop-controlled~~ intersections (3ST and 4ST) on rural multilane highways are applicable to the following base conditions:

- Intersection skew angle       $0^\circ - 5^\circ$
- Intersection left-turn lanes      0
- Intersection right-turn lanes      0
- Lighting      None

For four-leg signalized intersections (4SG) on rural multilane highways, the base conditions of which the SPFs are applicable, are the following:

- Intersection skew angle       $0^\circ - 5^\circ$
- Intersection left-turn lanes      0
- Intersection right-turn lanes      0
- Lighting      Present

The SPFs for crash frequency have two alternative functional forms, shown in Equations 11-11 and 11-12, and presented graphically in Figures 11-5, 11-6, and 11-7 (for total crashes only):

$$N_{spf\ int} = \exp \left[ a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}) \right] \quad (11-11)$$

or

$$N_{spf\ int} = \exp \left[ a + d \times \ln(TEV) \right] \quad (11-12)$$

Where:

$N_{spf\ int}$  = SPF estimate of intersection-related average crash frequency for base conditions;

$AADT_{maj}$  = AADT (vehicles per day) for major-road approaches;

$AADT_{min}$  = AADT (vehicles per day) for minor-road approaches;

**Deleted:** Three- and four-leg all-way stop-controlled

**Deleted:** Three-leg all-way stop-controlled intersections (3ST)

**Deleted:** Four-leg all-way stop-controlled intersections (4ST)

**Deleted:** three- and four-leg all-way stop-controlled



$TEV$  = total entering volume (vehicles per day) for major and minor-roads combined approaches (sum of  $AADT_{maj}$  and half of  $AADT_{min}$  for three leg intersections and sum of  $AADT_{maj}$  and  $AADT_{min}$  for four leg intersections); and

$a, b, c, d$  = regression coefficients for determining  $N_{spfint}$ .

The functional form shown in Equation 11-11 is used for most site types and crash severity levels; the functional form shown in Equation 11-12 is used for four-leg signalized intersections—as shown in Tables 11-5 and 11-6.

Guidance on the estimation of traffic volumes for the major- and minor-road legs for use in the SPFs is presented in Step 3 of the predictive method described in Section 11.4. The intersection SPFs for rural multilane highways are applicable to the following AADT ranges:

3ST:  $AADT_{maj}$  1,325 to 36,000 vehicles per day and  
 $AADT_{min}$  5 to 5,800 vehicles per day

4ST:  $AADT_{maj}$  2,425 to 34,500 vehicles per day and  
 $AADT_{min}$  25 to 4,650 vehicles per day

4SG:  $AADT_{maj}$  880 to 12,420 vehicles per day and  
 $AADT_{min}$  160 to 7,990 vehicles per day

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Table 11-5 presents the values of the coefficients  $a$ ,  $b$ , and  $c$  used in applying Equation 11-11 ~~for stop-controlled~~ intersections along with the overdispersion parameter and the base conditions.

**Deleted:** for all-way stop-controlled

Table 11-6 presents the values of the coefficients  $a$  and  $d$  used in applying Equation 11-12 for four-leg signalized intersections along with the overdispersion parameter. SPFs for three-leg signalized intersections on rural multilane roads are not currently available.

If feasible, separate calibration of the models in Tables 11-5 and 11-6 for application to intersections on divided and undivided roadway segments is preferable. Calibration procedures are presented in Part C, Appendix A.

**Commented [A26]:** This needs to be updated if necessary.

**Table 11-5. SPF Coefficients for Three- and Four-Leg Intersections with Minor-Road Stop Control for Total and Fatal-and-Injury Crashes** (for use in Equation 11-11)

**Deleted:** SPF Coefficients for All-Way Stop-Controlled Three- and Four-Leg Intersections for Total and Fatal-and-Injury Crashes

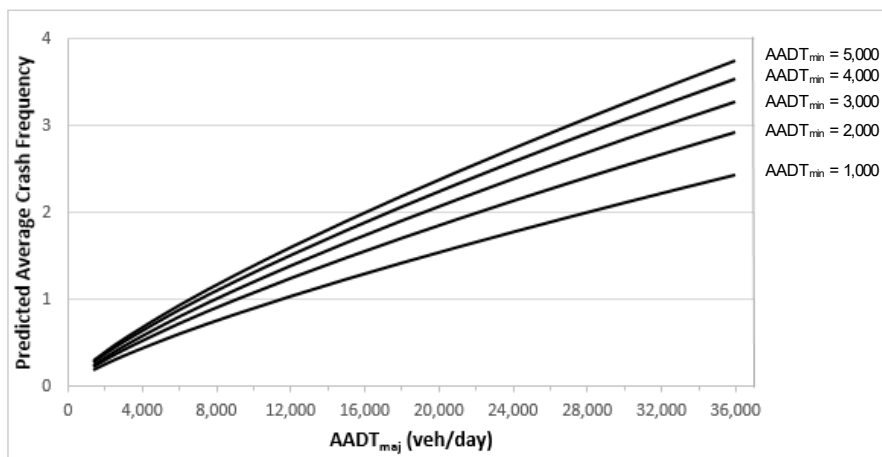
Intersection Type/Severity Level	a	b	c	Overdispersion Parameter (Fixed $k$ ) <sup>a</sup>
3ST KABCO	-9.118	0.776	0.270	0.323
3ST KABC	-9.392	0.659	0.346	0.261
3ST KAB	-9.208	0.546	0.357	0.367
4ST KABCO	-9.561	0.773	0.383	0.410
4ST KABC	-10.411	0.711	0.475	0.433
4ST KAB	-8.843	0.441	0.509	0.683

<sup>a</sup> This value should be used directly as the overdispersion parameter; no further computation is required.

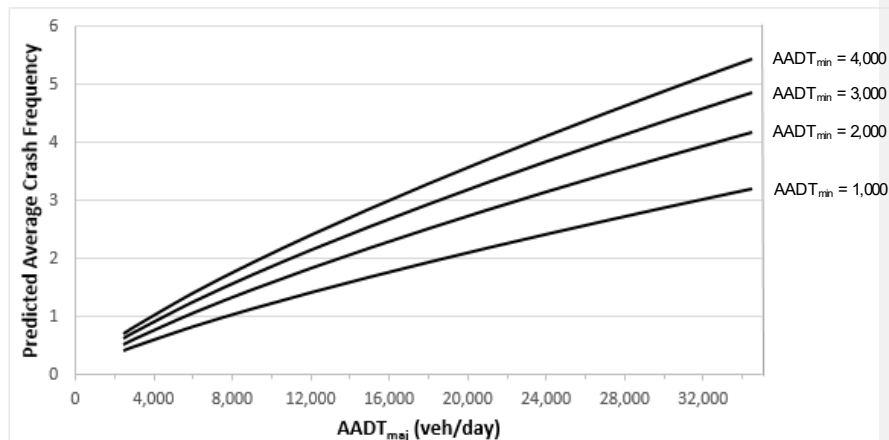
**Table 11-6.** SPF Coefficients for Four-Leg Signalized Intersections for Total and Fatal-and-Injury Crashes (for use in Equation 11-12)

Intersection Type/Severity Level	a	d	Overdispersion Parameter (Fixed $k$ ) <sup>a</sup>
4SG KABCO	-7.741	0.932	0.443
4SG KABC	-14.318	1.442	0.775
4SG KAB	-14.662	1.399	0.499

<sup>a</sup> This value should be used directly as the overdispersion parameter; no further computation is required.

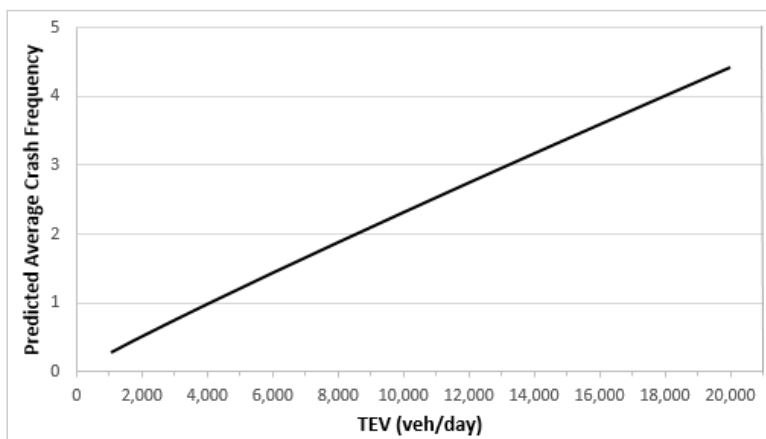
**Figure 11-5.** Graphical Form of SPF ~~for Three-Leg Stop-Controlled~~ Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-5)

**Deleted:** for Three-Leg All-Way Stop-Controlled



**Figure 11-6.** Graphical Form of SPF ~~for Four-Leg Stop-Controlled~~ Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-5)

**Deleted:** for Four-Leg All-Way Stop-Controlled



**Figure 11-7.** Graphical Form of SPF for Four-leg Signalized Intersections—for Total Crashes Only (from Equation 11-12 and Table 11-6)

Appendix 11B presents alternative SPFs that can be applied to predict crash frequencies for selected collision types (single vehicle, same direction and intersecting direction and opposite direction) ~~for intersections with stop control~~ and for signalized intersections on rural multilane highways. Use of these alternative models may be considered when safety predictions are needed for a specific collision type rather than for all crash types combined. Care must be exercised in using the alternative SPFs in Appendix 11B because they do not address all potential collision types of interest and because there is no assurance that the safety predictions for individual collision types would sum to the predictions for all collision types combined provided by the models in Tables 11-5 and 11-6.

**Deleted:** for intersections with all-way stop control

## 11.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 11.4, crash modification factors are applied to the selected safety performance function, which was selected in Step 9. SPF's provided in Chapter 11 are presented in Section 11.6. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the safety performance functions presented in Section 11.6.

Crash modification factors (CMFs) are used to adjust the SPF estimate of expected average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 11 shown in Equation 11-1. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher average crash frequency than the SPF base condition has a CMF with a value greater than 1.00; any feature associated with lower average crash frequency than the SPF base condition has a CMF with a value less than 1.00.

The CMFs in Chapter 11 were determined from a comprehensive literature review by an expert panel (5). They represent the collective judgment of the expert panel concerning the effects of each geometric design and traffic control feature of interest. Others were derived by modeling data assembled for developing the predictive models rural multilane roads. The CMFs used in Chapter 11 are consistent with the CMFs in Part D—Crash Modification Factors, although they have, in some cases, been expressed in a different form to be applicable to the base conditions. The CMFs presented in Chapter 11, and the specific SPF's to which they apply, are summarized in Table 11-10.

**Table 11-10.** Summary of CMFs in Chapter 11 and the Corresponding SPF's

Applicable SPF	CMF	CMF Description	CMF Equations and Exhibits
Undivided Roadway Segment SPF	$CMF_{1ru}$	Lane Width on Undivided Segments	Equation 11-13, Table 11-11, Figure 11-8
	$CMF_{2ru}$	Shoulder Width and Shoulder Type	Equation 11-14, Figure 11-9, Tables 11-12 and 11-13
	$CMF_{3ru}$	Sideslopes	Table 11-14
	$CMF_{4ru}$	Lighting	Equation 11-15, Table 11-15
	$CMF_{5ru}$	Automated Speed Enforcement	See text
Divided Roadway Segment SPF	$CMF_{1rd}$	Lane Width on Divided Segments	Equation 11-16, Table 11-16, Figure 11-10
	$CMF_{2rd}$	Right Shoulder Width on Divided Roadway Segment	Table 11-17
	$CMF_{3rd}$	Median Width	Table 11-18
	$CMF_{4rd}$	Lighting	Equation 11-17, Table 11-19
	$CMF_{5rd}$	Automated Speed Enforcement	See text
Three- and Four-Leg Stop-Controlled Intersection SPF's	$CMF_{1i}$	Intersection Angle	Tables 11-20, 11-21
	$CMF_{2i}$	Left-Turn Lane on Major Road	Tables 11-20, 11-21
	$CMF_{3i}$	Right-Turn Lane on Major Road	Tables 11-20, 11-21
	$CMF_{4i}$	Lighting	Tables 11-20, 11-21

**Commented [J27]:** This section has not been updated; will need to be updated according to what is decided for CMFs for these models.

**Commented [A28]:** CMFs section is not in our scope

### 11.7.1. Crash Modification Factors for Undivided Roadway Segments

The CMFs for geometric design and traffic control features of undivided roadway segments are presented below. These CMFs are applicable to the SPF presented in Section 11.6.1 for undivided roadway segments on rural multilane highways. Each of the CMFs applies to all of the crash severity levels shown in Table 11-3.

#### ***CMF<sub>tru</sub>—Lane Width***

The CMF for lane width on undivided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{tru} = (CMF_{RA} - 1.0) \times p_{RA} + 1.0 \quad (11-13)$$

Where:

$CMF_{tru}$  = crash modification factor for total crashes;

$CMF_{RA}$  = crash modification factor for related crashes (run-off-the-road, head-on, and sideswipe), from Table 11-11; and

$p_{RA}$  = proportion of total crashes constituted by related crashes (default is 0.27).

$CMF_{RA}$  is determined from Table 11-11 based on the applicable lane width and traffic volume range. The relationships shown in Table 11-11 are illustrated in Figure 11-8. This effect represents 75 percent of the effect of lane width on rural two-lane roads shown in Chapter 10, Predictive Method for Rural Two-Lane, Two-Way Roads. The default value of  $p_{RA}$  for use in Equation 11-13 is 0.27, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 27 percent of total crashes. This default value may be updated based on local data. The SPF base condition for the lane width is 12 ft. Where the lane widths on a roadway vary, the CMF is determined separately for the lane width in each direction of travel and the resulting CMFs are then averaged.

For lane widths with 0.5-ft increments that are not depicted specifically in Table 11-11 or in Figure 11-8, a CMF value can be interpolated using either of these exhibits since there is a linear transition between the various AADT effects.

**Table 11-11.**  $CMF_{RA}$  for Collision Types Related to Lane Width

Lane Width	Average Annual Daily Traffic (AADT) (vehicles per day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4} (AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4} (AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5} (AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

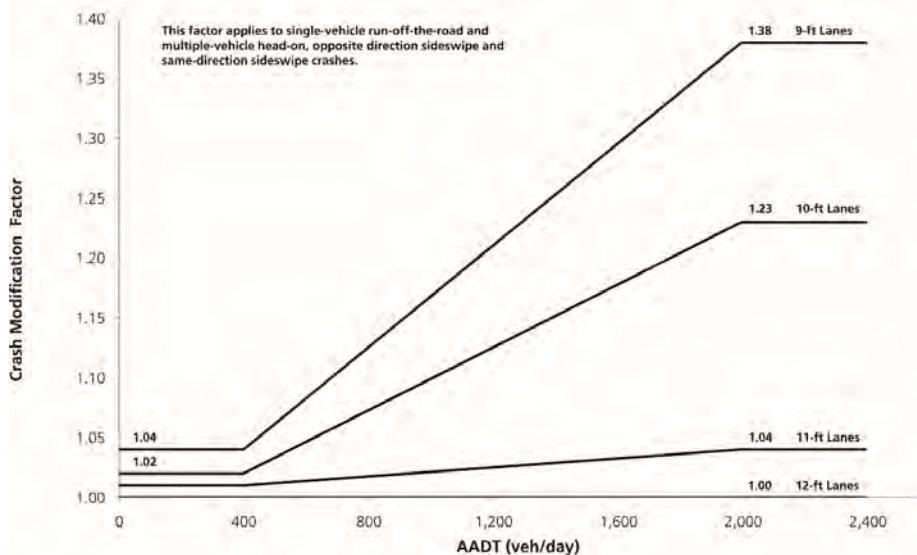


Figure 11-8.  $CMF_{RA}$  for Lane Width on Undivided Segments

#### $CMF_{2ru}$ —Shoulder Width

The  $CMF$  for shoulder width on undivided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0) \times p_{RA} + 1.0 \quad (11-14)$$

Where:

$CMF_{2ru}$  = crash modification factor for total crashes;

$CMF_{WRA}$  = crash modification factor for related crashes based on shoulder width from Table 11-12;

$CMF_{TRA}$  = crash modification factor for related crashes based on shoulder type from Table 11-13; and

$p_{RA}$  = proportion of total crashes constituted by related crashes (default is 0.27).

$CMF_{WRA}$  is determined from Table 11-12 based on the applicable shoulder width and traffic volume range. The relationships shown in Table 11-12 are illustrated in Figure 11-9. The default value of  $p_{RA}$  for use in Equation 11-14 is 0.27, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 27 percent of total crashes. This default value may be updated based on local data. The SPF base condition for shoulder width is 6 ft.

Table 11-12.  $CMF$  for Collision Types Related to Shoulder Width ( $CMF_{WRA}$ )

Shoulder Width	Annual Average Daily Traffic (AADT) (vehicles per day)		
	< 400	400 to 2000	> 2000

0 ft	1.10	$1.10 + 2.5 \times 10^{-4} (\text{AADT} - 400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4} (\text{AADT} - 400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5} (\text{AADT} - 400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5} (\text{AADT} - 400)$	0.87

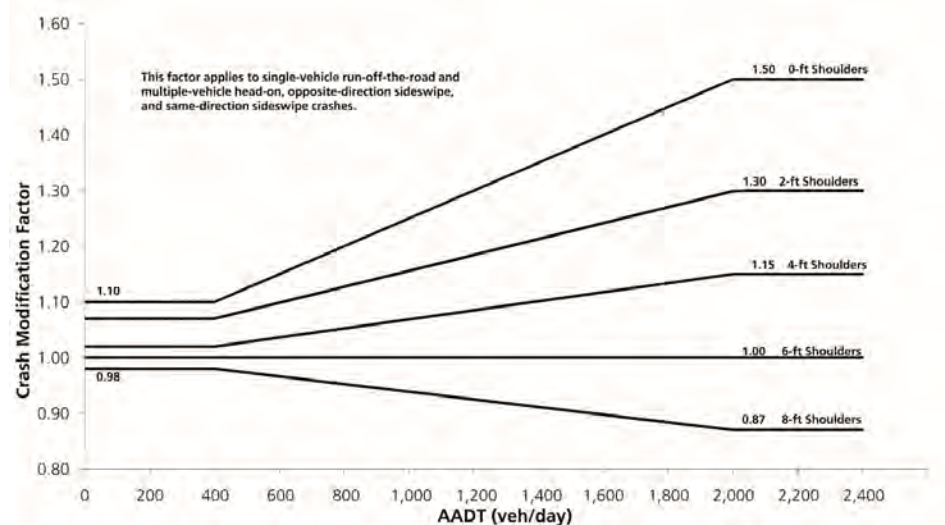


Figure 11-9.  $CMF_{WRA}$  for Shoulder Width on Undivided Segments

$CMF_{TRA}$  is determined from Table 11-13 based on the applicable shoulder type and shoulder width.

Table 11-13. CMF for Collision Types Related to Shoulder Type and Shoulder Width ( $CMF_{TRA}$ )

Shoulder Type	Shoulder Width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

If the shoulder types and/or widths for the two directions of a roadway segment differ, the CMF is determined separately for the shoulder type and width in each direction of travel and the resulting CMFs are then averaged.

#### $CMF_{3ru}$ —Sideslopes

A CMF for the sideslope for undivided roadway segments of rural multilane highways has been developed by Harkey et al. (3) from the work of Zegeer et al. (8). The CMF is presented in Table 11-14. The base conditions are for a sideslope of 1:7 or flatter.

**Table 11-14.** CMF for Sideslope on Undivided Roadway Segments ( $CMF_{3ru}$ )

1:2 or Steeper	1:3	1:4	1:5	1:6	1:7 or Flatter
1.18	1.15	1.12	1.09	1.05	1.00

 **$CMF_{4ru}$ —Lighting**

The SPF base condition for lighting of roadway segments is the absence of lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (1), as:

$$CMF_{4ru} = 1 - [(1 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \quad (11-15)$$

Where:

$CMF_{4ru}$  = crash modification factor for the effect of lighting on total crashes;

$p_{inr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

$p_{pnr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

$p_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

This CMF applies to total roadway segment crashes. Table 11-15 presents default values for the nighttime crash proportions  $p_{inr}$ ,  $p_{pnr}$ , and  $p_{nr}$ . HSM users are encouraged to replace the estimates in Table 11-15 with locally derived values.



**Table 11-15.** Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of Total Night-Time Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury $p_{inr}$	PDO $p_{pr}$	$p_{nr}$
4U	0.361	0.639	0.255

***CMF<sub>5ru</sub>—Automated Speed Enforcement***

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The SPF base condition for automated speed enforcement is that it is absent. Chapter 17, Road Networks presents a CMF of 0.83 for the reduction of all types of injury crashes from implementation of automated speed enforcement. This CMF applies to roadway segments with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. Fatal-and-injury crashes constitute 31 percent of total crashes on rural two-lane highway segments. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of  $CMF_{5ru}$  for automated speed enforcement would be 0.95 based on the injury crash proportion.

**11.7.2. Crash Modification Factors for Divided Roadway Segments**

The CMFs for geometric design and traffic control features of divided roadway segments for rural multilane highways are presented below. Each of the CMFs applies to all of the crash severity levels shown in Table 11-5.

***CMF<sub>1rd</sub>—Lane Width on Divided Roadway Segments***

The CMF for lane width on divided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{1rd} = (CMF_{RA} - 1.0) \times p_{RA} + 1.0 \quad (11-16)$$

Where:

$CMF_{1rd}$  = crash modification factor for total crashes;

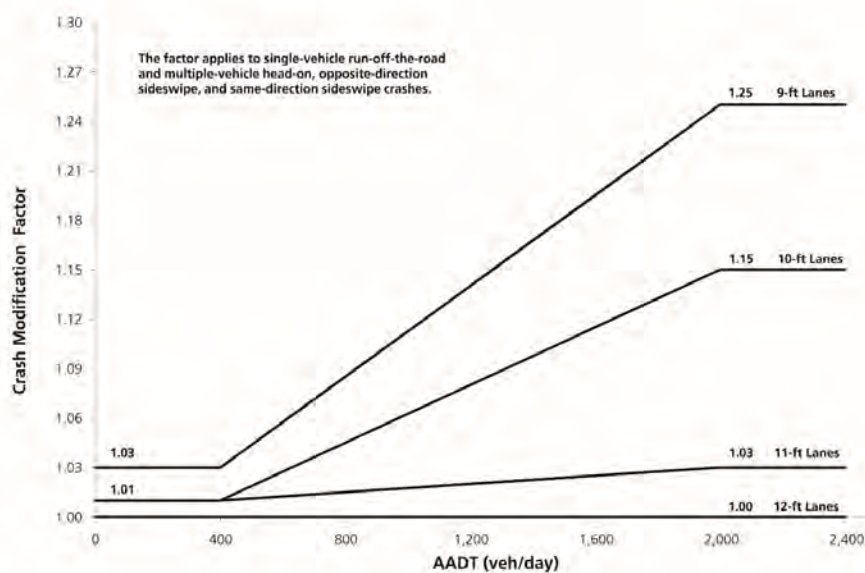
$CMF_{RA}$  = crash modification factor for related crashes (run-off-the-road, head-on, and sideswipe), from Table 11-16; and

$p_{RA}$  = proportion of total crashes constituted by related crashes (default is 0.50).

$CMF_{RA}$  is determined from Table 11-16 based on the applicable lane width and traffic volume range. The relationships shown in Table 11-16 are illustrated in Figure 11-10. This effect represents 50 percent of the effect of lane width on rural two-lane roads shown in Chapter 10. The default value of  $p_{RA}$  for use in Equation 11-16 is 0.50, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 50 percent of total crashes. This default value may be updated based on local data. The SPF base condition for lane width is 12 ft. Where the lane widths on a roadway vary, the CMF is determined separately for the lane width in each direction of travel and the resulting CMFs are then averaged.

**Table 11-16.** CMF for Collision Types Related to Lane Width ( $CMF_{RA}$ )

Lane Width	Annual Average Daily Traffic (AADT) (vehicles/day)		
	< 400	400 to 2000	> 2000
9 ft	1.03	$1.03 + 1.38 \times 10^{-4} (AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5} (AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5} (AADT - 400)$	1.03
12 ft	1.00	1.00	1.00

**Figure 11-10.**  $CMF_{RA}$  for Lane Width on Divided Roadway Segments **$CMF_{2rd}$ —Right Shoulder Width on Divided Roadway Segments**

The CMF for right shoulder width on divided roadway segments was developed by Lord et al. (5) and is presented in Table 11-17. The SPF base condition for the right shoulder width variable is 8 ft. If the shoulder widths for the two directions of travel differ, the CMF is based on the average of the shoulder widths. The safety effects of shoulder widths wider than 8 ft are unknown, but it is recommended that a CMF of 1.00 be used in this case.

The effects of unpaved right shoulders on divided roadway segments and of left (median) shoulders of any width or material are unknown. No CMFs are available for these cases.

**Table 11-17.** CMF for Right Shoulder Width on Divided Roadway Segments ( $CMF_{2rd}$ )

Average Shoulder Width (ft)				
0	2	4	6	8 or more
1.18	1.13	1.09	1.04	1.00

Note: This CMF applies to paved shoulders only.

#### **$CMF_{3rd}$ —Median Width**

A CMF for median widths on divided roadway segments of rural multilane highways is presented in Table 11-18 based on the work of Harkey et al. (3). The median width of a divided highway is measured between the inside edges of the through travel lanes in the opposing direction of travel; thus, inside shoulder and turning lanes are included in the median width. The base condition for this CMF is a median width of 30 ft. The CMF applies to total crashes, but represents the effect of median width in reducing cross-median collisions; the CMF assumes that nonintersection collision types other than cross-median collisions are not affected by median width. The CMF in Table 11-18 has been adapted from the CMF in Table 13-13 based on the estimate by Harkey et al. (3) that cross-median collisions represent 12.2 percent of crashes on multilane divided highways.

This CMF applies only to traversable medians without traffic barriers. The effect of traffic barriers on safety would be expected to be a function of the barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers.

**Table 11-18.** CMFs for Median Width on Divided Roadway Segments without a Median Barrier ( $CMF_{3rd}$ )

Median Width (ft)	CMF
10	1.04
20	1.02
30	1.00
40	0.99
50	0.97
60	0.96
70	0.96
80	0.95
90	0.94
100	0.94

Note: This CMF applies only to medians without traffic barriers.

#### **$CMF_{4rd}$ —Lighting**

The SPF base condition for lighting is the absence of roadway segment lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (1), as:

$$CMF_{4rd} = 1 - [(1 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \quad (11-17)$$

Where:

$CMF_{4rd}$  = crash modification factor for the effect of lighting on total crashes;

$p_{inr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

$p_{pnr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

$p_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

This CMF applies to total roadway segment crashes. Table 11-19 presents default values for the nighttime crash proportions  $p_{inr}$ ,  $p_{pnr}$ , and  $p_{nr}$ . HSM users are encouraged to replace the estimates in Table 11-19 with locally derived values.

**Table 11-19.** Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatality and Injury $p_{nr}$	PDO $p_{nr}$	$p_{nr}$
4D	0.323	0.677	0.426

#### ***CMF<sub>5rd</sub>—Automated Speed Enforcement***

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The SPF base condition for automated speed enforcement is that it is absent. Chapter 17 presents a CMF of 0.83 for the reduction of all types of fatal-and-injury crashes from implementation of automated speed enforcement. This CMF applies to roadway segments with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. Fatal-and-injury crashes constitute 37 percent of total crashes on rural multilane divided highway segments. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of  $CMF_{5rd}$  for automated speed enforcement would be 0.94 based on the injury crash proportion.

#### **11.7.3. Crash Modification Factors for Intersections**

The effects of individual geometric design and traffic control features of intersections are represented in the safety prediction procedure by CMFs. The equations and exhibits relating to CMFs for stop-controlled intersections are summarized in Tables 11-20 and 11-21 and presented below. Except where separate CMFs by crash severity level are shown, each of the CMFs applies to all of the crash severity levels shown in Table 11-7. As noted earlier, CMFs are not available for signalized intersections.

**Table 11-20.** CMFs for Three-Leg Intersections with Minor-Road Stop Control (3ST)

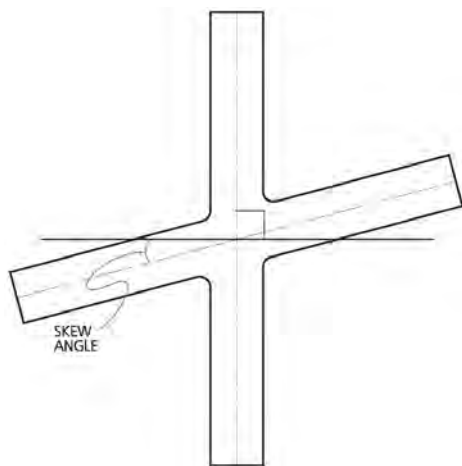
CMFs	Total	Fatal and Injury
Intersection Angle	Equation 11-18	Equation 11-19
Left-Turn Lane on Major Road	Table 11-22	Table 11-22
Right-Turn Lane on Major Road	Table 11-23	Table 11-23
Lighting	Equation 11-22	Equation 11-22

**Table 11-21.** CMFs for Four-Leg Intersection with Minor-Road Stop Control (4ST)

CMFs	Total	Fatal and Injury
Intersection Angle	Equation 11-20	Equation 11-21
Left-Turn Lane on Major Road	Table 11-22	Table 11-22
Right-Turn Lane on Major Road	Table 11-23	Table 11-23
Lighting	Equation 11-22	Equation 11-22

***CMF<sub>ti</sub>—Intersection Skew Angle***

The SPF base condition for intersection skew angle is 0 degrees of skew (i.e., an intersection angle of 90 degrees). Reducing the skew angle of three- or four-leg stop-controlled intersections on rural multilane highways reduces total intersection crashes, as shown below. The skew angle is the deviation from an intersection angle of 90 degrees. Skew carries a positive or negative sign that indicates whether the minor road intersects the major road at an acute or obtuse angle, respectively.

**Illustration of Intersection Skew Angle*****Three-Leg Intersections with Stop-Control on the Minor Approach***

The CMF for total crashes for intersection skew angle at three-leg intersections with stop-control on the minor approach is:

$$CMF_{ti} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1 \quad (11-18)$$

and the CMF for fatal-and-injury crashes is:

$$CMF_{fi} = \frac{0.017 \times skew}{(0.52 + 0.017 \times skew)} + 1 \quad (11-19)$$

Where:

$CMF_{li}$  = crash modification factor for the effect of intersection skew on total crashes; and

$skew$  = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

***Four-Leg Intersections with Stop-Control on the Minor Approaches***

The CMF for total crashes for intersection angle at four-leg intersection with stop-control on the minor approaches is:

$$CMF_{li} = \frac{0.053 \times skew}{(1.43 + 0.053 \times skew)} + 1.0 \quad (11-20)$$

The CMF for fatal-and-injury crashes is:

$$CMF_{li} = \frac{0.048 \times skew}{(0.72 + 0.048 \times skew)} + 1.0 \quad (11-21)$$

***CMF<sub>2i</sub>—Intersection Left-Turn Lanes***

The SPF base condition for intersection left-turn lanes is the absence of left-turn lanes on all of the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 11-22 for total crashes and injury crashes. These CMFs apply only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes (i.e., the CMFs are multiplicative, and Equation 3-7 can be used). There is no indication of any effect of providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Table 11-22. The CMFs for installation of left-turn lanes are based on research by Harwood et al. (4) and are consistent with the CMFs presented in Chapter 14, Intersections. A CMF of 1.00 is used when no left-turn lanes are present.

**Table 11-22.** Crash Modification Factors ( $CMF_{2i}$ ) for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	Crash Severity Level	Number of Non-Stop-Controlled Approaches with Left-Turn Lanes <sup>a</sup>	
		One Approach	Two Approaches
Three-leg minor-road stop control <sup>b</sup>	Total	0.56	—
	Fatal and Injury	0.45	—
Four-leg minor-road stop control <sup>b</sup>	Total	0.72	0.52
	Fatal and Injury	0.65	0.42

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes.

<sup>b</sup> Stop signs present on minor-road approaches only.

#### ***CMF<sub>3i</sub>—Intersection Right-Turn Lanes***

The SPF base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMFs for the presence of right-turn lanes are based on research by Harwood et al. (4) and are consistent with the CMFs in Chapter 14. These CMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes (i.e., the CMFs are multiplicative, and Equation 3-7 can be used). There is no indication of any safety effect for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Table 11-23. The CMFs for presence of right-turn lanes are presented in Table 11-23 for total crashes and injury crashes. A CMF value of 1.00 is used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

**Table 11-23.** Crash Modification Factors ( $CMF_{3i}$ ) for Installation of Right-Turn Lanes on Intersections Approaches

Intersection Type	Crash Severity Level	Number of Non-Stop-Controlled Approaches with Right-Turn Lanes <sup>a</sup>	
		One Approach	Two Approaches
Three-leg minor-road stop control <sup>b</sup>	Total	0.86	—
	Fatal and Injury	0.77	—
Four-leg minor-road stop control <sup>b</sup>	Total	0.86	0.74
	Fatal and Injury	0.77	0.59

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.

<sup>b</sup> Stop signs present on minor-road approaches only.

#### ***CMF<sub>4i</sub>—Lighting***

The SPF base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (1), as:

$$CMF_{4i} = 1.0 - 0.38 \times p_{ni} \quad (11-22)$$

Where:

$CMF_{4i}$  = crash modification factor for the effect of lighting on total crashes; and

$p_{ni}$  = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersections crashes. Table 11-24 presents default values for the nighttime crash proportion,  $p_{ni}$ . HSM users are encouraged to replace the estimates in Table 11-24 with locally derived values.

**Table 11-24.** Default Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night, $p_{ni}$
3ST	0.276
4ST	0.273

## 11.8. CALIBRATION TO LOCAL CONDITIONS

In Step 11 of the predictive method, presented in Section 11.4, the predictive model is calibrated to local state or geographic conditions. Crash frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash-reporting threshold, and crash-reporting practices. These variations may result in some jurisdictions experiencing a different number of traffic crashes on rural multilane highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments (defined as  $C_{ru}$  and  $C_{rd}$  for undivided and divided segments respectively) and intersections (defined as  $C_{int}$ ) will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes on average than the roadways used in the development of the SPFs will have values less than 1.0. The calibration procedures are presented in Part C, Appendix A.

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## 11.9. LIMITATIONS OF PREDICTIVE METHODS IN CHAPTER 11

This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 11.

Where rural multilane highways intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the rural multilane road within the interchange area, cannot be addressed with the predictive method for rural multilane highways.

~~The SPFs developed for Chapter 11 do not include signalized three-leg intersection models. Such intersections may be found on rural multilane highways.~~

CMFs have not been developed for the SPF for four-leg signalized intersections on rural multilane highways.

**Deleted:** The SPFs developed for Chapter 11 do not include uncontrolled intersection models, yield-controlled intersection models, models for intersections with stop signs provided solely for minor road approaches and signalized three-leg intersection models. Such intersections may be found on rural multilane highways.

## 11.10. APPLICATION OF CHAPTER 11, PREDICTIVE METHOD

The predictive method presented in Chapter 11 applies to rural multilane highways. The predictive method is applied to a rural multilane highway facility by following the 18 steps presented in Section 11.4. Worksheets are presented in Appendix 11A for applying calculations in the predictive method steps specific to Chapter 11. All computations of crash frequencies within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency to one decimal place is appropriate.

**Commented [J30]:** This sentence needs to be reviewed by the 17-71 contractor to determine if it will be accurate in the final version of HSM2.

## 11.11. SUMMARY

The predictive method can be used to estimate the expected average crash frequency for an entire rural multilane highway facility, a single individual site, or series of contiguous sites. A rural multilane highway facility is defined



in Section 11.3, and consists of a four-lane highway facility which does not have access control and is outside of cities or towns with populations greater than 5,000 persons.

The predictive method for rural multilane highways is applied by following the 18 steps of the predictive method presented in Section 11.4. Predictive models, developed for rural multilane highway facilities, are applied in Steps 9, 10, and 11 of the method. These predictive models have been developed to estimate the predicted average crash frequency of an individual intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Each predictive model in Chapter 11 consists of a safety performance function (SPF), crash modification factors (CMFs), and a calibration factor. The SPF is selected in Step 9 and is used to estimate the predicted average crash frequency for a site with base conditions. This estimate can be either for total crashes, crashes of a particular crash severity, crashes of a certain type or crashes of a particular severity of a certain crash type. In order to account for differences between the base conditions and the specific conditions of the site, CMFs are applied in Step 10, which adjust the prediction to account for the geometric design and traffic control features of the site. Calibration factors are also used to adjust the prediction to local conditions in the jurisdiction where the site is located. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Where observed data are available, the EB Method is applied to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project-specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Section 11.12 presents six sample problems which detail the application of the predictive method. Appendix 11A contains worksheets which can be used in the calculations for the predictive method steps.

## 11.12. SAMPLE PROBLEMS

In this section, six sample problems are presented using the predictive method for rural multilane highways. Sample Problem 1 illustrates how to calculate the predicted average crash frequency for a divided rural four-lane highway segment. Sample Problem 2 illustrates how to calculate the predicted average crash frequency for an undivided rural four-lane highway segment. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for a three-leg stop-controlled intersection. Sample Problem 4 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are available (i.e., using the site-specific EB Method). Sample Problem 5 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are not available (i.e., using project level EB Method). Sample Problem 6 applies the Project Estimation Method 1, presented in Section C.7, to determine the effectiveness of a proposed upgrade from a rural two-lane roadway to a rural four-lane highway.

**Commented [A31]:** This needs to be updated if necessary.

**Commented [A32]:** This needs to be updated if necessary.

**Commented [A33]:** The number of sample problems may change.

**Commented [J34]:** These sample problems are all out of date for the models proposed above.

**Commented [A35]:** Sample Problems section is not in our scope

**Table 11-25.** List of Sample Problems in Chapter 11

Problem No.	Page No.	Description
1	11-37	Predicted average crash frequency for a divided roadway segment
2	11-43	Predicted average crash frequency for an undivided roadway segment
3	11-49	Predicted average crash frequency for a three-leg stop-controlled intersection
4	11-54	Expected average crash frequency for a facility when site-specific observed crash frequencies are available
5	11-56	Expected average crash frequency for a facility when site-specific observed crash frequencies are not available
6	11-60	Expected average crash frequency and the crash reduction for a proposed rural four-lane highway facility that will replace an existing rural two-lane roadway

**11.12.1. Sample Problem 1****The Site/Facility**

A rural four-lane divided highway segment.

**The Question**

What is the predicted average crash frequency of the roadway segment for a particular year?

**The Facts**

- 1.5-mi length
- 10,000 veh/day
- 12-ft lane width
- 6-ft paved right shoulder
- 20-ft traversable median
- No roadway lighting
- No automated enforcement

**Assumptions**

Collision type distributions are the default values presented in Table 11-6.

The calibration factor is assumed to be 1.10.

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 3.3 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the roadway segment in Sample Problem 1, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

The SPF for a divided roadway segment is calculated from Equation 11-9 and Table 11-5 as follows:

$$N_{spf\ rd} = e^{(a+b \times \ln(AADT) + \ln(L))}$$

$$= e^{(-9.025 + 1.049 \times \ln(10,000) + \ln(1.5))} = 2.835 \text{ crashes/year}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.**

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

**Lane Width ( $CMF_{1rd}$ )**

Since the roadway segment in Sample Problem 1 has 12-ft lanes,  $CMF_{1rd} = 1.00$  (i.e., the base condition for  $CMF_{1rd}$  is 12-ft lane width).

**Shoulder Width and Type ( $CMF_{2rd}$ )**

From Table 11-17, for 6-ft paved shoulders,  $CMF_{2rd} = 1.04$ .

**Median Width ( $CMF_{3rd}$ )**

From Table 11-18, for a traversable median width of 20 ft,  $CMF_{3rd} = 1.02$ .

**Lighting ( $CMF_{4rd}$ )**

Since there is no lighting in Sample Problem 1,  $CMF_{4rd} = 1.00$  (i.e., the base condition for  $CMF_{4rd}$  is absence of roadway lighting).

**Automated Speed Enforcement ( $CMF_{5rd}$ )**

Since there is no automated speed enforcement in Sample Problem 1,  $CMF_{5rd} = 1.00$  (i.e., the base condition for  $CMF_{5rd}$  is the absence of automated speed enforcement).

The combined CMF value for Sample Problem 1 is calculated below.

$$CMF_{comb} = 1.04 \times 1.02$$

$$= 1.06$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in Sample Problem 1 that a calibration factor,  $C_r$ , of 1.10 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 11-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = N_{spf\ rd} \times C_r \times (CMF_{1rd} \times CMF_{2rd} \times \dots \times CMF_{5rd})$$

$$= 2.835 \times 1.10 \times (1.06)$$

$$= 3.305 \text{ crashes/year}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining the predicted average crash frequency. The five worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Multilane Roadway Segments

- Worksheet SP1B (Corresponds to Worksheet 1B (a))—Crash Modification Factors for Rural Multilane Divided Roadway Segments
- Worksheet SP1C (Corresponds to Worksheet 1C (a))—Roadway Segment Crashes for Rural Multilane Divided Roadway Segments
- Worksheet SP1D (Corresponds to Worksheet 1D (a))—Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments
- Worksheet SP1E (Corresponds to Worksheet 1E)—Summary Results for Rural Multilane Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

#### Worksheet SP1A—General Information and Input Data for Rural Multilane Roadway Segments

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”) and assumptions for Sample Problem 1.

##### Worksheet SP1A. General Information and Input Data for Rural Multilane Roadway Segments

General Information		Location Information	
Analyst		Highway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Roadway type (divided/undivided)		—	divided
Length of segment, L (mi)		—	1.5
AADT (veh/day)		—	10,000
Lane width (ft)		12	12
Shoulder width (ft)—right shoulder width for divided		8	6
Shoulder type—right shoulder type for divided		paved	paved
Median width (ft)—for divided only		30	20
Sideslopes—for undivided only		1:7 or flatter	N/A
Lighting (present/not present)		not present	not present
Auto speed enforcement (present/not present)		not present	not present
Calibration factor, $C_r$		1.0	1.1

#### Worksheet SP1B—Crash Modification Factors for Rural Multilane Divided Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs multiplied together in Column 6 of Worksheet SP1B which indicates the combined CMF value.

**Worksheet SP1B.** Crash Modification Factors for Rural Multilane Divided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	CMF for Right Shoulder Width	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{Lwd}$	$CMF_{Rsd}$	$CMF_{Med}$	$CMF_{Lit}$	$CMF_{Srd}$	$CMF_{Comb}$
from Equation 11-16	from Table 11-17	from Table 11-18	from Equation 11-17	from Section 11.7.2	$(1)*(2)*(3)*(4)*(5)$
1.00	1.04	1.02	1.00	1.00	1.06

**Worksheet SP1C—Roadway Segment Crashes for Rural Multilane Divided Roadway Segments**

The SPF for the roadway segment in Sample Problem 1 is calculated using the coefficients found in Table 11-5 (Column 2), which are entered into Equation 11-9 (Column 3). The overdispersion parameter associated with the SPF can be calculated using Equation 11-10 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates predicted average crash frequency using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

**Worksheet SP1C.** Roadway Segment Crashes for Rural Multilane Divided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{segment}$	Overdispersion Parameter, $k$	Combined CMFs	Calibration Factor, $C$	Predicted Average Crash Frequency, $N_{predicted}$
	from Table 11-5			from Equation 11-9	from Equation 11-10	(6) from Worksheet SP1B		$(3)*(5)*(6)$
	a	b	c					
Total	-9.025	1.049	1.549	2.835	0.142	1.06	1.10	3.306
Fatal and injury (FI)	-8.837	0.958	1.687	1.480	0.123	1.06	1.10	1.726
Fatal and injury <sup>a</sup> (FI <sup>a</sup> )	-8.505	0.874	1.740	0.952	0.117	1.06	1.10	1.110
Property damage only (PDO)								$(7)_{total} - (7)_{FI}$
								1.580

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP1D—Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments**

Worksheet SP1D presents the default proportions for collision type (from Table 11-6) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including “possible injury” crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)

- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including “possible injury”), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP1C) by crash severity and collision type.

**Worksheet SP1D. Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collision Type	Proportion of Collision Type $P_{coll}$	$N_{predicted\ total}$ (crashes/year)	Proportion of Collision Type $P_{FI}$	$N_{predicted\ FI}$ (crashes/year)	Proportion of Collision Type $P_{FI^a}$	$N_{predicted\ FI^a}$ (crashes/year)	Proportion of Collision Type $P_{PDO}$	$N_{predicted\ PDO}$
	from Table 11-6	(7) <sub>total</sub> from Worksheet SP1C	from Table 11-6	(7) <sub>FI</sub> from Worksheet SP1C	from Table 11-6	(7) <sub>FI^a</sub> from Worksheet SP1C	from Table 11-6	(7) <sub>PDO</sub> from Worksheet SP1C
Total	1.000	3.306	1.000	1.726	1.000	1.110	1.000	1.580
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>FI^a</sub>		(8)*(9) <sub>PDO</sub>
Head-on collision	0.006	0.020	0.013	0.022	0.018	0.020	0.002	0.003
Sideswipe collision	0.043	0.142	0.027	0.047	0.022	0.024	0.053	0.084
Rear-end collision	0.116	0.383	0.163	0.281	0.114	0.127	0.088	0.139
Angle collision	0.043	0.142	0.048	0.083	0.045	0.050	0.041	0.065
Single-vehicle collision	0.768	2.539	0.727	1.255	0.778	0.864	0.792	1.251
Other collision	0.024	0.079	0.022	0.038	0.023	0.026	0.024	0.038

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP1E—Summary Results for Rural Multilane Roadway Segments**

Worksheet SP1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 4).

**Worksheet SP1E. Summary Results for Rural Multilane Roadway Segments**

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(7) from Worksheet SP1C		(2)/(3)
Total	3.306	1.5	2.2
Fatal and injury (FI)	1.726	1.5	1.2
Fatal and injury <sup>a</sup> (FI <sup>a</sup> )	1.110	1.5	0.7
Property damage only (PDO)	1.580	1.5	1.1

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**11.12.2. Sample Problem 2**

The Site/Facility

A rural four-lane undivided highway segment.

#### The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

#### The Facts

- 0.1-mi length
- 8,000 veh/day
- 11-ft lane width
- 2-ft gravel shoulder
- Sideslope of 1:6
- Roadside lighting present
- Automated enforcement present

#### Assumptions

Collision type distributions have been adapted to local experience. The percentage of total crashes representing single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes is 33 percent.

The proportion of crashes that occur at night are not known, so the default proportions for nighttime crashes will be used.

The calibration factor is assumed to be 1.10.

#### Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 0.3 crashes per year (rounded to one decimal place).

#### Steps

##### Step 1 through 8

To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

##### Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

The SPF for an undivided roadway segment is calculated from Equation 11-7 and Table 11-3 as follows:

$$\begin{aligned}
 N_{spf\ ru} &= e^{(a + b \times \ln(AADT) + \ln(L))} \\
 &= e^{(-9.653 + 1.176 \times \ln(8,000) + \ln(0.1))} = 0.250 \text{ crashes/year}
 \end{aligned}$$

##### Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

##### Lane Width ( $CMF_{lru}$ )

$CMF_{lru}$  can be calculated from Equation 11-13 as follows:

$$CMF_{lru} = (CMF_{RA} - 1.0) \times P_{RA} + 1.0$$

For 11-ft lane width and AADT of 8,000,  $CMF_{RA} = 1.04$  (see Table 11-11).

The proportion of related crashes,  $p_{RA}$ , is 0.33 (from local experience, see assumptions).

$$CMF_{1ru} = (1.04 - 1.0) \times 0.33 + 1.0 = 1.01$$

**Shoulder Width and Type ( $CMF_{2ru}$ )**

$CMF_{2ru}$  can be calculated from Equation 11-14 as follows:

$$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0) \times p_{RA} + 1.0$$

For 2-ft shoulders and AADT of 8,000,  $CMF_{WRA} = 1.30$  (see Table 11-12).

For 2-ft gravel shoulders,  $CMF_{TRA} = 1.01$  (see Table 11-13).

The proportion of related crashes,  $p_{RA}$ , is 0.33 (from local experience, see assumptions).

$$CMF_{2ru} = (1.30 \times 1.01 - 1.0) \times 0.33 + 1.0 = 1.10$$

**Sideslopes ( $CMF_{3ru}$ )**

From Table 11-14, for a sideslope of 1:6,  $CMF_{3ru} = 1.05$ .

**Lighting ( $CMF_{4ru}$ )**

$CMF_{4ru}$  can be calculated from Equation 11-15 as follows:

$$CMF_{4ru} = 1 - [(1 - 0.72 \times p_{inv} - 0.83 \times p_{pmr}) \times p_{nr}]$$

Local values for nighttime crashes proportions are not known. The default nighttime crash proportions used are  $p_{inv} = 0.361$ ,  $p_{pmr} = 0.639$ , and  $p_{nr} = 0.255$  (see Table 11-15).

$$CMF_{4ru} = 1 - [(1 - 0.72 \times 0.361 - 0.83 \times 0.639) \times 0.255] = 0.95$$

**Automated Speed Enforcement ( $CMF_{5ru}$ )**

For an undivided roadway segment with automated speed enforcement,  $CMF_{5ru} = 0.95$  (see Section 11.7.1).

The combined CMF value for Sample Problem 2 is calculated below.

$$CMF_{comb} = 1.04 \times 1.02 \times 1.05 \times 0.95 \times 0.95 = 1.05$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in Sample Problem 2 that a calibration factor,  $C_r$ , of 1.10 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 11-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } rs} &= N_{\text{spf } ru} \times C_r \times (CMF_{1ru} \times CMF_{2ru} \times \dots \times CMF_{5ru}) \\ &= 0.250 \times 1.10 \times (1.05) \\ &= 0.289 \text{ crashes/year} \end{aligned}$$



## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining the predicted average crash frequency. The five worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Multilane Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B (b))*—Crash Modification Factors for Rural Multilane Undivided Roadway Segments
- *Worksheet SP2C (Corresponds to Worksheet 1C (b))*—Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D (b))*—Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Summary Results for Rural Multilane Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Chapter 11, Appendix 11A.

### Worksheet SP2A—General Information and Input Data for Rural Multilane Roadway Segments

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”) and assumptions for Sample Problem 2.

#### Worksheet SP2A. General Information and Input Data for Rural Multilane Roadway Segments

General Information		Location Information	
Analyst		Highway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Roadway type (divided/undivided)		—	undivided
Length of segment, L (mi)		—	0.1
AADT (veh/day)		—	8,000
Lane width (ft)		12	11
Shoulder width (ft)—right shoulder width for divided		6	2
Shoulder type—right shoulder type for divided		paved	gravel
Median width (ft)—for divided only		30	N/A
Sideslopes—for undivided only		1:7 or flatter	1:6
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	present
Calibration factor, $C_r$		1.0	1.1

**Worksheet SP2B—Crash Modification Factors for Rural Multilane Undivided Roadway Segments**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs multiplied together in Column 6 of Worksheet SP2B which indicates the combined CMF value.

**Worksheet SP2B. Crash Modification Factors for Rural Multilane Undivided Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	CMF for Shoulder Width	CMF for Sideslopes	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
$CMF_{1ru}$	$CMF_{2ru}$	$CMF_{3ru}$	$CMF_{4ru}$	$CMF_{5ru}$	$CMF_{comb}$
from Equation 11-13	from Equation 11-14	from Table 11-14	from Equation 11-15	from Section 11.7.1	(1)*(2)*(3)*(4)*(5)
1.01	1.10	1.05	0.95	0.95	1.05

**Worksheet SP2C—Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments**

The SPF for the roadway segment in Sample Problem 2 is calculated using the coefficients found in Table 11-3 (Column 2), which are entered into Equation 11-7 (Column 3). The overdispersion parameter associated with the SPF can be calculated using Equation 11-8 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

**Worksheet SP2C. Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments**

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{SPFR}$	Overdispersion Parameter, $k$	Combined CMFs	Calibration Factor, $C$ ,	Predicted Average Crash Frequency, $N_{predicted\ CR}$
	from Table 11-3			from Equation 11-7	from Equation 11-8	(6) from Worksheet SP2B		(3)*(5)*(6)
	a	b	c					
Total	-9.653	1.176	1.675	0.250	1.873	1.05	1.10	0.289
Fatal and injury (FI)	-9.410	1.094	1.796	0.153	1.660	1.05	1.10	0.177
Fatal and injury <sup>a</sup> (FI <sup>a</sup> )	-8.577	0.938	2.003	0.086	1.349	1.05	1.10	0.099
Property damage only (PDO)	—	—	—	—	—	—	—	(7) <sub>total</sub> - (7) <sub>FI</sub> = 0.112

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP2D—Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments**

Worksheet SP2D presents the default proportions for collision type (from Table 11-4) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including “possible-injury” crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including “possible injury”), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP2C) by crash severity and collision type.

**Worksheet SP2D. Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Proportion of Collision Type $\alpha_{\text{coll}}$	$N_{\text{predicted } r, s, \text{ total}}$ (crashes/year)	Proportion of Collision Type $\beta_{FI}$	$N_{\text{predicted } r, s, FI}$ (crashes/year)	Proportion of Collision Type $\beta_{FI^a}$	$N_{\text{predicted } r, s, FI^a}$ (crashes/year)	Proportion of Collision Type $\beta_{PDO}$	$N_{\text{predicted } r, s, PDO}$ (crashes/year)
Collision Type	from Table 11-4	(7) <sub>total</sub> from Worksheet SP2C	from Table 11-4	(7) <sub>FI</sub> from Worksheet SP2C	from Table 11-4	(7) <sub>FI^a</sub> from Worksheet SP2C	from Table 11-4	(7) <sub>PDO</sub> from Worksheet SP2C
Total	1.000	0.289	1.000	0.177	1.000	0.099	1.000	0.112
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>FI^a</sub>		(8)*(9) <sub>PDO</sub>
Head-on collision	0.009	0.003	0.029	0.005	0.043	0.004	0.001	0.000
Sideswipe collision	0.098	0.028	0.048	0.008	0.044	0.004	0.120	0.013
Rear-end collision	0.246	0.071	0.305	0.054	0.217	0.021	0.220	0.025
Angle collision	0.356	0.103	0.352	0.062	0.348	0.034	0.358	0.040
Single-vehicle collision	0.238	0.069	0.238	0.042	0.304	0.030	0.237	0.027
Other collision	0.053	0.015	0.028	0.005	0.044	0.004	0.064	0.007

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP2E—Summary Results for Rural Multilane Roadway Segments**

Worksheet SP2E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 4).

**Worksheet SP2E.** Summary Results for Rural Multilane Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(7) from Worksheet SP2C		(2)/(3)
Total	0.289	0.1	2.9
Fatal and injury (FI)	0.177	0.1	1.8
Fatal and injury <sup>a</sup> (FI <sup>a</sup> )	0.099	0.1	1.0
Property damage only (PDO)	0.112	0.1	1.1

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**11.12.3. Sample Problem 3**

The Site/Facility

A three-leg stop-controlled intersection located on a rural four-lane highway.

**The Question**

What is the predicted average crash frequency of the stop-controlled intersection for a particular year?

**The Facts**

- 3 legs
- Minor-road stop control
- 0 right-turn lanes on major road
- 1 left-turn lane on major road
- 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- Calibration factor = 1.50
- Intersection lighting is present

**Assumptions**

- Collision type distributions are the default values from Table 11-9.
- The calibration factor is assumed to be 1.50.

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem 3 is determined to be 0.8 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the intersection in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

The SPF for a three-leg intersection with minor-road stop control is calculated from Equation 11-11 and Table 11-7 as follows:

$$N_{spf\ int} = \exp \left[ a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}) \right]$$

$$= \exp[-12.526 + 1.204 \times \ln(8,000) + 0.236 \times \ln(1,000)] = 0.928 \text{ crashes/year}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features**

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

**Intersection Skew Angle ( $CMF_{li}$ )**

$CMF_{li}$  can be calculated from Equation 11-18 as follows:

$$CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1$$

The intersection skew angle for Sample Problem 3 is 30 degrees.

$$CMF_{li} = \frac{0.016 \times 30}{(0.98 + 0.016 \times 30)} + 1 = 1.08$$

**Intersection Left-Turn Lanes ( $CMF_{2i}$ )**

From Table 11-22, for a left-turn lane on one non-stop-controlled approach at a three-leg stop-controlled intersection,  $CMF_{2i} = 0.56$ .

**Intersection Right-Turn Lanes ( $CMF_{3i}$ )**

Since no right-turn lanes are present,  $CMF_{3i} = 1.00$  (i.e., the base condition for  $CMF_{3i}$  is the absence of right-turn lanes on the intersection approaches).

**Lighting ( $CMF_{4i}$ )**

$CMF_{4i}$  can be calculated from Equation 11-22 as follows:

$$CMF_{4i} = 1.0 - 0.38 \times p_{ni}$$

From Table 11-24, for intersection lighting at a three-leg stop-controlled intersection,  $p_{ni} = 0.276$ .

$$CMF_{4i} = 1.0 - 0.38 \times 0.276 = 0.90$$

The combined CMF value for Sample Problem 3 is calculated below.

$$CMF_{comb} = 1.33 - 0.56 \times 0.90 = 0.67$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed that a calibration factor,  $C_i$ , of 1.50 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predictive models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 11-4 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted int}} = N_{\text{spf int}} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{4i})$$
$$= 0.928 \times 1.50 \times (0.67) = 0.933 \text{ crashes/year}$$

## WORKSHEETS

The step-by-step instructions above are the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps, a series of five worksheets are provided for determining the predicted average crash frequency. The five worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Multilane Highway Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Multilane Highway Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Multilane Highway Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections
- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Summary Results for Rural Multilane Highway Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

### Worksheet SP3A—General Information and Input Data for Rural Multilane Highway Intersections

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”) and assumptions for Sample Problem 3.

**Worksheet SP3A.** General Information and Input Data for Rural Multilane Highway Intersections

General Information		Location Information	
Analyst		Highway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		—	3ST
AADT <sub>maj</sub> (veh/day)		—	8,000
AADT <sub>mi</sub> (veh/day)		—	1,000
Intersection skew angle (degrees)		0	30
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	1
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)		0	0
Intersection lighting (present/not present)		not present	present
Calibration factor, C <sub>i</sub>		1.0	1.5

**Worksheet SP3B—Crash Modification Factors for Rural Multilane Highway Intersections**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP3B which indicates the combined CMF value.

**Worksheet SP3B.** Crash Modification Factors for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)
CrashSeverity Level	CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
	$CMF_{li}$	$CMF_{lt}$	$CMF_{rt}$	$CMF_{li}$	$CMF_{comb}$
	from Equations 11-18 or 11-20 and 11-19 or 11-21	from Table 11-22	from Table 11-23	from Equation 11-22	(1)*(2)*(3)*(4)
	Total	1.33	0.56	1.00	0.90
Fatal and injury (FI)	1.50	0.45	1.00	0.90	0.61

**Worksheet SP3C—Intersection Crashes for Rural Multilane Highway Intersections**

The SPF for the intersection in Sample Problem 3 is calculated using the coefficients shown in Table 11-7 (Column 2), which are entered into Equation 11-11 (Column 3). The overdispersion parameter associated with the SPF is also found in Table 11-7 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP3B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency using the values in Column 3, the combined CMF in Column 5, and the calibration factor in Column 6.

**Worksheet SP3C. Intersection Crashes for Rural Multilane Highway Intersections**

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{ij}/k$	Overdispersion Parameter, $k$	Combined CMFs	Calibration Factor, $C_i$	Predicted Average Crash Frequency, $N_{predicted}$
	from Tables 11-7 or 11-8			from Equation 11-11 or 11-12	from Tables 11-7 or 11-8	from (6) of Worksheet SP3B		(3)*(5)*(6)
	a	b	c					
Total	−12.526	1.204	0.236	0.928	0.460	0.67	1.50	0.933
Fatal and injury (FI)	−12.664	1.107	0.272	0.433	0.569	0.61	1.50	0.396
Fatal and injury <sup>a</sup> (FI <sup>a</sup> )	−11.989	1.013	0.228	0.270	0.566	0.61	1.50	0.247
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}-(7)_{FI} = 0.537$

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP3D—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections**

Worksheet SP3D presents the default proportions for collision type (from Table 11-9) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including “possible-injury” crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including “possible injury”), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP3C) by crash severity and collision type.



**Worksheet SP3D.** Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collision Type	Proportion of Collision Type $N_{\text{total}}$	$N_{\text{predicted int total}}$ (crashes/year)	Proportion of Collision Type $F_I$	$N_{\text{predicted int FI}}$ (crashes/year)	Proportion of Collision Type $F_I^a$	$N_{\text{predicted int FI}^a}$ (crashes/year)	Proportion of Collision Type (PDO)	$N_{\text{predicted int PDO}}$ (crashes/year)
	from Table 11-9	(7) <sub>total</sub> from Worksheet SP3C	from Table 11-9	(7) <sub>FI</sub> from Worksheet SP3C	from Table 11-9	(7) <sub>FI</sub> <sup>a</sup> from Worksheet SP3C	from Table 11-9	(7) <sub>PDO</sub> from Worksheet SP3C
Total	1.000	0.933	1.000	0.396	1.000	0.247	1.000	0.537
		(2)*(3) <sub>total</sub>		(4)*(5) <sub>FI</sub>		(6)*(7) <sub>FI</sub> <sup>a</sup>		(8)*(9) <sub>PDO</sub>
Head-on collision	0.029	0.027	0.043	0.017	0.052	0.013	0.020	0.011
Sideswipe collision	0.133	0.124	0.058	0.023	0.057	0.014	0.179	0.096
Rear-end collision	0.289	0.270	0.247	0.098	0.142	0.035	0.315	0.169
Angle collision	0.263	0.245	0.369	0.146	0.381	0.094	0.198	0.106
Single-vehicle collision	0.234	0.218	0.219	0.087	0.284	0.070	0.244	0.131
Other collision	0.052	0.049	0.064	0.025	0.084	0.021	0.044	0.024

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**Worksheet SP3E—Summary Results for Rural Multilane Highway Intersections**

Worksheet SP3E presents a summary of the results.

**Worksheet SP3E.** Summary Results for Rural Multilane Highway Intersections

(1)	(2)
Crash Severity Level	Predicted Average Crash Frequency (crashes/year)
	(7) from Worksheet SP3C
Total	0.933
Fatal and injury (FI)	0.396
Fatal and injury* (FI*)	0.247
Property damage only (PDO)	0.537

<sup>a</sup> Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

**11.12.4. Sample Problem 4**

The Project

A project of interest consists of three sites: a rural four-lane divided highway segment, a rural four-lane undivided highway segment, and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2, and 3.)

**The Question**

What is the expected average crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1, 2, and 3 and the observed crash frequencies using the **site-specific EB Method**?

**The Facts**

- 2 roadway segments (4D segment, 4U segment)
- 1 intersection (3ST intersection)
- 9 observed crashes (4D segment: 4 crashes; 4U segment: 2 crashes; 3ST intersection: 3 crashes)

**Outline of Solution**

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted average crash frequencies for the project using the site-specific EB Method (i.e., observed crashes are assigned to specific intersections or roadway segments) presented in Part C, Appendix A.2.4.

**Results**

The expected average crash frequency for the project is 5.7 crashes per year (rounded to one decimal place).

**WORKSHEETS**

To apply the site-specific EB Method to multiple roadway segments and intersections on a rural multilane highway combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet 3A)*—Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways
- *Worksheet SP4B (Corresponds to Worksheet 3B)*—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

**Worksheets SP4A—Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways**

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered into Columns 2 through 4 of Worksheet SP4A. Column 5 presents the observed crash frequencies by site type, and Column 6 the overdispersion parameter. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from Part C, Appendix A is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8.

**Worksheet SP4A.** Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	Weighted Adjustment, $w$	Expected Average Crash Frequency, $N_{\text{expected}}$
	$N_{\text{predicted total}}$	$N_{\text{predicted FI}}$	$N_{\text{predicted PDO}}$			Equation A-5	Equation A-4
	Roadway Segments						
Segment 1	3.306	1.726	1.580	4	0.142	0.681	3.527
Segment 2	0.289	0.177	0.112	2	1.873	0.649	0.890
Intersections							
Intersection 1	0.933	0.396	0.537	3	0.460	0.700	1.554
Combined (Sum of Column)	4.528	2.299	2.229	9	—	—	5.971

**Column 7—Weighted Adjustment**

The weighted adjustment,  $w$ , to be placed on the predictive model estimate is calculated using Equation A-5 as follows:

$$w = \frac{1}{1 + k \times \left( \sum_{\text{all study years}} N_{\text{predicted}} \right)}$$

Segment 1

$$w = \frac{1}{1 + 0.142 \times (3.306)} = 0.681$$

Segment 2

$$w = \frac{1}{1 + 1.873 \times (0.289)} = 0.649$$

Intersection 1

$$w = \frac{1}{1 + 0.460 \times (0.933)} = 0.700$$

**Column 8—Expected Average Crash Frequency**

The estimate of expected average crash frequency,  $N_{\text{expected}}$ , is calculated using Equation A-4 as follows:

$$N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}}$$

$$\text{Segment 1: } N_{\text{expected}} = 0.681 \times 3.306 + (1 - 0.681) \times 4 = 3.527$$

$$\text{Segment 2: } N_{\text{expected}} = 0.649 \times 0.289 + (1 - 0.649) \times 2 = 0.890$$

$$\text{Intersection 1: } N_{\text{expected}} = 0.700 \times 0.933 + (1 - 0.700) \times 3 = 1.554$$

#### Worksheet SP4B—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Worksheet SP4B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

#### Worksheet SP4B. Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	$N_{\text{expected}}$
Total	(2) <sub>comb</sub> from Worksheet SP4A 4.528	(8) <sub>comb</sub> from Worksheet SP4A 6.0
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet SP4A 2.299	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub> 3.0
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet SP4A 2.229	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub> 3.0

#### 11.12.5. Sample Problem 5

##### The Project

A project of interest consists of three sites: a rural four-lane divided highway segment, a rural four-lane undivided highway segment, and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2, and 3.)

##### The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1, 2, and 3 and the observed crash frequencies using the **project-level EB Method**?

##### The Facts

- 2 roadway segments (4D segment, 4U segment)
- 1 intersection (3ST intersection)
- 9 observed crashes (but no information is available to attribute specific crashes to specific sites within the project)

##### Outline of Solution

Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e., observed crash data for individual roadway segments and intersections are not available, but observed crashes are assigned to a facility as a whole) presented in Part C, Appendix A.2.5.

**Results**

The expected average crash frequency for the project is 5.8 crashes per year (rounded to one decimal place).

**WORKSHEETS**

To apply the project-level EB Method to multiple roadway segments and intersections on a rural multilane highway combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- *Worksheet SP5A (Corresponds to Worksheet 4A)*—Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways
- *Worksheet SP5B (Corresponds to Worksheet 4B)*—Project-Level Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

**Worksheets SP5A—Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways**

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered in Columns 2 through 4 of Worksheet SP5A. Column 5 presents the observed crash frequencies by site type, and Column 6 the overdispersion parameter. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates  $N_{w,0}$  and Column 8  $N_{w,1}$ . Equations A-10 through A-14 from Part C, Appendix A are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Part C, Appendix A.2.5 defines all the variables used in this worksheet.

**Worksheet SP5A.** Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, $k$	$N_{w0}$	$N_{w1}$	$w_0$	$N_0$	$w_1$	$N_1$	$N_{expected,observed}$
	$N_{predicted,observed}$	$N_{predicted,EB(1)}$	$N_{predicted,EB(DD)}$			Equation A-8 (6)* (2) <sup>2</sup>	Equation A-9 $\sqrt{((6)*(2))}$	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
Roadway Segments												
Segment 1	3.306	1.726	1.580	4	0.142	1.552	0.685	—	—	—	—	—
Segment 2	0.289	0.177	0.112	2	1.873	0.156	0.736	—	—	—	—	—
Intersections												
Intersection 1	0.933	0.396	0.537	3	0.460	0.400	0.655	—	—	—	—	—
Combined (sum of column)	4.528	2.299	2.229	9	—	2.109	2.076	0.682	5.95	0.686	5.932	5.941

Note:  $N_{predicted w0}$  = Predicted number of total crashes assuming that crash frequencies are statistically independent

$$N_{predicted w0} = \sum_{j=1}^5 k_{rmj} N_{rmj}^2 + \sum_{j=1}^5 k_{rsj} N_{rsj}^2 + \sum_{j=1}^5 k_{rdj} N_{rdj}^2 + \sum_{j=1}^4 k_{imj} N_{imj}^2 + \sum_{j=1}^4 k_{isj} N_{isj}^2 \quad (A-8)$$

$N_{predicted w1}$  = Predicted number of total crashes assuming that crash frequencies are perfectly correlated

$$N_{predicted w1} = \sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}} + \sum_{j=1}^5 \sqrt{k_{rdj} N_{rdj}} + \sum_{j=1}^4 \sqrt{k_{imj} N_{imj}} + \sum_{j=1}^4 \sqrt{k_{isj} N_{isj}} \quad (A-9)$$

#### Column 9— $w_0$

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent,  $w_0$ , is calculated using Equation A-10 as follows:

$$\begin{aligned} w_0 &= \frac{1}{1 + \frac{N_{predicted w0}}{N_{predicted (total)}}} \\ &= \frac{1}{1 + \frac{2.109}{4.528}} \\ &= 0.682 \end{aligned}$$

#### Column 10— $N_0$

The expected crash frequency based on the assumption that different roadway elements are statistically independent,  $N_0$ , is calculated using Equation A-11 as follows:

$$\begin{aligned}
 N_0 &= w_0 \times N_{\text{predicted (total)}} + (1 - w_0) \times N_{\text{observed (total)}} \\
 &= 0.682 \times 4.528 + (1 - 0.682) \times 9 = 5.950
 \end{aligned}$$

**Column 11— $w_1$** 

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated,  $w_1$ , is calculated using Equation A-12 as follows:

$$\begin{aligned}
 w_1 &= \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}} \\
 &= \frac{1}{1 + \frac{2.076}{4.528}} \\
 &= 0.686
 \end{aligned}$$

**Column 12— $N_1$** 

The expected crash frequency based on the assumption that different roadway elements are perfectly correlated,  $N_1$ , is calculated using Equation A-13 as follows:

$$\begin{aligned}
 N_1 &= w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}} \\
 &= 0.686 \times 4.528 + (1 - 0.686) \times 9 = 5.932
 \end{aligned}$$

**Column 13— $N_{\text{expected/comb}}$** 

The expected average crash frequency based of combined sites,  $N_{\text{expected/comb}}$  is calculated using Equation A-14 as follows:

$$\begin{aligned}
 N_{\text{expected/comb}} &= \frac{N_0 + N_1}{2} \\
 &= \frac{5.950 + 5.932}{2} \\
 &= 5.941
 \end{aligned}$$

**Worksheet SP5B—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways**

Worksheet SP5B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

**Worksheet SP5B.** Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{predicted}$	$N_{expected}$
Total	(2) <sub>comb</sub> from Worksheet SP5A 4.528	(13) <sub>comb</sub> from Worksheet SP5A 5.9
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet SP5A 2.299	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub> 3.0
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet SP5A 2.229	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub> 2.9

**11.12.6. Sample Problem 6****The Project**

An existing rural two-lane roadway is proposed for widening to a four-lane highway facility. One portion of the project is planned as a four-lane divided highway, while another portion is planned as a four-lane undivided highway. There is one three-leg stop-controlled intersection located within the project limits.

**The Question**

What is the expected average crash frequency of the proposed rural four-lane highway facility for a particular year, and what crash reduction is expected in comparison to the existing rural two-lane highway facility?

**The Facts**

- Existing rural two-lane roadway facility with two roadway segments and one intersection equivalent to the facilities in Chapter 10's Sample Problems 1, 2, and 3.
- Proposed rural four-lane highway facility with two roadway segments and one intersection equivalent to the facilities in Sample Problems 1, 2, and 3 presented in this chapter.

**Outline of Solution**

Sample Problem 6 applies the Project Estimation Method 1 presented in Section C.7 (i.e., the expected average crash frequency for existing conditions is compared to the predicted average crash frequency of proposed conditions). The expected average crash frequency for the existing rural two-lane roadway can be represented by the results from applying the site-specific EB Method in Chapter 10's Sample Problem 5. The predicted average crash frequency for the proposed four-lane facility can be determined from the results of Sample Problems 1, 2, and 3 in this chapter. In this case, Sample Problems 1 through 3 are considered to represent a proposed facility rather than an existing facility; therefore, there is no observed crash frequency data, and the EB Method is not applicable.

**Results**

The predicted average crash frequency for the proposed four-lane facility project is 4.5 crashes per year, and the predicted crash reduction from the project is 7.8 crashes per year. Table 11-26 presents a summary of the results.



**Table 11-26.** Summary of Results for Sample Problem 6

Site	Expected Average Crash Frequency for the Existing Condition (crashes/year) <sup>a</sup>	Predicted Average Crash Frequency for the Proposed Condition (crashes/year) <sup>b</sup>	Predicted Crash Reduction from Project Implementation (crashes/year)
Segment 1	8.02	3.3	4.7
Segment 2	1.34	0.3	1.1
Intersection 1	2.94	0.9	2.0
Total	12.3	4.5	7.8

<sup>a</sup> From Sample Problems 5 in Chapter 10<sup>b</sup> From Sample Problems 1 through 3 in Chapter 11**11.13. REFERENCES**

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- (6) Srinivasan, R., C. V. Zegeer, F. M. Council, D. L. Harkey, and D. J. Torbic. *Updates to the Highway Safety Manual Part D CMFs*. Unpublished memorandum prepared as part of the FHWA Highway Safety Information System Project. Highway Safety Research Center, University of North Carolina, Chapel Hill, NC, July 2008.
- (7) Srinivasan, R., F. M. Council, and D. L. Harkey. *Calibration Factors for HSM Part C Predictive Models*. Unpublished memorandum prepared as part of the FHWA Highway Safety Information System Project. Highway Safety Research Center, University of North Carolina, Chapel Hill, NC, October 2008.
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**Commented [A36]:** Some references need to be updated if necessary.

**Commented [A37]:** This is the NCHRP report's reference

## APPENDIX 11A. WORKSHEETS FOR APPLYING THE PREDICTIVE METHOD FOR RURAL MULTILANE ROADS

**Worksheet 1A.** General Information and Input Data for Rural Multilane Roadway Segments

General Information		Location Information	
Analyst		Highway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Roadway type (divided/undivided)		—	
Length of segment, L (mi)		—	
AADT (veh/day)		—	
Lane width (ft)		12	
Shoulder width (ft)—right shoulder width for undivided		≥ 6	
Shoulder width (ft)—right shoulder width for divided		≥ 8	
Shoulder type—right shoulder type		paved	
Median width (ft)—for divided only		≥ 30	
Sideslopes—for undivided only		1:7 or flatter	
Lighting (present/not present)		not present	
Auto speed enforcement (present/not present)		not present	
Calibration factor, $C_{rd}$ (for divided), $C_{ru}$ (for undivided)		1.0	

**Worksheet 1B (a).** Crash Modification Factors for Rural Multilane Divided Roadway Segments

**Commented [A38]:** table needs to be updated if necessary.

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	CMF for Right Shoulder Width	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{1rd}$	$CMF_{2rd}$	$CMF_{3rd}$	$CMF_{4rd}$	$CMF_{5rd}$	$CMF_{comb}$
from Equation 11-16	from Table 11-17	from Table 11-18	from Equation 11-17	from Section 11.7.2	(1)*(2)*(3)*(4)*(5)

**Worksheet 1B (b).** Crash Modification Factors for Rural Multilane Undivided Roadway ~~Segments~~**Commented [A39]:** table needs to be updated if necessary.

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	CMF for Shoulder Width	CMF for Sideslopes	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{1ru}$	$CMF_{2ru}$	$CMF_{3ru}$	$CMF_{4ru}$	$CMF_{5ru}$	$CMF_{comb}$
from Equation 11-13	from Equation 11-14	from Table 11-14	from Equation 11-15	from Section 11.7.1	$(1)*(2)*(3)*(4)*(5)$

**Worksheet 1C (a).** Roadway Segment Crashes for Rural Multilane Divided Roadway Segments**Commented [A40]:** column needs to be updated if necessary.

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{spf,rd}$	Overdispersion Parameter, $k$	Combined CMFs	Calibration Factor, $C_{rd}$	Predicted Average Crash Frequency, $N_{predicted,rd}$
	from Table 11-4			from Equation 11-9	from Equation 11-10	(6) from Worksheet 1B (a)		(3)*(5)*(6)
	a	b	c					
KABCO	-9.644	1.050	0.669					
KABC	-10.817	1.064	1.023					
KAB	-10.690	0.983	2.090					
KA	-7.690	0.508	11.238					
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{KABCO} - (7)_{KABC}$

**Worksheet 1C (b).** Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{spf}$	Overdispersion Parameter, $k$	Combined CMFs		Predicted Average Crash Frequency, $N_{predicted\ rs}$
	from Table 11-3			from Equation 11-7	from Equation 11-8	(6) from Worksheet 1B (b)	Calibration Factor, $C_{rs}$	
	a	b	c					(3)*(5)*(6)
	KABCO	-9.129	1.055	0.476				
KABC	-9.652	1.009	0.611					
KAB	-9.704	0.950	0.783					
KA	-9.799	0.847	-0.216					
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{KABCO} - (7)_{KABC}$

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**Worksheet 1E.** Summary Results for Rural Multilane Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(7) from Worksheet 1C (a) or (b)		(2)/(3)
KABCO			
KABC			
KAB			
KA			
Property damage only (PDO)			

**Worksheet 2A.** General Information and Input Data for Rural Multilane Highway Intersections

General Information		Local Information	
Analyst		Highway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		—	
AADT <sub>major</sub> (veh/day)		—	
AADT <sub>minor</sub> (veh/day)		—	
Intersection skew angle (degrees)		0 – 5	
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)		0	
Intersection lighting (present/not present)		not present (for stop-controlled intersections), present (for signalized intersections)	
Calibration factor, $C_{nt}$		1.0	

Deleted: for all-way stop-controlled

**Worksheet 2B.** Crash Modification Factors for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
	$CMF_{i1}$	$CMF_{i2}$	$CMF_{i3}$	$CMF_{i4}$	
	from Equations 11-18 or 11-20 and 11-19 or 11-21	from Table 11-22	from Table 11-23	from Equation 11-22	
					(1)*(2)*(3)*(4)
Total					
Fatal and injury (FI)					

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**Worksheet 2C.** Intersection Crashes for Rural Multilane Highway Intersections

(1)	(2)				(3)	(4)	(5)	(6)	(7)
Intersection Type/Crash Severity Level	SPF Coefficients				$N_{\text{input}}$	Overdispersion Parameter, $k$	Combined CMFs	Calibration Factor	Predicted Average Crash Frequency, $N_{\text{predicted}}$
	from Table 11-5 or 11-6				from Equation 11- 11 or 11-12	from Table 11-5 or 11-6	from (6) of Worksheet 2B	$C_{\text{adj}}$	(3)*(5)*(6)
	a	b	c	d					
3ST KABCO	-9.118	0.776	0.270	—		0.323			
3ST KABC	-9.392	0.659	0.346	—		0.261			
3ST KAB	-9.208	0.546	0.357	—		0.367			
3ST Property damage only (PDO)	—	—	—	—	—	—	—	—	$(7)_{3STKABCO} -$ $(7)_{3STKABC}$
4ST KABCO	-9.561	0.773	0.383	—		0.410			
4ST KABC	-10.411	0.711	0.475	—		0.433			
4ST KAB	-8.843	0.441	0.509	—		0.683			
4ST Property damage only (PDO)	—	—	—	—	—	—	—	—	$(7)_{4STKABCO} -$ $(7)_{4STKABC}$
4SG KABCO	-7.741	—	—	0.932		0.443			
4SG KABC	-14.318	—	—	1.442		0.775			
4SG KAB	-14.662	—	—	1.399		0.499			
4SG Property damage only (PDO)	—	—	—	—	—	—	—	—	$(7)_{4SGKABCO} -$ $(7)_{4SGKABC}$

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**Worksheet 2E.** Summary Results for Rural Multilane Highway Intersections

(1)	(2)
	Predicted Average Crash Frequency (crashes/year)
Crash Severity Level	(7) from Worksheet 2C
KABCO	
KABC	
KAB	
KA	
Property damage only (PDO)	

**Worksheet 3A.** Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, <i>N<sub>observed</sub></i> (crashes/year)	Overdispersion Parameter, <i>k</i>	Weighted Adjustment, <i>w</i>	Expected Average Crash Frequency, <i>N<sub>expected</sub></i>
	<i>N<sub>predicted (a+b)</sub></i>	<i>N<sub>predicted (F1)</sub></i>	<i>N<sub>predicted (PDO)</sub></i>			Equation A-5	Equation A-4
Roadway Segments							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Segment 5							
Segment 6							
Segment 7							
Segment 8							
Intersections							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Intersection 5							
Intersection 6							
Intersection 7							
Intersection 8							
Combined (Sum of Column)					—	—	

**Commented [A44]:** equation numbers need to be updated if necessary.



**Worksheet 3B.** Site-Specific EB Method Summary Results

(1)	(2)	(3)
Crash Severity Level	$N_{predicted}$	$N_{expected}$
Total	(2) <sub>comb</sub> from Worksheet 3A	(8) <sub>comb</sub> from Worksheet 3A
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet 3A	(3) <sub>btul</sub> * (2) <sub>FI</sub> / (2) <sub>btul</sub>
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet 3A	(3) <sub>btul</sub> * (2) <sub>PDO</sub> / (2) <sub>btul</sub>

**Worksheet 4A.** Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, $k$	$N_{uo}$	$N_{ui}$	$w_o$	$N_o$	$w_i$	$N_i$	$N_{expected,amb}$
	$N_{predicted,amb}$	$N_{predicted,FI}$	$N_{predicted,PDO}$			Equation A-8 (6)*(2) <sup>2</sup>	Equation A-9 sqrt((6)*(2))	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
Roadway Segments												
Segment 1				—				—	—	—	—	—
Segment 2				—				—	—	—	—	—
Segment 3				—				—	—	—	—	—
Segment 4				—				—	—	—	—	—
Segment 5				—				—	—	—	—	—
Segment 6				—				—	—	—	—	—
Segment 7				—				—	—	—	—	—
Segment 8				—				—	—	—	—	—
Intersections												
Intersection 1				—				—	—	—	—	—
Intersection 2				—				—	—	—	—	—
Intersection 3				—				—	—	—	—	—
Intersection 4				—				—	—	—	—	—
Intersection 5				—				—	—	—	—	—
Intersection 6				—				—	—	—	—	—
Intersection 7				—				—	—	—	—	—
Intersection 8				—				—	—	—	—	—
Combined (Sum of Column)					—							

**Commented [A45]:** equation numbers need to be updated if necessary.

**Worksheet 4B.** Project-Level EB Method Summary Results

(1)	(2)	(3)
Crash Severity Level	$N_{predicted}$	$N_{expected}$
Total	(2) <sub>comb</sub> from Worksheet 4A	(13) <sub>comb</sub> from Worksheet 4A
Fatal and injury (FI)	(3) <sub>comb</sub> from Worksheet 4A	(3) <sub>total</sub> * (2) <sub>FI</sub> / (2) <sub>total</sub>
Property damage only (PDO)	(4) <sub>comb</sub> from Worksheet 4A	(3) <sub>total</sub> * (2) <sub>PDO</sub> / (2) <sub>total</sub>

**APPENDIX 11B. PREDICTIVE MODELS FOR SELECTED COLLISION TYPES**

The main text of this chapter presents predictive models for crashes by severity level. These safety prediction models are presented in this appendix for application by HSM users, where appropriate. However, prediction models are available only for selected collision types. And such models must be used with caution by HSM users because the results of a series of collision models for individual collision types will not necessarily sum to the predicted crash frequency for all collision types combined. In other words, when predicted crash frequencies for several collision types are used together, some adjustment of those predicted crash frequencies may be required to assure that their sum is consistent with results from the models presented in the main text of this chapter.

**11B.1. ROADWAY SEGMENTS*****Undivided Roadway Segments***

Table 11B-1 summarizes the values for the coefficients used in prediction models that apply Equations 11-7 and 11-8 for estimating crash frequencies by collision type for undivided roadway segments. Specific collision types are addressed: single-vehicle, same direction, intersecting direction and opposite-direction collisions. These models are assumed to apply for base conditions represented as the average values of the variables in a jurisdiction. Thus, when using these models for predicting crash frequencies, applicable CMFs, presented in Section 11.7, should be used.

**Commented [A46]:** need to know the section including the CMFs for adjusting SPFs for specific crash types (single vehicle, same direction etc)

**Table 11B-1.** SPFs for Selected Collision Types on Four-Lane Undivided Roadway Segments (Based on Equations 11-7 and 11-8)

Collision Type/Severity Level	a	b	c
Single Vehicle KABCO	-7.127	0.688	1.018
Single Vehicle KABC	-6.738	0.545	13.202
Single Vehicle KAB	-6.941	0.518	0.476
Same Direction KABCO	-13.541	1.431	0.033
Same Direction KABC	-16.650	1.654	0.365
Int. Direction KABCO	-10.209	1.000	-0.825
Int. Direction KABC	-10.944	0.978	-1.199
Int. Direction KAB	-11.340	0.955	-0.764
Opp. Direction KABCO	-15.344	1.495	-0.923
Opp. Direction KABC	-16.518	1.540	0.365
Opp. Direction KAB	-18.421	1.711	13.203
Opp. Direction KA	-16.573	1.482	0.885

**Divided Roadway Segments**

The values for the coefficients used in prediction models that apply Equations 11-9 and 11-10 for estimating crash frequencies by collision type for divided roadway segments are summarized in Table 11B-2. The specific collision types addressed are single-vehicle, same direction and opposite-direction collisions. These models are applicable to base conditions represented as the average values of the variables in a jurisdiction. Thus, when applying these SPFs for predicting crash frequencies, applicable CMFs, presented in Section 11.7, should be used.

**Table 11B-2.** SPFs for Selected Collision Types on Four-Lane Divided Roadway Segments (Based on Equations 11-9 and 11-10)

Collision Type /Severity Level	a	b	c
Single Vehicle KABCO	-7.990	0.816	1.262
Single Vehicle KABC	-9.473	0.879	10.025
Single Vehicle KAB	-10.952	0.973	1.422
Single Vehicle KA	-1.524	-0.176	9.978
Same Direction KABCO	-14.701	1.479	-0.473
Same Direction KABC	-18.512	1.730	-1.620
Same Direction KAB	-14.914	1.261	-2.190
Opp. Direction KABCO	-17.478	1.470	9.638
Opp. Direction KABC	-17.132	1.403	1.553
Opp. Direction KAB	-20.211	1.656	9.871
Opp. Direction KA	-20.211	1.656	9.871

**Commented [A47]:** need to know the section including the CMFs for adjusting SPFs for specific crash types (single vehicle, same direction etc)

11B.2. INTERSECTIONS

Stop-Controlled Intersections

Table 11B-3 summarizes the values for the coefficients used in prediction models that apply Equations 11-11 and 11-12 for estimating crash frequencies by collision type for stop-controlled intersections on rural multilane highways. Four specific collision types are addressed:

- Single-vehicle collisions
- Same-direction collisions (rear-end and sideswipe collisions)
- Intersecting direction collisions (angle and left-turn-through collisions)

Table 11B-3 presents values for the coefficients a, b, c and d used in applying Equations 11-11 and 11-12 for predicting crashes by collision type for three- and four-leg stop-controlled intersections. The models presented in this exhibit were developed for intersections for base conditions. Thus, when using these models for predicting crash frequencies, applicable CMFs, presented in Section 11.7, should be used.

**Deleted:** *All-Way Stop-Controlled*

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**Deleted:** for three- and four-leg all-way stop-controlled

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**Table 11B-3. Collision Type Models for Three- and Four-Leg Intersections with Minor-Road Stop Control**  
(Based on Equations 11-11 and 11-12)

**Deleted:** Collision Type Models for Three- and Four-Leg All-Way Stop-Controlled Intersections

Intersection Type/Collision Type/ Severity Level	a	b	c	d	Overdispersion Parameter (Fixed $k_{\lambda}$ )
3ST Single Vehicle KABCO	-7.259	—	—	0.663	0.826
3ST Single Vehicle KABC	-7.837	—	—	0.608	0.256
3ST Same Direction KABCO	-14.411	1.033	0.502	—	0.236
3ST Same Direction KABC	-12.552	0.737	0.504	—	0.539
3ST Int. Direction KABCO	-12.652	0.746	0.651	—	0.602
3ST Int. Direction KABC	-14.356	0.728	0.833	—	0.435
3ST Int. Direction KAB	-13.058	0.575	0.774	—	0.365
4ST Single Vehicle KABCO	-9.855	—	—	0.929	0.337
4ST Single Vehicle KABC	-10.416	—	—	0.876	0.154
4ST Same Direction KABCO	-14.343	1.158	0.345	—	0.362
4ST Same Direction KABC	-13.190	—	—	1.118	0.619
4ST Int. Direction KABCO	-11.531	0.496	0.939	—	0.942
4ST Int. Direction KABC	-8.626	—	—	0.757	1.867
4ST Int. Direction KAB	-9.196	—	—	0.740	3.498
4ST Int. Direction KA	-10.886	—	—	0.770	11.215

<sup>a</sup> This value should be used directly as the overdispersion parameter; no further computation is required.

#### Signalized Intersections

Table 11B-4 summarizes the values for the coefficients used in prediction models that apply Equation 11-12 for estimating crash frequencies by collision type for signalized intersections on rural multilane highways. Specific collision types are addressed: same direction (rear-end and sideswipe collisions), intersecting direction (angle and left-turn-through collisions) and opposite-direction collisions (head-on and sideswipe collisions). The models presented in this exhibit were developed for the intersections' base conditions. Thus, when using these models for predicting crash frequencies, the appropriate CMFs, presented in Section 11.7, should be applied.

**Commented [A49]:** need to know the section including the CMFs for adjusting SPFs for specific crash types (single vehicle, same direction etc)

**Table 11B-3.** Collision Type Models for Four-Leg Signalized Intersections (Based on Equation 11-12)

Collision Type/Severity Level	a	d	Overdispersion Parameter (Fixed $k$ ) <sup>a</sup>
Same Direction KABCO	-12.709	1.391	0.443
Same Direction KABC	-17.140	1.659	0.786
Int. Direction KABCO	-9.724	1.024	0.561
Int. Direction KABC	-14.965	1.412	1.925
Int. Direction KAB	-20.048	1.921	2.105
Opp. Direction KABCO	-9.904	0.965	0.999

<sup>a</sup> This value should be used directly as the overdispersion parameter; no further computation is required.

## CHAPTER 12. Predictive Method for Urban and Suburban Arterials

### 12.1. INTRODUCTION

This chapter presents the predictive method for urban and suburban arterial facilities. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in the Part C—Introduction and Applications Guidance.

The predictive method for urban or suburban arterial facilities provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for facilities with known characteristics. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians, and between vehicles and animals. If the expected number of vehicle-animal crashes is of interest the ratio of vehicle-animal to non-vehicle-animal crashes for that facility type in the jurisdiction under study should be applied as a multiplier to the total crash prediction. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the SPFs in Chapter 12 is documented by Harwood et al. (8, 9). The CMFs used in this chapter have been reviewed and updated by Harkey et al. (6) and in related work by Srinivasan et al. (13).

This chapter presents the following information about the predictive method for urban and suburban arterial facilities:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 12, and site types for which predictive models have been developed for Chapter 12.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing an urban or suburban arterial facility into individual sites, consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for urban and suburban arterials.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 12.
- Guidance for applying the Chapter 12 predictive method, and limitations of the predictive method specific to Chapter 12.
- Sample problems illustrating the application of the Chapter 12 predictive method for urban and suburban arterials.

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**Commented [CL1]:** Update with 17-62 report reference. Keep the Harwood reference for the bike and pedestrian predictions.

**Commented [CL2]:** Update according to what is decided overall about CMFs in the chapters

**Commented [ST3]:** 1. CMF issue needs to be resolved and this text has to be updated accordingly.

2. The current CMFs will only apply to KABCO models for all types.

3. CMFs for other severities will have to be identified.

**Deleted:** . (13). The SPF coefficients, default collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (14).

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**Commented [ST5]:** To be updated by the production contractor



## 12.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the “expected average crash frequency,”  $N_{\text{expected}}$  (by total crashes, crash severity, or collision type) of a roadway network, facility, or site. In the predictive method, the roadway is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments referred to as “sites.” Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type, a number of different site types may exist, such as divided and undivided roadway segments and signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities.

The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The estimate relies on estimates made using predictive models which are combined with observed crash data using the Empirical Bayes (EB) Method.

The predictive models used within the Chapter 12 predictive method are described in detail in Section 12.3.

The predictive models used in Chapter 12 to predict average crash frequency,  $N_{\text{predicted}}$ , are of the general form shown in Equation 12-1.

$$N_{\text{predicted}} = (N_{\text{spf } x} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) + N_{\text{pedx}} + N_{\text{bikex}}) \times C_x \quad (12-1)$$

Where:

- $N_{\text{predicted}}$  = predicted average crash frequency for a specific year on site type  $x$ ;
- $N_{\text{spf } x}$  = predicted average crash frequency determined for base conditions of the SPF developed for site type  $x$ ;
- $N_{\text{pedx}}$  = predicted average number of vehicle-pedestrian collisions per year for site type  $x$ ;
- $N_{\text{bikex}}$  = predicted average number of vehicle-bicycle collisions per year for site type  $x$ ;
- $CMF_{yx}$  = crash modification factors specific to site type  $x$  and specific geometric design and traffic control features  $y$ ; and
- $C_x$  = calibration factor to adjust SPF for local conditions for site type  $x$ .

The predictive models in Chapter 12 provide estimates of crash frequency for roadway segments and intersections. The SPFs in Chapter 12 address multiple crash types and severity. Crash severity is defined as (K), (A), (B), (C), and no injury (O). Crash type was defined differently for segments and intersections; details are provided with the modeling framework. For each individual crash type, models were estimated for KABCO, KABC, KAB, and KA severity levels. In some cases, SPFs could not be reliably estimated alternative crash prediction approaches need to be considered. Guidelines for developing those approaches are provided in Chapter 14 under the heading “Guidelines for HSM users for crash predictions where SPFs could not be reliably estimated”

## 12.3. URBAN AND SUBURBAN ARTERIALS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 12

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 12. These predictive models are applied following the steps of the predictive method presented in Section 12.4.

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Deleted: severity levels: fatal-

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Deleted: and property-damage-only crashes. Fatal-and-injury crashes include crashes involving all levels of injury severity including fatalities, incapacitating injuries, nonincapacitating injuries, and possible injuries. The relative proportions of crashes

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12.3.1. Definition of Chapter 12 Facility Types

The predictive method in Chapter 12 addresses the following urban and suburban arterial facilities: two- and four-lane undivided facilities, four-lane divided facilities, and three- and five-lane facilities with center two-way left-turn lanes. Divided arterials are nonfreeway facilities (i.e., facilities without full control of access) that have lanes in the two directions of travel separated by a raised or depressed median. Such facilities may have occasional grade-separated interchanges, but these are not the primary form of access. The predictive models do not apply to any section of an arterial within the limits of an interchange which has free-flow ramp terminals on the arterial of interest. Arterials with a flush separator (i.e., a painted median) between the lanes in the two directions of travel are considered undivided facilities, not divided facilities. Separate prediction models are provided for arterials with a flush separator that serves as a center two-way left-turn lane. Chapter 12 does not address arterial facilities with six or more lanes.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all urban and suburban arterials independent of official state or local highway designation.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas is based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas where the population is less than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area. The term “arterial” refers to facilities the meet the FHWA definition of “roads serving major traffic movements (high-speed, high volume) for travel between major points” (5).

Table 12-1 identifies the specific site types on urban and suburban arterial highways that have predictive models. ~~crashes by type and severity. Crash types are defined differently for segments and intersections; details are provided in the next two sections~~

Table 12-1. Urban and Suburban Arterial Site Type SPFs included in Chapter 12

Site Type	Site Types with SPFs in Chapter 12
Roadway Segments	Two-lane undivided arterials (2U)
	Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
	Four-lane undivided arterials (4U)
	Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
	Five-lane arterials including a center TWLTL (5T)
Intersections	Unsignalized three-leg <del>intersections</del> (stop control on minor-road approaches) (3ST)
	Signalized three-leg intersections (3SG)
	Unsignalized four-leg <del>intersections</del> (stop control on minor-road approaches) (4ST)
	Signalized four-leg <del>intersections</del> (4SG)

These specific site types are defined as follows:

- *Two-lane undivided arterial (2U)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Three-lane arterials (3T)*—a roadway consisting of three lanes with a continuous cross-section providing two directions of travel in which center lane is a two-way left-turn lane (TWLTL).
- *Four-lane undivided arterials (4U)*—a roadway consisting of four lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.

**Deleted:** In Chapter 12, separate SPFs are used for each individual site to predict multiple-vehicle nondriveway collisions, single-vehicle collisions, driveway-related collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions for both roadway segments and intersections. These are combined to predict the total average crash frequency at an individual site.

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- *Four-lane divided arterials (i.e., including a raised or depressed median) (4D)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Five-lane arterials including a center TWLTL (5T)*—a roadway consisting of five lanes with a continuous cross-section providing two directions of travel in which the center lane is a two-way left-turn lane (TWLTL).
- *Three-leg intersection with stop control (3ST)*—an intersection of a urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection only.
- *Three-leg signalized intersection (3SG)*—an intersection of a urban or suburban arterial and one minor road. Signalized control is provided at the intersection by traffic lights.
- *Four-leg intersection with stop control (4ST)*—an intersection of a urban or suburban arterial and two minor roads. A stop sign is provided on both the minor road approaches to the intersection.
- *Four-leg signalized intersection (4SG)*—an intersection of a urban or suburban arterial and two minor roads. Signalized control is provided at the intersection by traffic lights.

### 12.3.2. Predictive Models for Urban and Suburban Arterial Roadway Segments

The predictive models can be used to estimate total average crashes (i.e., all crash severities and collision types) or can be used to predict average frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines the SPF, CMFs, and a calibration factor. Chapter 12 contains separate predictive models for roadway segments and for intersections.

The predictive models for roadway segments estimate the predicted average crash frequency of non-intersection-related crashes. Non-intersection-related crashes may include crashes that occur within the limits of an intersection but are not related to the intersection. The roadway segment predictive models estimate crashes that would occur regardless of the presence of the intersection.

The predictive models for roadway segments are presented in Equations 12-2 and 12-3 below.

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker}) \quad (12-2)$$

$$N_{br} = N_{spfrs} \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{nr}) \quad (12-3)$$

Where:

$N_{\text{predicted } rs}$	= predicted <b>total</b> average crash frequency of an individual roadway segment for the selected year <b>(excluding vehicle-animal collisions);</b>
$N_{br}$	= predicted <b>total</b> average crash frequency of an individual roadway segment (excluding vehicle-pedestrian, <b>vehicle-bicycle</b> and vehicle- <b>animal</b> collisions);
$N_{spfrs}$	= predicted total average crash frequency of an individual roadway segment for base conditions (excluding vehicle-pedestrian, <b>vehicle-bicycle</b> and vehicle- <b>animal</b> collisions);
$N_{pedr}$	= predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment;
$N_{biker}$	= predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment;
$CMF_{1r} \dots CMF_{nr}$	= crash modification factors for roadway segments; and
$C_r$	= calibration factor for roadway segments of a specific type developed for use for a particular geographical area.

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The SPF portion of  $N_{brs}$ , designated as  $N_{spf\ rs}$ , should reflect the crash type(s) of interest and the CMFs applied in Equation 12-3 should apply to those crash types. If multiple crash types are of interest then the separate SPF estimates can be added.

### 12.3.3. Predictive Models for Urban and Suburban Arterial Intersections

The predictive models for intersections estimate the predicted total average crash frequency including those crashes that occur within the limits of an intersection and are a result of the presence of the intersection. The predictive model for an urban or suburban arterial intersection is given by:

$$N_{\text{predicted int}} = C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \quad (12-4)$$

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{6i}) \quad (12-5)$$

Where:

$N_{int}$  = predicted average crash frequency of an intersection for the selected year;

$N_{bi}$  = predicted average crash frequency of an intersection (excluding vehicle-pedestrian, vehicle-bicycle, and vehicle-animal crashes);

$N_{spf\ int}$  = predicted total average crash frequency of intersection-related crashes for base conditions (excluding vehicle-pedestrian, vehicle-bicycle, and vehicle-animal crashes);

$N_{pedi}$  = predicted average crash frequency of vehicle-pedestrian crashes;

$N_{bikei}$  = predicted average crash frequency of vehicle-bicycle crashes;

$CMF_{1i} \dots CMF_{6i}$  = crash modification factors for intersections; and

$C_i$  = calibration factor for intersections developed for use for a particular geographical area.

The CMFs shown in Equation 12-6 do not apply to vehicle-pedestrian and vehicle-bicycle collisions. A separate set of CMFs that apply to vehicle-pedestrian crashes at signalized intersections is presented in Section 12.7.

The SPFs for urban and suburban arterial highways are presented in Section 12.6. The associated CMFs for each of the SPFs are presented in Section 12.7 and summarized in Table 12-22. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors,  $C_r$  and  $C_i$ , are determined in Part C, Appendix A.1.1. Due to continual change in the crash frequency and severity distributions with time, the value of the calibration factors may change for the selected year of the study period.

## 12.4. PREDICTIVE METHOD STEPS FOR URBAN AND SUBURBAN ARTERIALS

The predictive method for urban and suburban arterials is shown in Figure 12-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for an urban or suburban arterial facility. The components of the predictive models in Chapter 12 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Part C, Appendix A. In some situations, certain steps will not require any action. For example, a new facility will not have observed crash data and therefore steps relating to the EB Method require no action.

There are 18 steps in the predictive method. In some situations certain steps will not be needed because data is not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be

**Deleted:** Equation 12-2 shows that roadway segment crash frequency is estimated as the sum of three components:  $N_{brs}$ ,  $N_{pedr}$ , and  $N_{biker}$ . The following equation shows that the

**Deleted:** is further separated into three components by collision

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$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy} \quad (12-4)$$

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Where:¶

**Deleted:**  $N_{brmv}$  = predicted average

**Deleted:** frequency of

**Deleted:** -vehicle nondriveway collisions for base conditions;¶  
 $N_{brsv}$  = predicted average

**Deleted:** frequency of single-vehicle crashes for base conditions; and¶  
 $N_{brdwy}$  = predicted average crash frequency of multiple-vehicle driveway-related collisions.¶

Thus,

**Deleted:** SPFs and adjustment factors are applied to determine five components:  $N_{brmv}$ ,  $N_{brsv}$ ,  $N_{brdwy}$ ,  $N_{pedr}$ , and  $N_{biker}$  which together provide a prediction of total average crash frequency for a roadway segment.

**Deleted:** Equations 12-2 through 12-4 are applied to estimate roadway segment crash frequencies for all crash severity levels combined (i.e., total crashes) or for fatal-and-injury or property-damage-only crashes.¶

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**Commented [ST6]:** Vehicle – Animal crashes were also not included in the models.

Should an identifier for animal crashes be added to Equation 12-5 in the same way as pedestrian and bicycle crashes.

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**Deleted:** Equation 12-5 shows that the intersection crash frequency is estimated as the sum of three components:  $N_{bi}$ ,  $N_{pedi}$ , and  $N_{bikei}$ . The following equation shows that the SPF portion of  $N_{bi}$ , designated as  $N_{spf\ int}$ , is further separated into two components by collision type:¶

$$N_{spf\ int} = N_{bimv} + N_{bisv} \quad (12-7)¶$$

**Moved down [2]:** Where:¶

**Deleted:**  $N_{bimv}$  = predicted average number of multiple-vehicle collisions for base conditions; and¶

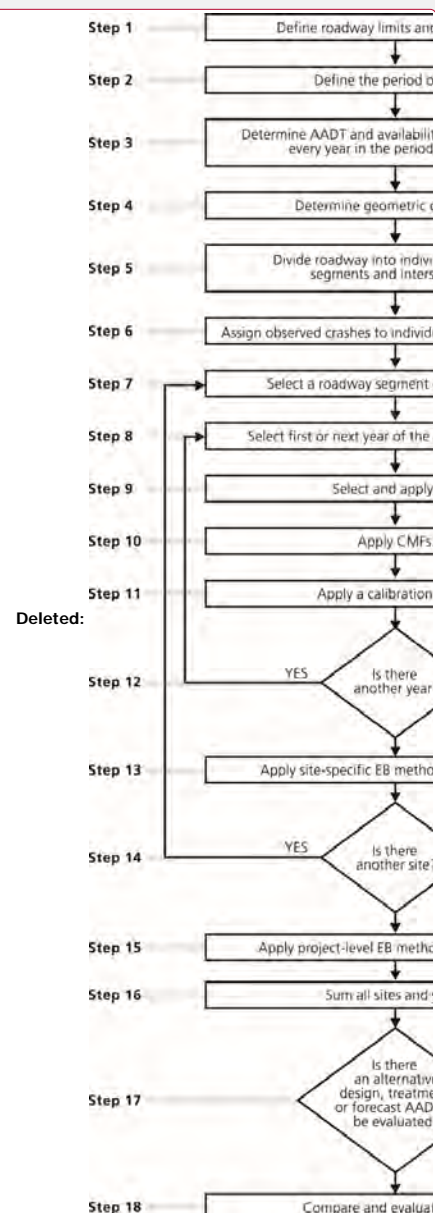
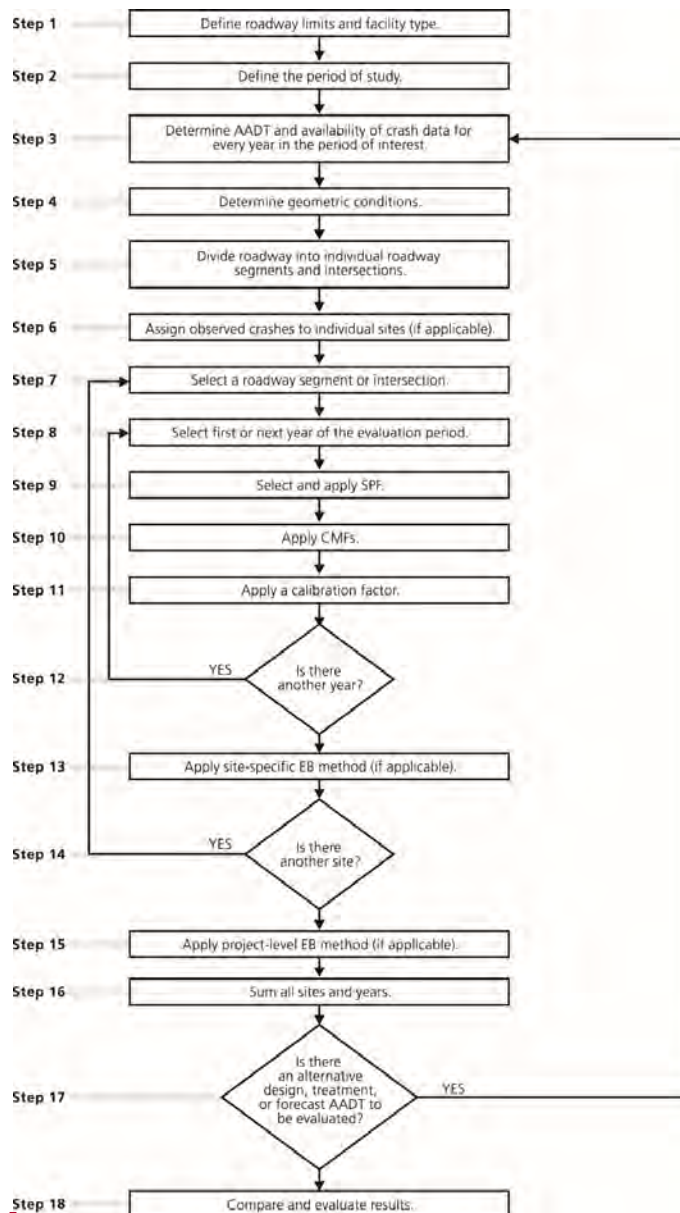
$N_{bisv}$  = predicted average number of single-vehicle collisions for base conditions.¶

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**Commented [ST8]:** Update after CMF issue is resolved and new chapter on calibration process is drafted

repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario, or proposed treatment option (within the same period to allow for comparison).

The following explains the details of each step of the method as applied to urban and suburban arterials.



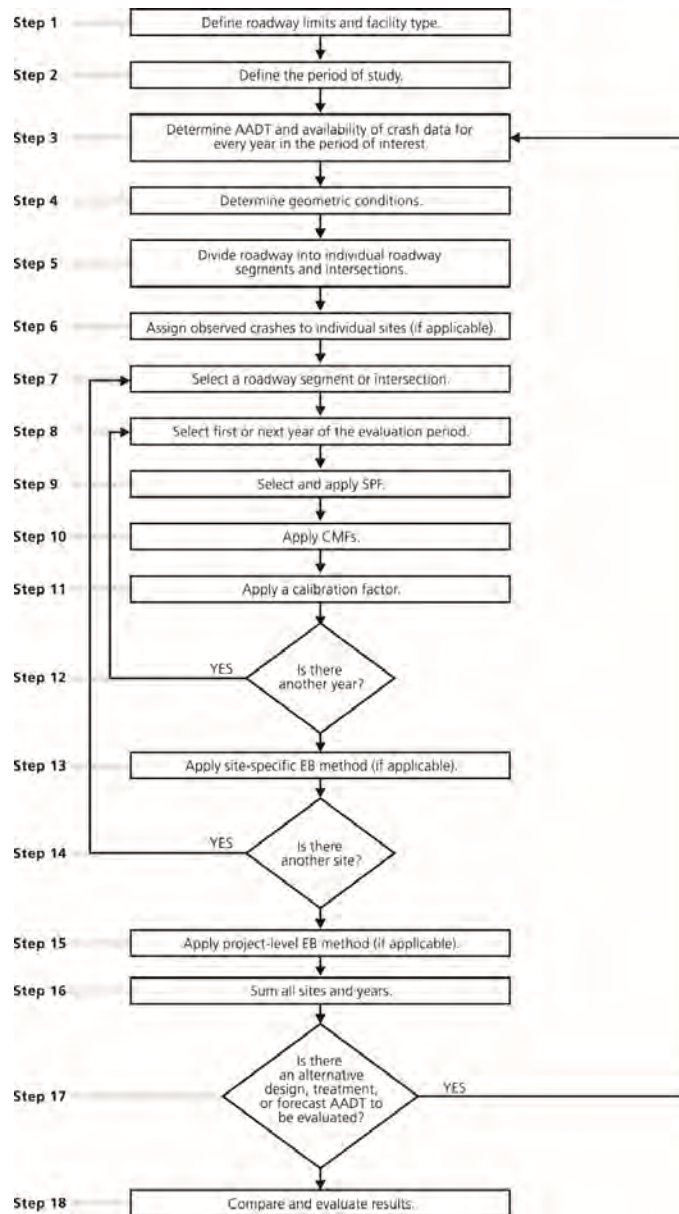


Figure 12-1. The HSM Predictive Method

**Step 1—Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated.**

The predictive method can be undertaken for a roadway network, a facility, or an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and

unsignalized intersections. The definitions of urban and suburban arterials, intersections, and roadway segments and the specific site types included in Chapter 12 are provided in Section 12.3.

The predictive method can be undertaken for an existing roadway, a design alternative for an existing roadway, or a new roadway (which may be either unconstructed or yet to experience enough traffic to have observed crash data).

The limits of the roadway of interest will depend on the nature of the study. The study may be limited to only one specific site or a group of contiguous sites. Alternatively, the predictive method can be applied to a very long corridor for the purposes of network screening which is discussed in Chapter 4.

#### **Step 2—Define the period of interest.**

The predictive method can be undertaken for either a past period or a future period. All periods are measured in years. Years of interest will be determined by the availability of observed or forecast average annual daily traffic (AADT) volumes, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

- A past period (based on observed AADTs) for:
  - An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features and traffic volumes are known.
  - An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).
- A future period (based on forecast AADTs) for:
  - An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
  - An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
  - A new roadway network, facility, or site that does not currently exist but is proposed for construction during some future period.

**Step 3—For the study period, determine the availability of annual average daily traffic volumes, pedestrian crossing volumes, and, for an existing roadway network, the availability of observed crash data (to determine whether the EB Method is applicable).**

#### ***Determining Traffic Volumes***

The SPFs used in Step 9 (and some CMFs in Step 10) include AADT volumes (vehicles per day) as a variable. For a past period the AADT may be determined by an automated recording or estimated by a sample survey. For a future period, the AADT may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models or based on the assumption that current traffic volumes will remain relatively constant.

For each roadway segment, the AADT is the average daily two-way 24-hour traffic volume on that roadway segment in each year of the period to be evaluated selected in Step 8.

For each intersection, two values are required in each predictive model. These are: the two-way AADT of the major street ( $AADT_{maj}$ ) and the two-way AADT of the minor street ( $AADT_{min}$ ).

$AADT_{maj}$  and  $AADT_{min}$  are determined as follows: if the AADTs on the two major-road legs of an intersection differ, the larger of the two AADT values is used for the intersection. If the AADTs on the two minor road legs of a four-leg intersection differ, the larger of the AADTs for the two minor road legs is used. For a three-leg intersection, the AADT of the single minor road leg is used. If AADTs are available for every roadway segment along a facility, the major-road AADTs for intersection legs can be determined without additional data.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated, as appropriate. If there is



not an established procedure for doing this, the following may be applied within the predictive method to estimate the AADTs for years for which data are not available.

- If AADT data are available for only a single year, that same value is assumed to apply to all years of the before period.
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation.
- The AADTs for years before the first year for which data are available are assumed to be equal to the AADT for that first year.
- The AADTs for years after the last year for which data are available are assumed to be equal to the last year.

If the EB Method is used (discussed below), AADT data are needed for each year of the period for which observed crash frequency data are available. If the EB Method will not be used, AADT data for the appropriate time period—past, present, or future—determined in Step 2 are used.

For signalized intersections, the pedestrian volumes crossing each intersection leg are determined for each year of the period to be evaluated. The pedestrian crossing volumes for each leg of the intersection are then summed to determine the total pedestrian crossing volume for the intersection. Where pedestrian volume counts are not available, they may be estimated using the guidance presented in Table 12-15. Where pedestrian volume counts are not available for each year, they may be interpolated or extrapolated in the same manner as explained above for AADT data.

#### ***Determining Availability of Observed Crash Data***

Where an existing site or alternative conditions for an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable observed crash data are available for the specific study roadway network, facility, or site. Observed data may be obtained directly from the jurisdiction's crash report system. At least two years of observed crash frequency data are desirable to apply the EB Method. The EB Method and criteria to determine whether the EB Method is applicable are presented in Part C, Appendix A.2.1.

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but cannot be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash frequency data are not available, then Steps 6, 13, and 15 of the predictive method are not conducted. In this case the estimate of expected average crash frequency is limited to using a predictive model (i.e., the predictive average crash frequency).

#### **Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the study network.**

In order to determine the relevant data needs and avoid unnecessary collection of data, it is necessary to understand the base conditions and CMFs in Step 9 and Step 10. The base conditions are defined in Section 12.6.1 for roadway segments and in Section 12.6.2 for intersections.

The following geometric design and traffic control features are used to determine whether the site specific conditions vary from the base conditions and, therefore, whether a CMF is applicable:

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Number of through lanes
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
- Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of street)



- Number of driveways for each driveway type (major commercial, minor commercial; major industrial/institutional; minor industrial/institutional; major residential; minor residential; other)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Presence/absence of roadway lighting
- Speed category (based on actual traffic speed or posted speed **limit**)
- Presence of automated speed enforcement

**Commented [CL9]:** 17-71 Contractor: I don't see where speed comes into any of the CMFs or base conditions

For all intersections within the study area, the following geometric and traffic control features are identified:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road stop or signal)
- Number of approaches with intersection left-turn lane (all approaches, 0, 1, 2, 3, or 4 for signalized intersection; only major approaches, 0, 1, or 2, for stop-controlled intersections)
- Number of approaches with left-turn signal phasing (0, 1, 2, 3, or 4) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, permissive/protected, or protected)
- Number of approaches with intersection right turn lane (all approaches, 0, 1, 2, 3, or 4 for signalized intersection; only major approaches, 0, 1, or 2, for stop-controlled intersections)
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Presence/absence of intersection lighting
- Maximum number of traffic lanes to be crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands (for signalized intersections only)
- Proportions of nighttime crashes for unlighted intersections (by total, fatal, injury, and property damage only)

For signalized intersections, land use and demographic data used in the estimation of vehicle-pedestrian collisions include:

- Number of bus stops within 1,000 feet of the intersection
- Presence of schools within 1,000 feet of the intersection
- Number of alcohol sales establishments within 1,000 feet of the intersection
- Presence of red light camera
- Number of approaches on which right-turn-on-red is allowed
- Pedestrian volumes

**Step 5—Divide the roadway network or facility into individual homogenous roadway segments and intersections which are referred to as sites.**

Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 12 predictive models are provided in Section 12.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will decrease data collection and management efforts.

**Step 6—Assign observed crashes to the individual sites (if applicable).**

Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, proceed to Step 7. In Step 3, the availability of observed data and whether the data

could be assigned to specific locations was determined. The specific criteria for assigning crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

Crashes that occur at an intersection or on an intersection leg, and are related to the presence of an intersection, are assigned to the intersection and used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections, and are not related to the presence of an intersection, are assigned to the roadway segment on which they occur. Such crashes are used in the EB Method together with the predicted average crash frequency for the roadway segment.

**Step 7—Select the first or next individual site in the study network. If there are no more sites to be evaluated, proceed to Step 15.**

In Step 5 the roadway network within the study limits has been divided into a number of individual homogenous sites (intersections and roadway segments).

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, which is the sum of all of the individual sites, for each year in the study. Note that this value will be the total number of crashes expected to occur over all sites during the period of interest. If a crash frequency is desired, the total can be divided by the number of years in the period of interest.

The estimation for each site (roadway segments or intersection) is conducted one at a time. Steps 8 through 14, described below, are repeated for each site.

**Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 14**

Steps 8 through 14 are repeated for each site in the study and for each year in the study period.

The individual years of the evaluation period may have to be analyzed one year at a time for any particular roadway segment or intersection because SPFs and some CMFs (e.g., lane and shoulder widths) are dependent on AADT, which may change from year to year.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

Steps 9 through 13, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 12 follow the general form shown in Equation 12-1. Each predictive model consists of a SPF, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site. The SPFs available for urban and suburban arterials are presented in Section 12.6.

The SPF (which is a regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the same base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 12.6. A detailed explanation and overview of the SPFs are provided in Section C.6.3.

The SPFs developed for Chapter 12 are summarized in Table 12-2. For the selected site, determine the appropriate SPF for the crash type(s) of interest, site type (intersection or roadway segment) and the geometric and traffic control features (undivided roadway, divided roadway, stop-controlled intersection, signalized intersection). The SPF for the selected site is calculated using the AADT determined in Step 3 ( $AADT_{maj}$  and  $AADT_{min}$  for intersections) for the selected year.

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.**

In order to account for differences between the base conditions (Section 12.6) and the specific conditions of the site, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple

**Commented [ST10]:** Update based on the new chapter on calibration process.

**Deleted:** Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type (presented in Section 12.6). These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.¶

CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

**Commented [CL11]:** 17-71 Contractor: This section can be updated using the 17-63 report.

All CMFs used in Chapter 12 have the same base conditions as the SPFs used in Chapter 12 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 12.7 may be used as part of the Chapter 12 predictive method. Table 12-18 indicates which CMFs are applicable to the SPFs in Section 12.6.

The CMFs for roadway segments are those described in Section 12.7.1. These CMFs are applied as shown in Equation 12-3.

The CMFs for intersections are those described in Section 12.7.2, which apply to both signalized and stop-controlled intersections, and in Section 12.7.3, which apply to signalized intersections only. These CMFs are applied as shown in Equations 12-6 and 12-28.

**Commented [CL12]:** 17-71 Contractor: Previous 3 paragraphs need updating depending on what is decided about CMFs in HSM

**Commented [ST13]:** CMF issue needs to be resolved and this section needs to be updated accordingly.

**Deleted:** In Chapter 12, the multiple- and single-vehicle base

In Chapter 12, if estimates of vehicle-bicycle or vehicle-pedestrian crashes are desired, the estimates of total crashes excluding vehicle-pedestrian and vehicle-bicycle crashes determined in Step 9 and the CMFs values calculated in Step 10 are then used to estimate the vehicle-pedestrian and vehicle-bicycle base crashes for roadway segments and intersections (present in Sections 12.6.1 and 12.6.2 respectively).

#### Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.

The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods. Calibration to local conditions will account for these differences. A calibration factor ( $C_r$  for roadway segments or  $C_i$  for intersections) is applied to each SPF in the predictive method. An overview of the use of calibration factors is provided in Section C.6.5. Detailed guidance for the development of calibration factors is included in Part C, Appendix A.1.1.

Steps 9, 10, and 11 together implement the predictive models in Equations 12-2 through 12-7 to determine predicted average crash frequency.

#### Step 12—If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 13.

This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

#### Step 13—Apply site-specific EB Method (if applicable).

Whether the site-specific EB Method is applicable is determined in Step 3. The site-specific EB Method combines the Chapter 12 predictive model estimate of predicted average crash frequency,  $N_{\text{predicted}}$  with the observed crash frequency of the specific site,  $N_{\text{observed}}$ . This provides a more statistically reliable estimate of the expected average crash frequency of the selected site.

In order to apply the site-specific EB Method, overdispersion parameter,  $k$ , for the SPF is also used. This is in addition to the material in Part C, Appendix A.2.4. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to  $N_{\text{predicted}}$  and  $N_{\text{observed}}$ . Overdispersion parameters are provided for each SPF in Section 12.6.

Apply the site-specific EB Method to a future time period, if appropriate.

The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period to a future time period. In doing this, consideration is given to significant changes in geometric or roadway characteristics caused by the treatments considered for future time period.

#### Step 14—If there is another site to be evaluated, return to 7, otherwise, proceed to Step 15.

This step creates a loop through Steps 7 to 13 that is repeated for each roadway segment or intersection within the facility.

**Step 15—Apply the project level EB Method (if the site-specific EB Method is not applicable).**

This step is only applicable to existing conditions when observed crash data are available, but cannot be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in Part C, Appendix A.2.5.

**Step 16—Sum all sites and years in the study to estimate total crash frequency.**

The total estimated number of crashes within the network or facility limits during a study period of  $n$  years is calculated using Equation 12-8:

$$N_{\text{total}} = \sum_{\text{all roadway segments}} N_{rs} + \sum_{\text{all intersections}} N_{int} \quad (12-7)$$

Where:

$N_{\text{total}}$  = total expected number of crashes within the limits of an urban or suburban arterial for the period of interest.  
Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits within the study period;

$N_{rs}$  = expected average crash frequency for a roadway segment using the predictive method for one specific year;  
and

$N_{int}$  = expected average crash frequency for an intersection using the predictive method for one specific year.

Equation 12-8 represents the total expected number of crashes estimated to occur during the study period. Equation 12-9 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total average}} = \frac{N_{\text{total}}}{n} \quad (12-8)$$

Where:

$N_{\text{total average}}$  = total expected average crash frequency estimated to occur within the defined network or facility limits during the study period; and

$n$  = number of years in the study period.

**Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.**

Steps 3 through 16 of the predictive method are repeated as appropriate for the same roadway limits but for alternative conditions, treatments, periods of interest, or forecast AADTs.

**Step 18—Evaluate and compare results.**

The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time, for given geometric design and traffic control features, and known or estimated AADT.

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**Commented [ST14]:** Update based on the new chapter on calibration process

**Deleted:** In addition to estimating total crashes, the estimate can be made for different crash severity types and different collision types. Default distributions of crash severity and collision type are provided with each SPF in Section 12.6. These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

## 12.5. ROADWAY SEGMENTS AND INTERSECTIONS

Section 12.4 provides an explanation of the predictive method. Sections 12.5 through 12.8 provide the specific detail necessary to apply the predictive method steps. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

In Step 5 of the predictive method, the roadway within the defined limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as “sites.” A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA *Interactive Highway Safety Design Model* (IHSDM) (4).

Roadway segments begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Figure 12-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 12 provides predictive models for stop-controlled (three- and four-leg) and signalized (three- and four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 12-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 12-2).

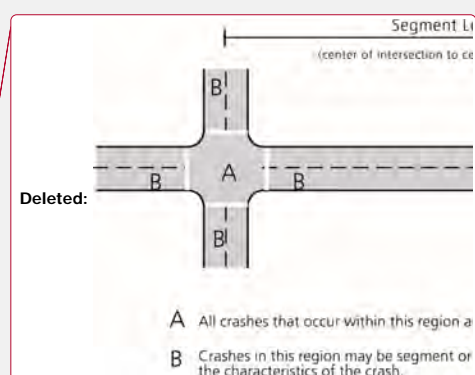
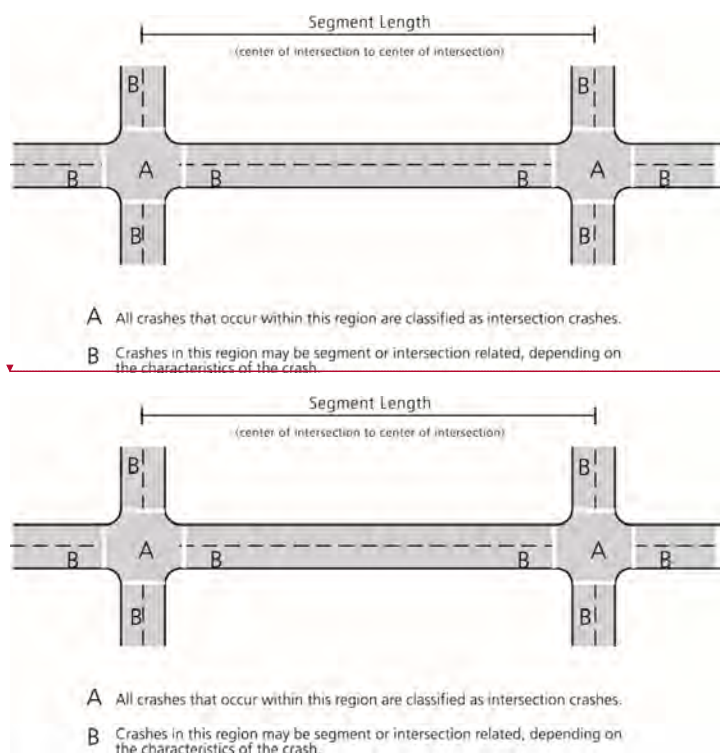


Figure 12-2. Definition of Roadway Segments and Intersections

The segmentation process produces a set of roadway segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes and key roadway design characteristics and traffic control features. Figure 12-2 shows the segment length,  $L$ , for a single homogenous roadway segment occurring between two intersections. However, several homogenous roadway segments can occur between two intersections. A new (unique) homogeneous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

- Annual average daily traffic volume (AADT) (vehicles/day)
- Number of through lanes
- Presence/type of median
- Presence of TWLTL

The following rounded widths for medians without barriers are recommended before determining “homogeneous” segments:

Measured Median Width	Rounded Median Width
1 ft to 14 ft	10 ft
15 ft to 24 ft	20 ft
25 ft to 34 ft	30 ft
35 ft to 44 ft	40 ft
45 ft to 54 ft	50 ft
55 ft to 64 ft	60 ft
65 ft to 74 ft	70 ft
75 ft to 84 ft	80 ft
85 ft to 94 ft	90 ft
95 ft or more	100 ft

- Presence/type of on-street parking
- Roadside fixed object density
- Presence of lighting
- Speed category (based on actual traffic speed or posted speed limit)
- Automated enforcement

In addition, each individual intersection is treated as a separate site for which the intersection-related crashes are estimated using the predictive method.

There is no minimum roadway segment length,  $L$ , for application of the predictive models for roadway segments. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results.

In order to apply the site-specific EB Method, observed crashes are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway-segment related. The methodology for assigning crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3.

**Commented [CL15]:** Removed since new models using non-fixed overdispersion

**Commented [BP16]:** I expect that this will be in the renamed Chapter 14 for which we are writing the Calibration content.

**Deleted:** . In applying the EB Method for urban and suburban arterials, whenever the predicted average crash frequency for a specific roadway segment during the multiyear study period is less than  $1/k$  (the inverse of the overdispersion parameter for the relevant SPF), consideration should be given to combining adjacent roadway segments and applying the project-level EB Method. This guideline for the minimum crash frequency for a roadway segment applies only to Chapter 12 which uses fixed-value overdispersion parameters. It is not needed in Chapters 10 or 11, which use length-dependent overdispersion parameters.

## 12.6. SAFETY PERFORMANCE FUNCTIONS

In Step 9 of the predictive method, the appropriate safety performance functions (SPFs) are used to predict crash frequencies for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimates the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for this HSM chapter, the dependent variable estimated is the predicted average crash frequency for a roadway segment or intersection under base conditions, and the independent variables are the AADTs of the roadway segment or intersection legs (and, for roadway segments, the length of the roadway segment).

The predicted crash frequencies for base conditions obtained with the SPFs are used in the predictive models in Equations 12-2 through 12-7. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3.

Each SPF prediction also has an associated overdispersion parameter,  $k$ . The overdispersion parameter provides an indication of the statistical reliability of the SPF prediction. The closer the overdispersion parameter is to zero, the more statistically reliable is the SPF prediction. This parameter is used in the EB Method discussed in Part C, Appendix A. The SPFs in Chapter 12 are summarized in Table 12-2. Note that SPFs are not provided for some combinations of crash type and severity level due to an insufficient number of observed crashes of that combination, failure of the estimated SPF to converge in the estimation process, estimated parameters failing modest significance tests, estimated parameters taking unrealistic values, or a combination of these reasons.

**Table 12-2.** Safety Performance Functions included in Chapter 12

Chapter 12 SPFs for Urban and Suburban Arterials	SPF Components by Collision Type	SPF Equations, Tables, and <u>Figures</u>
<u>Roadway segments</u>	<u>KABCO severity of any type</u>	
	<u>KABC severity of any type</u>	
	<u>KA severity of any type</u>	
	<u>multiple-vehicle nondriveway collisions (MVN)</u>	
	<u>rear-end collisions (RE)</u>	
	<u>sideswipe-same-direction collisions (SSD)</u>	
	<u>head-on+sideswipe-opposite-direction collisions (HO+SOD)</u>	
	<u>multiple-vehicle nondriveway collisions (MVNOther)</u>	
	<u>multiple-vehicle driveway-related collisions</u>	
	<u>single-vehicle crashes (SV)</u>	
	<u>night time collisions (NIGHT)</u>	
	<u>vehicle-pedestrian collisions</u>	
	<u>vehicle-bicycle collisions</u>	
<u>Intersections</u>	<u>2ST intersections (single vehicle, same direction, opposite direction, and intersecting direction crashes)</u>	
	<u>3SG intersections (single vehicle, same direction, opposite direction, and intersecting direction crashes)</u>	

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**Commented [BP17]:** Subtle edits because on non-fixed dispersion parameter. Same edits could be made as applicable to other chapters.

**Commented [BP18]:** Chap 14?

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~~4ST intersections (single vehicle, same direction, opposite direction, and intersecting direction crashes)~~

~~4SG intersections (single vehicle, same direction, opposite direction, and intersecting direction crashes)~~

~~vehicle-pedestrian crashes~~

~~vehicle-bicycle crashes~~

**Deleted:** collisions

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<sup>1</sup>Includes RE, SSD, HO+SOD and MVNOther

Following are the definitions of the crash types that were estimated for intersections in Chapter 12:

- **Same Direction (SD) Crashes**, including rear-end (RE), sideswipe same direction (SSD) and turning same direction (TSD);
- **Intersecting Direction (ID) Crashes**, including angle (ANG) and turning intersecting direction (TID);
- **Opposite Direction (OD) Crashes**, including head one (HO), sideswipe opposite direction (SOD) and turning opposite direction (TOD); and
- **Single Vehicle (SV) Crashes**, including rollover or overturn (RO), fixed object (FO) and moving object (MO).

Note that animal collisions are not included in any of the crash types (they are most likely to be identified as single-vehicle crashes).

Crashes are classified into five severity levels: fatal injury (K); incapacitating injury (A); non-incapacitating injury (B); possible injury (C); and no injury or property damage only (O). Cumulative crash count SPF are provided, building from the highest level, e.g., KA indicates K and A level crashes, KAB indicates K, A and B crashes, etc. KABCO crash count SPFs predict crashes at all severity levels for the respective crash type or total crashes.

Some highway agencies may have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience. These models may be substituted for models presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Part C, Appendix A.

**Commented [BP23]:** Production contractor: This may need re-thinking since we are suggesting that this only be considered where a recommended model does not calibrate well.

12.6.1. Safety Performance Functions for Urban and Suburban Arterial Roadway Segments

The predictive model for predicting average crash frequency on a particular urban or suburban arterial roadway segment was presented in Equation 12-2. ~~The SPFs were estimated using data from Ohio and Minnesota. In adopting these SPFs the intercept terms have taken on the value of the Ohio data, which dominated the estimation dataset. Additionally, the SPFs for multiple-vehicle non-driveway and multiple-vehicle non-driveway other had the driveway density value set to the average value from the calibration dataset where driveway density was included in the estimated SPF. SPFs that included fixed object density or median width had these variables set to 0 and 15 respectively, reflecting the values of the base conditions.~~ The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPF for urban and suburban arterial roadway segments is presented in this section. Urban and suburban arterial roadway segments are defined in Section 12.3.

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SPFs and adjustment factors are provided for five types of roadway segments on urban and suburban arterials:

- Two-lane undivided arterials (2U)



- Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
- Four-lane undivided arterials (4U)
- Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
- Five-lane arterials including a center TWLTL (5T)

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 12.4. The SPFs for roadway segments on urban and suburban arterials are applicable to the following AADT ranges:

- 2U: ~~1,000~~ to ~~23,032.00~~ vehicles per day
- 3T: ~~1,350~~ to ~~23,832.00~~ vehicles per day
- 4U: ~~1,150~~ to ~~41,440.00~~ vehicles per day
- 4D: ~~250~~ to ~~52,850~~ vehicles per day
- 5T: ~~5,350~~ to ~~50,550~~ vehicles per day

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Other types of roadway segments may be found on urban and suburban arterials but are not addressed by the predictive model in Chapter 12.

The predictive model for estimating average crash frequency on roadway segments is shown in Equations 12-2 through 12-4. The effect of traffic volume on predicted crash frequency is incorporated through the SPFs, while the effects of geometric design and traffic control features are incorporated through the CMFs. SPFs are provided for multiple ~~crash severities~~ and ~~collision types shown in Table 12-2.~~

### Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions is applied as follows:

#### SPFs For All Collision Types by Crash Severity

The SPFs for all collision types by crash severity are applied as follows:

$N_{\text{SPF}} = \exp(a + b \times \ln(AADT) + \ln(L) + c \times DWYDENS)$  (12-9) formula for calculating the overdispersion parameter, k, is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

Where:

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi);

$DWYDENS$  = total number of driveways divided by length of roadway segment; and

$a, b, c, \alpha, \beta$  = regression coefficients.

Table 12-3 presents the values of the coefficients  $a, b, c, \alpha, \beta$ .

$$N_{\text{SPF}} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

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multiple-vehicle nondriveway collisions¶  
single-vehicle crashes¶  
multiple-vehicle driveway-related collisions¶  
vehicle-pedestrian collisions¶  
vehicle-bicycle collisions¶

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The formula for calculating the overdispersion parameter,  $k$ , is applied as follows:

$$k = \exp(\alpha + \beta \ln(L)) \quad (12-10)$$

Where:

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a, b, \alpha, \beta$  = regression coefficients.

3 presents the values of the coefficients  $a, b, \alpha$  and  $\beta$  used in applying Equation 12-10.

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**Table 12-3.** SPF Coefficients for Multiple-Vehicle Nondriveway Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	-13.0201	1.4403	-0.6182	-0.5753
3T	-15.7769	1.7234	-0.2706	-0.2234
4U	-17.2781	1.8756	-0.0044	-0.3995
4D	-15.2678	1.5965	-0.4376	-0.4917
5T	-15.0471	1.6077	-0.6279	-0.8216

**Rear-End Collisions**

The SPF for rear-end collisions is applied as follows:

$$N_{re} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

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The formula for calculating the overdispersion parameter,  $k$ , is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

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Where:

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a$ ,  $b$ ,  $\alpha$ ,  $\beta$  = regression coefficients. Table 12-3 presents the values of the coefficients  $a$ ,  $b$ ,  $\alpha$  and  $\beta$  used in applying Equation 12-10.

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**Table 12-3.** SPF Coefficients for Rear-End Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	-17.1033	1.8433	-0.2692	-0.5029
3T	-20.0106	2.1326	0.1870	-0.2297
4U	-20.6059	2.1519	0.1871	-0.3413
4D	-22.6816	2.3241	0.0222	-0.5113
5T	-18.0784	1.9239	-0.1217	-0.5654

**Sideswipe-Same Direction Collisions**

The SPF for sideswipe-same-direction collisions is applied as follows:

$$N_{ss} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

The formula for calculating the overdispersion parameter,  $k$ , is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

Where:

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a, b, \alpha, \beta$  = regression coefficients. Table 12-3 presents the values of the coefficients  $a, b, \alpha$  and  $\beta$  used in applying Equation 12-10.

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Table 12-3. SPF Coefficients for Multiple-Vehicle Nondriveway Collisions on Roadway Segments¶

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**Table 12-3.** SPF Coefficients for Sideswipe-Same-Direction Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	-14.2955	1.2943	0.4303	-0.4248
3T	-15.2619	1.3985	-0.5623	-0.7902
4U	-21.0090	2.0999	0.0841	-0.5012
4D	-9.9348	0.9255	-0.3942	0.0000
5T	-13.9677	1.3932	-0.4866	-0.2846

**Head-On+Sideswipe-Opposite-Direction Collisions**

The SPF for head-on+sideswipe-opposite-direction collisions is applied as follows:

$$N_{\text{head-on}} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

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The formula for calculating the overdispersion parameter, k, is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

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Where:

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AADT = average annual daily traffic volume (vehicles/day) on roadway segment;

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L = length of roadway segment (mi); and

a, b, alpha, beta = regression coefficients.

Table 12-3 presents the values of the coefficients a, b, alpha and beta used in applying Equation 12-10.

**Table 12-3.** SPF Coefficients for Head-On+Sideswipe-Opposite-Direction Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	-8.1608	0.6884	-0.0349	-0.4037
3T	-18.7994	1.7503	-0.5740	0.0000
4U	-12.7426	1.1343	-0.4689	-0.4739
4D	-9.6625	0.7000	-0.2926	-0.5178
5T	-10.1844	0.8631	-0.4456	0.0000

**Multi-Vehicle Non-Driveway Other Collisions**

The SPF for multi-vehicle non-driveway other collisions is applied as follows:

$$N_{\text{multi-vehicle non-driveway other collisions}} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

The formula for calculating the overdispersion parameter,  $k$ , is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a, b, \alpha, \beta$  = regression coefficients.

Table 12-3 presents the values of the coefficients  $a, b, \alpha$  and  $\beta$  used in applying Equation 12-10.

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$$N_{\text{brmv}}(FI) = N_{\text{brmv}}(\text{total}) \left( \frac{N'_{\text{brmv}}(FI)}{N'_{\text{brmv}}(FI) + N'_{\text{brmv}}(PDO)} \right) \quad (12-11)$$

$$N_{\text{brmv}}(PDO) = N_{\text{brmv}}(\text{total}) - N_{\text{brmv}}(FI) \quad (12-12)$$

The proportions in Table 12-4 are used to separate  $N_{\text{brmv}}(FI)$  and  $N_{\text{brmv}}(PDO)$  into components by collision type.

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**Table 12-3.** SPF Coefficients for Multi-Vehicle Non-Driveway Other Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	-11.0325	1.0308	-0.2403	-1.0218
3T	-10.5545	0.9931	-1.1242	0.0000
4U	-14.0819	1.3778	0.4001	-0.5018
4D	-9.0136	0.8329	-0.7641	-0.4188
5T	-9.1928	0.9049	-1.0932	-1.0932

**Single-Vehicle Collisions**

The SPF for single-vehicle collisions is applied as follows:

$$N_{sv} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12-9)$$

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The formula for calculating the overdispersion parameter, k, is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

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$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a, b, \alpha, \beta$  = regression coefficients.

Table 12-3 presents the values of the coefficients  $a, b, \alpha$  and  $\beta$  used in applying Equation 12-10.

**Table 12-3**  
SPF Coefficients for Single-Vehicle Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10			
	Intercept (a)	AADT (b)	alpha	beta
2U	=	=	=	=
3T	-5.2930	0.4605	-0.1893	-0.2883
4U	-8.4610	0.7804	-0.1446	-0.2903
4D	-6.4009	0.6158	-0.7961	-0.4715
5T	-1.5005	0.1118	-0.2065	-0.5637

For 2U sites it is recommended to use the SPF for all collision types and apply the appropriate proportion of single-vehicle crashes.

### Night Time Collisions

The SPF for night time collisions is applied as follows:

$$N_{\text{crash/night}} = \exp(a + b \times \ln(AADT) + \ln(L) + c \times DWYDENS) \quad (12-9)$$

The formula for calculating the overdispersion parameter, k, is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

Where:

AADT = average annual daily traffic volume (vehicles/day) on roadway segment;

L = length of roadway segment (mi); and

a, b, c alpha, beta = regression coefficients.

Table 12-3 presents the values of the coefficients a, b, c, alpha and beta used in applying Equation 12-10.

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Deleted: 5 presents the values of the coefficients and factors used in Equation 12-13 for each roadway type. Equation 12-13 is first applied to determine  $N_{brsv}$  using the coefficients for total crashes in Table 12-5.  $N_{brsv}$  is then divided into components by severity level;  $N_{brsv(FI)}$  for fatal-and-injury crashes and  $N_{brsv(PDO)}$  for property-damage-only crashes. Preliminary values of  $N_{brsv(FI)}$  and  $N_{brsv(PDO)}$ , designated as  $N'_{brsv(FI)}$  and  $N'_{brsv(PDO)}$  in Equation 12-14, are determined with Equation 12-13 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-5. The following adjustments are then made to assure that  $N_{brsv(FI)}$  and  $N_{brsv(PDO)}$  sum to  $N_{brsv}$ :

$$N_{brsv(FI)} = N_{brsv(\text{total})} \left( \frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}} \right) \quad (12-14)$$

$$N_{brsv(PDO)} = N_{brsv(\text{total})} - N_{brsv(FI)} \quad (12-15)$$

The proportions in Table 12-6 are used to separate  $N_{brsv(FI)}$  and  $N_{brsv(PDO)}$  into components by crash type.

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**Table 12-5**

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**Table 12-3.** SPF Coefficients for Night Time Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10				
	Intercept (a)	AADT (b)	DWYDENS (c)	alpha	beta
2U	-4.0342	0.3012	-	-0.2936	-0.5305
3T	-12.4161	1.1744	-	-0.0771	-0.1357
4U	-16.2950	1.5836	-	0.0294	-0.3047
4D	-9.9085	0.9517	-0.0154	-0.6972	-0.3866
5T	-11.7765	1.1560	-	-0.8875	-0.7748

**Multiple-Vehicle Driveway-Related Collisions**

The SPF for multiple-vehicle driveway-related collisions is applied as follows:

$$N_{\text{brdwy}} = \exp(a + b \times \ln(AADT) + c \times \ln(L) + \alpha \times DWYDENS) \quad (12-9)$$

The formula for calculating the overdispersion parameter,  $k$ , is applied as follows:

$$k = \exp(\alpha + \beta \times \ln(L)) \quad (12-10)$$

Where:

$AADT$  = average annual daily traffic volume (vehicles/day) on roadway segment;

$L$  = length of roadway segment (mi); and

$a, b, c$  alpha, beta = regression coefficients.

Table 12-3 presents the values of the coefficients  $a, b, c$ , alpha and beta used in applying Equation 12-10.

Deleted: 6. Distribution of Single-Vehicle Crashes for

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Deleted: collisions addressed only collisions that are not related to driveways. Driveway-related collisions also generally involve multiple vehicles, but are addressed separately because the frequency of

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Deleted: depends on the number and type of driveways. Only unsignalized driveways are considered; signalized driveways are analyzed as signalized intersections.

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$$N_{\text{brdwy}} = \sum_{\text{all driveway types}} n_j \times N_j \times \left( \frac{AADT}{15,500} \right)^{(\alpha)} \quad (12-16)$$

Moved up [4]: Where:

Deleted:  $N_j$  = Number of driveway-related collisions per driveway per year for driveway type  $j$  from

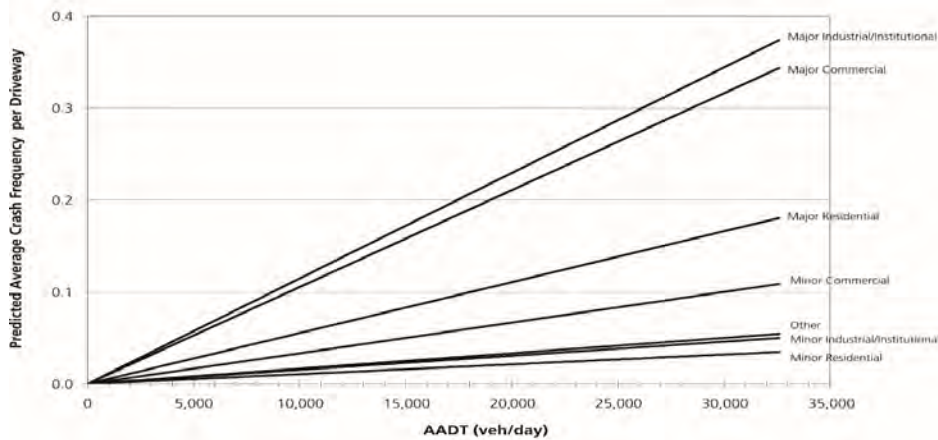
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 $n_j$  = number of driveways within roadway segment of driveway type  $j$  including all driveways on both sides of

Deleted: road;

Deleted:  $t$  = coefficient for traffic volume adjustment from

**Table 12-3.** SPF Coefficients for Multiple-Vehicle Driveway-Related Collisions on Roadway Segments

Road Type	Coefficients Used in Equation 12-10				
	Intercept (a)	AADT (b)	DWYDENS (c)	alpha	beta
2U	-13.0600	1.2126	0.0177	0.1486	-0.7353
3T	-11.4053	1.1270	-	0.5494	-0.1044
4U	-18.7080	1.7873	0.0183	0.3580	-0.5745
4D	-11.1849	0.9784	0.0562	0.3945	-0.7538
5T	-11.0178	1.0472	0.0186	-0.4074	-1.0384

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The number of driveways of a specific type,  $n_j$ , is the sum of the number of driveways of that type for both sides of the road combined. The number of driveways is determined separately for each side of the road and then added together.¶

Seven specific driveway types have been considered in modeling. These are:¶

Major commercial driveways¶

Minor commercial driveways¶

Major industrial/institutional driveways¶

Minor industrial/institutional driveways¶

Major residential driveways¶

Minor residential driveways¶

Other driveways¶

Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with less than 50 parking spaces. It is not intended that an exact count of the number of parking spaces be made for each site. Driveways can be readily classified as major or minor from a quick review of aerial photographs that show parking areas or through user judgment based on the character of the establishment served by the driveway. Commercial driveways provide access to establishments that serve retail customers. Residential driveways serve single- and multiple-family dwellings.

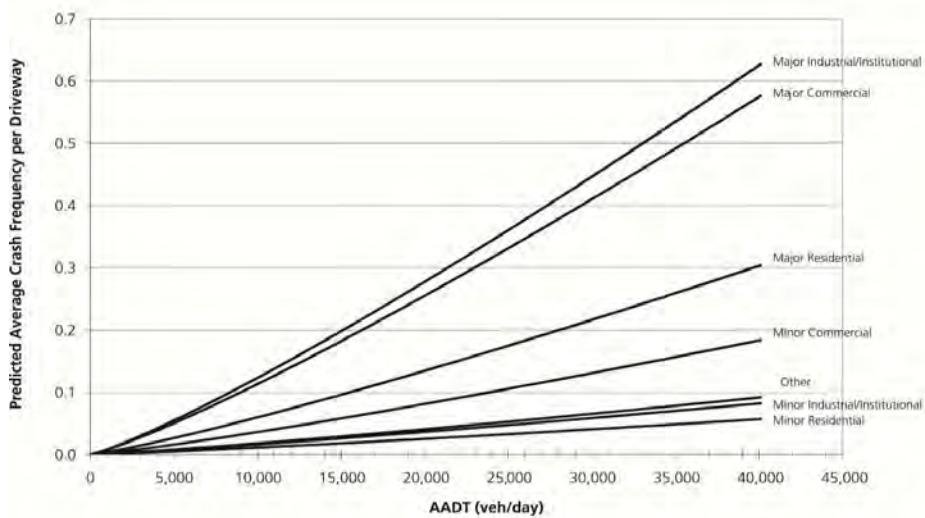
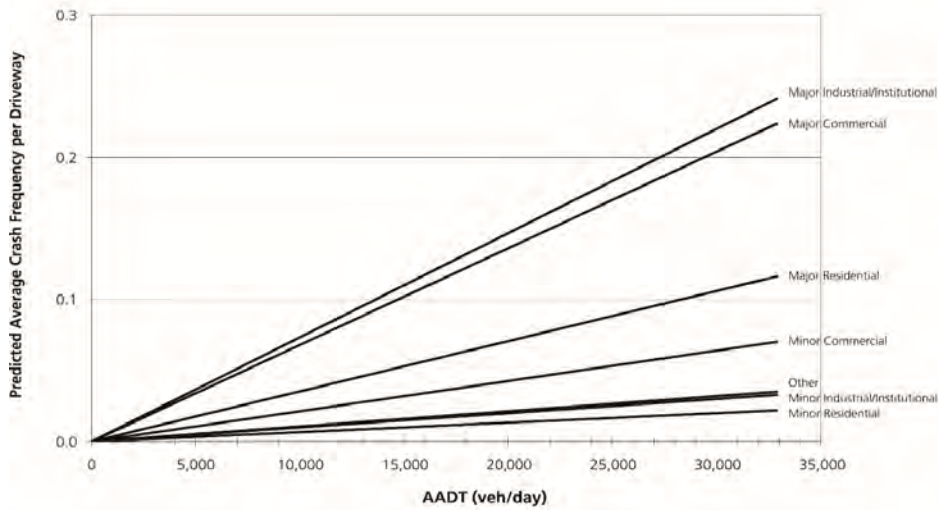
Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Commercial sites with no restriction on access along an entire property frontage are generally counted as two driveways.¶

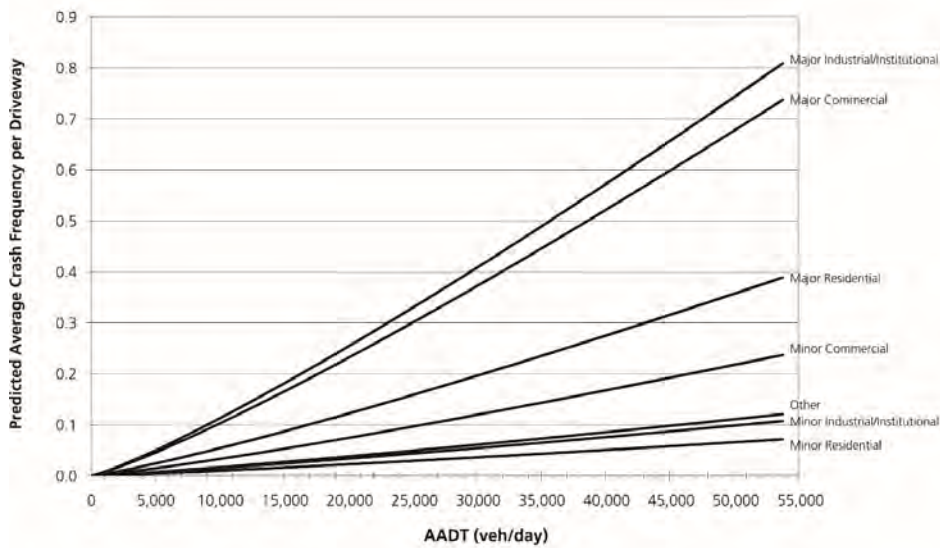
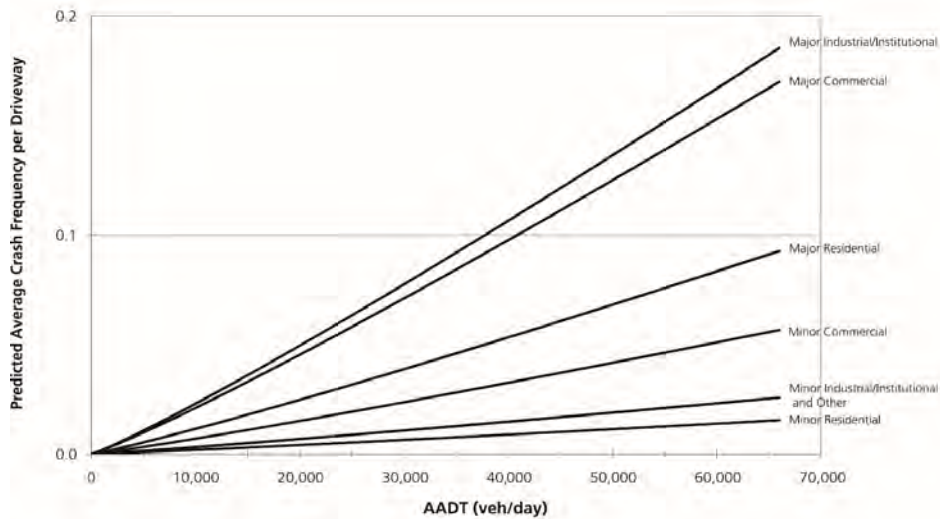
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**Table 12-7****Deleted:****Moved up [5]:** Where:¶**Deleted:** Driveway Type (j) ...

**Deleted:**  $f_{dwy}$  = proportion of driveway-related collisions that involve fatalities or injuries¶

The values of  $N_j$  and  $f_{dwy}$  are shown in Table 12-7.¶





#### Vehicle-Pedestrian Collisions

The number of vehicle-pedestrian collisions per year for a roadway segment is estimated as:

$$N_{ped} = N_{AVD} \times f_{ped}$$

(12-19)

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Where:

$f_{pedr}$  = pedestrian crash adjustment factor.

The value  $N_{KABCO}$  used in Equation 12-19 is that determined with Equation 12-3.

Table 12-8 presents the values of  $f_{pedr}$  for use in Equation 12-19. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of  $f_{pedr}$  are likely to depend on the climate and the walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-8 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

**Table 12-8.** Pedestrian Crash Adjustment Factor for Roadway Segments

Road Type	Pedestrian Crash Adjustment Factor ( $f_{pedr}$ )	
	Posted Speed 30 mph or Lower	Posted Speed Greater than 30 mph
2U	0.036	0.005
3T	0.041	0.013
4U	0.022	0.009
4D	0.067	0.019
5T	0.030	0.023

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.  
Source: HGIS data for Washington (2002–2006)

#### Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for a roadway segment is estimated as:

$$N_{\text{total}} = N_{KABCO} \times f_{\text{biker}} \quad (12-20)$$

Where:

$f_{biker}$  = bicycle crash adjustment factor.

The value of  $N_{KABCO}$  used in Equation 12-20 is determined with Equation 12-3.

Table 12-9 presents the values of  $f_{biker}$  for use in Equation 12-18. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of  $f_{biker}$  are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-9 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

**Table 12-9.** Bicycle Crash Adjustment Factors for Roadway Segments

Road type	Bicycle Crash Adjustment Factor ( $f_{biker}$ )	
	Posted Speed 30 mph or Lower	Posted Speed Greater than 30 mph
2U	0.018	0.004
3T	0.027	0.007
4U	0.011	0.002
4D	0.013	0.005

**Commented [CL26]:** Need to update these equation numbers as appropriate

**Deleted:**  $N_{br}$

**Deleted:**  $N_{biker} = N_{br} \times f_{biker}$

**Field Code Changed**

**Deleted:**  $N_{br}$

5T

0.050

0.012

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.  
Source: HSIS data for Washington (2002–2006)

### 12.6.2. Safety Performance Functions for Urban and Suburban Arterial Intersections

The predictive models for predicting the frequency of crashes related to an intersection ~~are~~ presented in Equations 12-5 through 12-7. The structure of the predictive models for intersections is similar to the predictive models for roadway segments.

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The effect of traffic volume on predicted crash frequency for intersections is incorporated through SPFs, while the effect of geometric and traffic control features are incorporated through CMFs. Each of the SPFs for intersections incorporates separate effects for the AADTs on the major- and minor-road legs, respectively. Data for the estimation of SPFs were provided by Ohio DOT and consisted of three years (2009 – 2011).

SPFs  ~~factors~~ have been developed for four types of intersections on urban and suburban arterials. These are:

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- Three-leg intersections with stop control on the minor-road approach (3ST)
- Three-leg signalized intersections (3SG)
- Four-leg intersections with stop control on the minor-road approaches (4ST)
- Four-leg signalized intersections (4SG)

Other types of intersections may be found on urban and suburban arterials but are not addressed by the Chapter 12 SPFs.

The SPFs for each of the four intersection types identified above predict total crash frequency per year for crashes that occur within the limits of the intersection and intersection-related crashes. The SPFs ~~address the following four~~ types of ~~crashes~~, (the corresponding equations, tables, and figures are indicated in Table 12-2):

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- Single-Vehicle (SV) crashes
- Same direction (SD) crashes
- Opposite direction (OD) crashes
- Intersecting direction (ID) crashes

Deleted: <#>multiple-vehicle collisions¶  
single-vehicleDeleted: <#>vehicle-pedestrian collisions¶  
vehicle-bicycle collisions¶

Guidance on the estimation of traffic volumes for the major and minor road legs for use in the SPFs is presented in Step 3. The AADT(s) used in the SPF are the AADT(s) for the selected year of the evaluation period. The SPFs for intersections are applicable to the following AADT ranges:

3ST Intersections	AADT <sub>maj</sub> : <del>250</del> to <del>38,640</del> vehicles per day and	AADT <sub>min</sub> : 0 to <del>18,640</del> vehicles per day
4ST Intersections	AADT <sub>maj</sub> : <del>450</del> to <del>37,301</del> vehicles per day and	AADT <sub>min</sub> : 0 to <del>13,773</del> vehicles per day
3SG Intersections	AADT <sub>maj</sub> : <del>3,050</del> to <del>32,109</del> vehicles per day and	AADT <sub>min</sub> : 0 to <del>18,415</del> vehicles per day
4SG Intersections	AADT <sub>maj</sub> : <del>1,800</del> to <del>34,960</del> vehicles per day and	AADT <sub>min</sub> : 0 to <del>27,228</del> vehicles per day

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Commented [ST27]: Leave the Pedestrian Models 'as is'

#### 4SG Intersections Pedestrian Models:

- AADT<sub>maj</sub>: 80,200 vehicles per day
- AADT<sub>min</sub>: 49,100 vehicles per day
- PedVol: 34,200 pedestrians per day crossing all four legs combined

Application to sites with AADTs substantially outside these ranges and sites with values of  $AADT_{maj}$  smaller than  $AADT_{min}$  may not provide reliable results. The prediction models for pedestrian crashes were estimated using data from Toronto, Canada, and Charlotte, North Carolina.

Tables 12-10 – 12-13 show the descriptive statistics of the data (based on 3 years of data for each site) used for estimating the SPFs.

For stop-controlled intersections (3ST and 4ST), the base conditions were defined as follows:

- No left-turn lanes
- No right-turn lanes
- No lighting
- No schools within 1000 feet
- No bus stops within 1000 feet
- No alcohol sales establishments within 1000 feet

For signalized intersections (3SG and 4SG), the base conditions were defined as follows:

- No left-turn lanes
- No right-turn lanes
- No right-turn on red prohibition (i.e., right-turn on red is allowed on all legs)
- No red light cameras
- Lighting is present

Table 12-10. Descriptive Statistics for Base Condition SPFs for 3ST Intersections

Variable	Descriptive Statistics for Base Condition SPFs (3ST: 2082 Intersections)
----------	--

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Deleted: Multiple-Vehicle Collisions¶  
SPFs for multiple-vehicle intersection-related collisions are applied as follows:¶

$$N_{bimv} = \exp \left( a + b \times \ln \left( AADT_{maj} \right) + c \times \ln \left( AADT_{min} \right) \right) \quad (12-21)¶$$

Commented [1J28]: This table has been changed extensively; individual changes are not marked to limit the tracking.

Moved up [7]: Where:¶

Deleted:  $AADT_{maj}$  = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);¶  
 $AADT_{min}$  = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined); and¶  
 $a, b, c$  = regression coefficients.¶

Table 12-10 presents the values of the coefficients  $a, b$ , and  $c$  used in applying Equation 12-21. The SPF overdispersion parameter,  $k$ , is also presented in Table 12-10.¶

Equation 12-21 is first applied to determine  $N_{bimv}$  using the coefficients for total crashes in Table 12-10.  $N_{bimv}$  is then divided into components by crash severity level,  $N_{bimv(FI)}$  for fatal-and-injury crashes and  $N_{bimv(PDO)}$  for property-damage-only crashes. Preliminary values of  $N_{bimv(FI)}$  and  $N_{bimv(PDO)}$ , designated as  $N'_{bimv(FI)}$  and  $N'_{bimv(PDO)}$  in Equation 12-22, are determined with Equation 12-21 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-10. The following adjustments are then made to assure that  $N_{bimv(FI)}$  and  $N_{bimv(PDO)}$  sum to  $N_{bimv}$ .¶

$$N_{bimv(FI)} = N_{bimv(total)} \times \left( \frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}} \right) \quad (12-22)¶$$

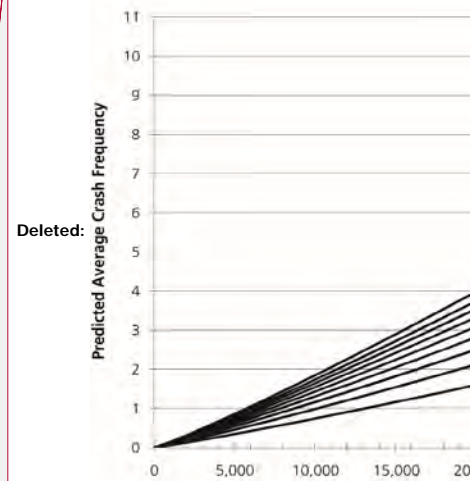
$$N_{bimv(PDO)} = N_{bimv(total)} - N_{bimv(FI)} \quad (12-23)¶$$

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The

Deleted: proportions in Table 12-11 are used to separate  $N_{bimv(FI)}$  and  $N_{bimv(PDO)}$  into components by manner of collision.¶

Table 12-10. SPF Coefficients for Multiple-Vehicle Collisions at Intersections¶

	Number of Crashes	Mean	Standard Deviation	Minimum	Maximum
$AADT_{maj}$		8187	5221	270	38460
$AADT_{min}$		2137	1400	33	18460
$AADT_{tot}$		10324	5810	540	56920
Ratio of $AADT_{min}$ to $AADT_{tot}$		0.23	0.12	0	0.50
Total (KA)	198	0.10	0.32	0	3
Total (KAB)	840	0.40	0.78	0	7
Total (KABC)	1422	0.68	1.15	0	11
Total (KABCO)	4756	2.28	3.47	0	49
SV (KA)	59	0.03	0.18	0	2
SV (KAB)	222	0.11	0.36	0	5
SV (KABC)	297	0.14	0.43	0	6
SV (KABCO)	952	0.46	0.87	0	13
SD (KA)	52	0.02	0.16	0	2
SD (KAB)	323	0.16	0.48	0	6
SD (KABC)	661	0.32	0.75	0	9
SD (KABCO)	2390	1.15	2.37	0	31
OD (KA)	43	0.02	0.14	0	1
OD (KAB)	128	0.06	0.25	0	2
OD (KABC)	184	0.09	0.3	0	3
OD(KABCO)	453	0.22	0.54	0	4
ID (KA)	43	0.02	0.16	0	3
ID (KAB)	163	0.08	0.33	0	4
ID (KABC)	272	0.08	0.33	0	4
ID (KABCO)	885	0.43	1.08	0	14



**Figure 12-10.** Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-21 and Table 12-10)\*

**Table 12-11.** Descriptive Statistics for Base Condition SPFs for 4ST Intersections

Variable	Descriptive Statistics for Base Condition SPFs (4ST: 551 Intersections)
----------	---

**Commented [1J29]:** This table is also substantially replaced.

**Moved down [9]:** Figure 12-11.

**Deleted:** Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on

**Moved down [10]:** Three-Leg Signalized Intersections (3SG)

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**Deleted:** (from Equation 12-21 and Table 12-10)\*



	Number of Crashes	Mean	Standard Deviation	Minimum	Maximum
$AADT_{maj}$		8251	6179	450	37301
$AADT_{min}$		2088	1459	50	13773
$AADT_{tot}$		10339	6658	810	40111
Ratio of $AADT_{min}$ to $AADT_{tot}$		0.23	0.13	0	0.50
Total (KA)	120	0.22	0.56	0	4
Total (KAB)	432	0.78	1.39	0	9
Total (KABC)	706	1.28	1.99	0	16
Total (KABCO)	1931	3.25	4.58	0	51
SV (KA)	20	0.04	0.20	0	2
SV (KAB)	61	0.11	0.37	0	2
SV (KABC)	72	0.13	0.39	0	2
SV (KABCO)	265	0.48	0.81	0	5
SD (KA)	15	0.03	0.18	0	2
SD (KAB)	84	0.15	0.46	0	4
SD (KABC)	219	0.4	1.05	0	14
SD (KABCO)	720	1.31	2.91	0	46
OD (KA)	21	0.04	0.20	0	2
OD (KAB)	60	0.11	0.38	0	3
OD (KABC)	83	0.15	0.44	0	3
OD (KABCO)	214	0.39	0.82	0	6
ID (KA)	64	0.12	0.41	0	4
ID (KAB)	225	0.41	0.99	0	7
ID (KABC)	328	0.6	1.31	0	9
ID (KABCO)	705	1.28	2.24	0	15

**Table 12-12.** Descriptive Statistics for Base Condition SPFs for 3SG Intersections

Variable Descriptive Statistics for Base Condition SPFs (3SG: 345 Intersections)

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**Commented [1J30]:** This table has also been extensively updated.

**Deleted:** Source: HSIS data

**Deleted:** California (2002–2006) Single-Vehicle Crashes

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**Deleted:** single-vehicle crashes are applied as follows:

$$N_{biv} = \exp \left( a + b \times \ln \left( AADT_{maj} \right) + c \times \ln \left( AADT_{min} \right) \right) \quad (12-24)$$

Table 12-12 presents the values of the coefficients and factors used in Equation 12-24 for each roadway type. Equation 12-24 is first applied to determine  $N_{biv}$  using the coefficients for total crashes in Table 12-12.  $N_{biv}$  is then divided into components by severity level,  $N_{biv(FI)}$  for fatal-and-injury crashes and  $N_{biv(PDO)}$  for property-damage-only crashes. Preliminary values of  $N_{biv(FI)}$  and  $N_{biv(PDO)}$ , designated as  $N'_{biv(FI)}$  and  $N'_{biv(PDO)}$  in Equation 12-25, are determined with Equation 12-24 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-12. The following adjustments are then made to assure that  $N_{biv(FI)}$  and  $N_{biv(PDO)}$  sum to  $N_{biv}$ :

$$N_{biv(FI)} = N_{biv(total)} \times \left( \frac{N'_{biv(FI)}}{N'_{biv(FI)} + N'_{biv(PDO)}} \right) \quad (12-25)$$

$$N_{biv(PDO)} = N_{biv(total)} - N_{biv(FI)} \quad (12-26)$$

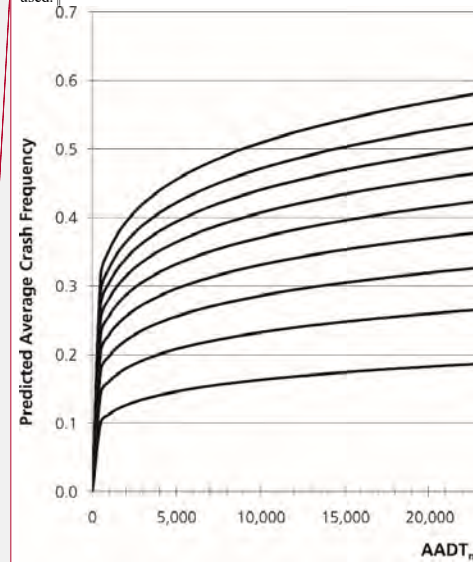
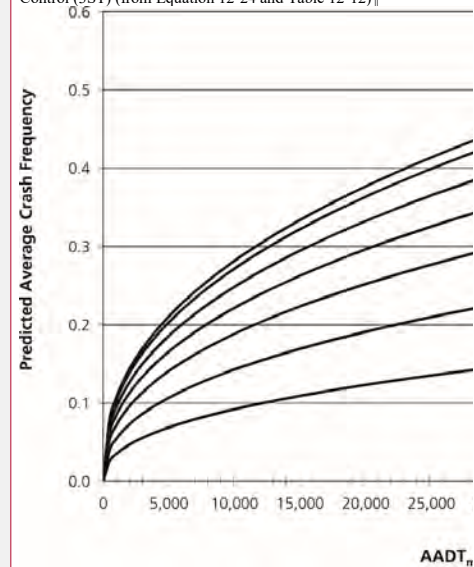
**Table 12-12.** SPF Coefficients for Single-Vehicle Crashes at

	Number of Crashes	Mean	Standard Deviation	Minimum	Maximum
$AADT_{maj}$		12363	4949	3050	32109
$AADT_{min}$		4077	3026	110	18415
$AADT_{tot}$		16440	5989	4440	44345
Ratio of $AADT_{min}$ to $AADT_{tot}$		0.25	0.13	0.02	0.50
Total (KA)	62	0.18	0.42	0	2
Total (KAB)	375	1.09	1.37	0	9
Total (KABC)	854	2.48	2.47	0	13
Total (KABCO)	4026	11.67	9.14	0	52
SV (KA)	13	0.04	0.19	0	1
SV (KAB)	47	0.14	0.38	0	3
SV (KABC)	67	0.19	0.47	0	4
SV (KABCO)	253	0.73	1.21	0	15
SD (KA)	22	0.06	0.24	0	1
SD (KAB)	158	0.46	0.75	0	4
SD (KABC)	424	1.23	1.38	0	6
SD (KABCO)	2302	6.67	5.80	0	39
OD (KA)	10	0.03	0.17	0	1
OD (KAB)	60	0.17	0.53	0	6
OD (KABC)	99	0.29	0.68	0	7
OD (KABCO)	369	1.07	1.47	0	11
ID (KA)	17	0.05	0.24	0	2
ID (KAB)	108	0.31	0.73	0	6
ID (KABC)	253	0.73	1.36	0	10
ID (KABCO)	974	2.82	3.52	0	24

**Table 12-13.** Descriptive Statistics for Base Condition SPFs for 4SG Intersections

Variable	Descriptive Statistics for Base Condition SPFs (4SG: 589 Intersections)
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**Deleted:** Note: Where no models are available, Equation 12-27 is used.<sup>¶</sup>

**Figure 12-14.** Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-24 and Table 12-12)<sup>¶</sup>**Figure 12-15.** Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Three-Leg Signalized Intersections (3SG) (from Equation 12-24 and Table 12-12)<sup>¶</sup>

**Commented [IJ31]:** This table has been extensively updated; individual changes are omitted.

	Number of Crashes	Mean	Standard Deviation	Minimum	Maximum
$AADT_{maj}$		11067	5650	1810	34960
$AADT_{min}$		3803	3167	72	27228
$AADT_{tot}$		14870	7344	2061	56488
Ratio of $AADT_{min}$ to $AADT_{tot}$		0.25	0.13	0.01	0.50
Total (KA)	148	0.25	0.56	0	4
Total (KAB)	767	1.30	1.79	0	14
Total (KABC)	1798	3.05	3.67	0	35
Total (KABCO)	7253	12.31	12.70	0	109
SV (KA)	16	0.03	0.16	0	1
SV (KAB)	73	0.12	0.37	0	3
SV (KABC)	112	0.19	0.48	0	3
SV (KABCO)	409	0.69	1.05	0	9
SD (KA)	53	0.09	0.33	0	3
SD (KAB)	283	0.48	0.92	0	8
SD (KABC)	868	1.47	2.15	0	18
SD (KABCO)	3964	6.73	8.32	0	76
OD (KA)	27	0.05	0.23	0	2
OD (KAB)	167	0.28	0.74	0	6
OD (KABC)	309	0.52	1.14	0	10
OD (KABCO)	1021	1.73	2.81	0	25
ID (KA)	51	0.09	0.29	0	2
ID (KAB)	239	0.41	0.83	0	8
ID (KABC)	483	0.82	1.34	0	8
ID (KABCO)	1671	2.84	3.36	0	26

The intersection SPFs takes one of the two forms: **Model A** and **Model B**. Equations 12-21 and 12-22 show the different variables that were considered in each functional form as a starting point.

#### Model A:

$$N = e^a \times e^{b \times \left(\frac{AADT_{maj}}{10000}\right)} \times (AADT_{maj})^c \times e^{d \times \left(\frac{AADT_{min}}{10000}\right)} \times (AADT_{min})^e \quad (12-21)$$

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**Commented [ST32]:** The final model form and the variables to use were decided based on backward elimination.

**Commented [ST33]:** Depending on the final model variables used for each crash type and severity, some models may predict non-zero crashes for zero total or major road AADT.

**Deleted:** Source: HSIS data for California (2002–2006)¶ Since there are no models for fatal-and-injury crashes at three- and four-leg stop-controlled intersections in Table 12-12, Equation 12-25 is replaced with the following equation in these cases:¶

$$N_{bisy(FI)} = N_{bisy(total)} \times f_{bisy} \quad (12-27)¶$$

**Commented [ST34]:** Changed the presentation of the model form.

Where:

$N$  = predicted average crash frequency of an intersection (excluding vehicle-pedestrian, vehicle-bicycle, and vehicle-animal crashes);

$AADT_{maj}$  = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$  = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined);

$a, b, c, d, e$  = regression coefficients.

#### Model B:

$$N = e^a \times e^{b \times \left(\frac{AADT_{tot}}{10000}\right)} \times (AADT_{tot})^c \times e^{d \times \left(\frac{AADT_{min}}{AADT_{tot}}\right)} \times \left(\frac{AADT_{min}}{AADT_{tot}}\right)^e \quad (12-22)$$

Where:

$AADT_{tot}$  = sum of the average daily traffic volumes (vehicles/day) for major and minor roads (both directions of travel combined).

For both model forms A and B, the SPF estimation started with all the variables presented above and through backward elimination, variables that were not statistically significant were removed.

In both model forms, A and B,  $N$  can be identified by the crash type (of interest) as  $N_{bisy}$ ,  $N_{bisd}$ ,  $N_{biqd}$  and  $N_{biid}$ .

For the crash type - severity combinations for which SPF's could not be estimated, it is recommended to use the prediction for the next closest SPF and multiplying the prediction by the proportion of that crash type - severity combination. For example, if a prediction model for KA crashes are not available, but a prediction model for KAB crashes are available, then the prediction for KA crashes could be obtained by the following equation:

$$\text{Predicted KA crashes} = \text{Predicted KAB crashes} \times \left(\frac{\text{Number of KA crashes in the data set}}{\text{Number of KAB crashes in the data set}}\right) \quad (12-23)$$

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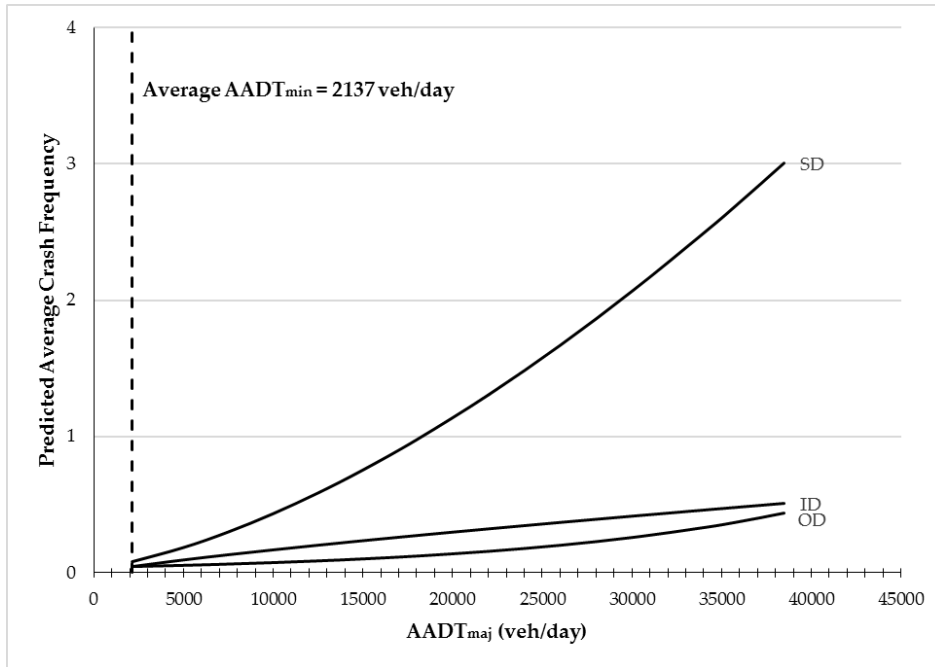
#### Three-Leg Intersections with Minor Road Stop Control (3ST)

Table 12-14 identifies the model form used for each SPF and presents the values of the coefficients  $a, b, c, d$  and  $e$  used in applying Equations 12-21 and 12-22 for each crash type at three-leg intersections with minor road stop control (3ST). The SPF overdispersion parameter,  $k$ , is also presented in Table 12-14.

Figure 12-10 presents a graphical form of the KABCO severity SPFs presented in Table 12-14. The plot shows predictions for the four crash types, i.e.  $N_{b1sv}$ ,  $N_{b1sd}$ ,  $N_{b1od}$  and  $N_{b1id}$ , for increasing values of  $AADT_{maj}$  and average value of  $AADT_{min}$ .

**Table 12-14.** SPF Coefficients for Crashes at Three-Leg Intersections with Minor-Road Stop Control (3ST)

Coefficients for 3ST Models							Overdispersion Parameter
Severity	Model Form	a	b	c	d	e	(k)
Total Crashes							
KABCO	A	-3.1275	0.6210	0.2319	0.7280		0.8087
KABC	B	-2.3919	0.7690				0.7615
KAB	B	-2.7900	0.6705				0.8031
KA	B	-4.0506	0.5272				0.8594
Single Vehicle (SV) Crashes -- $N_{b1sv}$							
Could not obtain useful models							
Same Direction (SD) Crashes -- $N_{b1sd}$							
KABCO	B	-14.8383		1.4636		-0.1385	1.1428
KABC	B	-14.2585		1.3176	-1.1784		0.9478
KAB	B	-14.1222		1.2298	-1.2920		1.3071
KA	B	-11.5340		0.7330			1.7962
Opposite Direction (OD) Crashes -- $N_{b1od}$							
KABCO	B	-3.3353	0.6177				1.1523
KABC	B	-4.1549	0.5514				0.2950
KAB	B	-4.4870	0.5270				0.6168
Intersecting Direction (ID) Crashes -- $N_{b1id}$							
KABCO	A	-11.1651		0.8094		0.2535	2.2740
KABC	A	-12.7177		0.8967		0.1974	3.3635
KAB	A	-14.4692		0.9112		0.3412	3.0787



**Figure 12-10.** Graphical Form of the Intersection SPFs for Crashes on Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equations 12-21 and 12-22 and Table 12-14)

**Three-Leg Signalized Intersections (3SG)**

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Table 12-15 identifies the model form used for each SPF and presents the values of the coefficients  $a$ ,  $b$ ,  $c$ ,  $d$  and  $e$  used in applying Equations 12-21 and 12-22 for each crash type at three-leg signalized intersections (3SG). The SPF overdispersion parameter,  $k$ , is also presented in Table 12-15.

Figure 12-11 presents a graphical form of the KABCO severity SPFs presented in Table 12-15. The plot shows predictions for the four crash types, i.e.  $N_{bisv}$ ,  $N_{bisd}$ ,  $N_{btod}$  and  $N_{btid}$ , for increasing values of  $AADT_{maj}$  and average value of  $AADT_{in}$ .

**Table 12-15.** SPF Coefficients for Crashes at Three-Leg Signalized Intersections (3SG)

Coefficients for 3SG Models						Overdispersion Parameter	
Severity	Model Form	a	b	c	d	e	(k)
Total Crashes							
KABCO	B	-4.5704		0.6366		0.1519	0.4669
KABC	A	-6.7956		0.4799		0.2585	0.5344
KAB	A	-8.0554		0.5062		0.2814	0.5745
Single Vehicle (SV) Crashes -- $N_{bisv}$							
KABCO	A	-2.3447	0.3894		0.9168		0.4113
Same Direction (SD) Crashes -- $N_{bisd}$							
KABCO	A	-6.2255		0.5414		0.2390	0.4615
KABC	A	-9.1985		0.6682		0.2495	0.3761
KAB	A	-9.3282		0.5844		0.2413	0.4521
Opposite Direction (OD) Crashes -- $N_{btod}$							
KABCO	B	-10.0017		0.9248			0.7486
KABC	A	-17.9744		1.3504		0.3523	1.1826
KAB	A	-21.2395		1.4846		0.5304	1.4144
Intersecting Direction (ID) Crashes -- $N_{btid}$							
KABCO	B	-2.3636		0.2385			1.0859

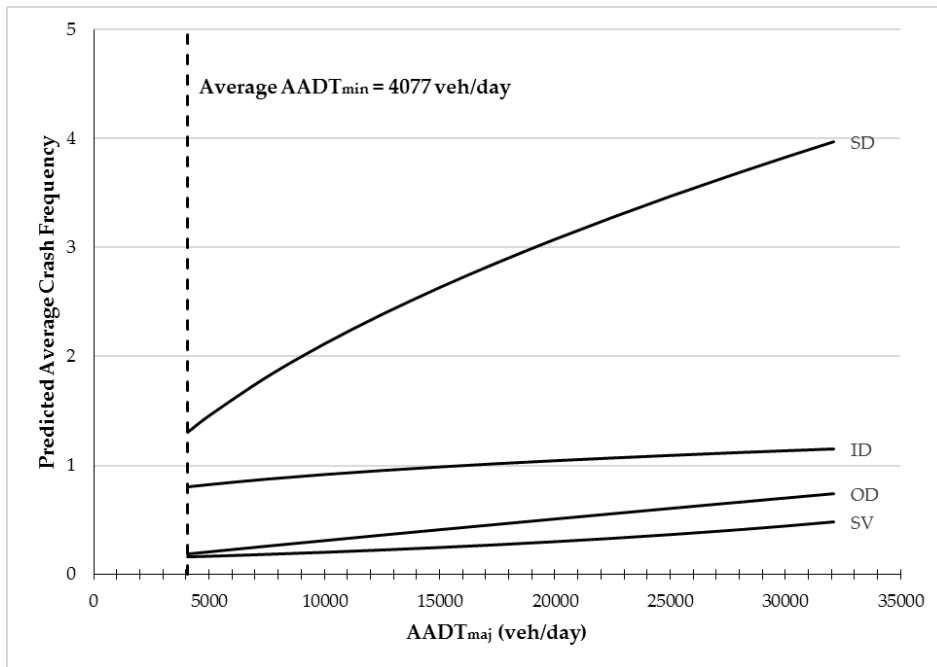


Figure 12-11. Graphical Form of the Intersection SPFs for Crashes on Three-Leg Signalized Intersections (3SG) (from Equations 12-21 and 12-22 and Table 12-15)

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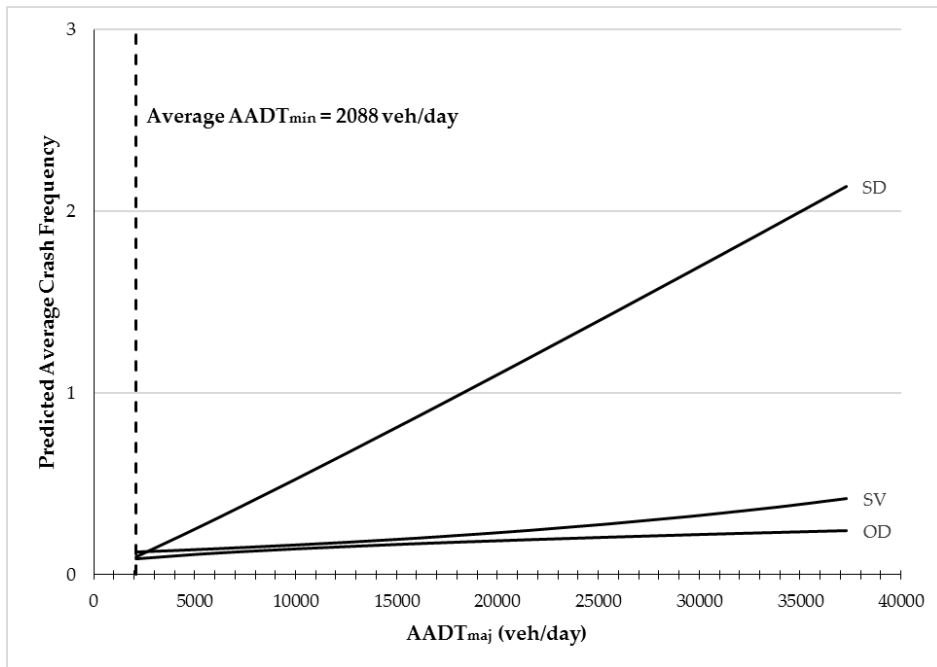
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Table 12-16 identifies the model form used for each SPF and presents the values of the coefficients  $a, b, c, d$  and  $e$  used in applying Equations 12-21 and 12-22 for each crash type at four-leg intersections with minor road stop control (4ST). The SPF overdispersion parameter,  $k$ , is also presented in Table 12-16.

**Table 12-16. SPF Coefficients for Crashes at Four-Leg Intersections with Minor-Road Stop Control (4ST)**

		<u>Coefficients for 4ST Models</u>					<u>Overdispersion</u>
<u>Severity</u>	<u>Model Form</u>	<u>a</u>	<u>b</u>	<u>c</u>	<u>d</u>	<u>e</u>	<u>Parameter</u>
							<u>(k)</u>
<u>Total Crashes</u>							
<u>KABCO</u>	<u>A</u>	<u>-3.6743</u>		<u>0.4071</u>	<u>0.9208</u>		<u>1.0155</u>
<u>KABC</u>	<u>B</u>	<u>-3.9675</u>		<u>0.3417</u>			<u>1.6020</u>
<u>Single Vehicle (SV) Crashes -- <math>N_{bisv}</math></u>							
<u>KABCO</u>	<u>B</u>	<u>-2.2170</u>	<u>0.3435</u>				<u>0.5835</u>
<u>KABC</u>	<u>B</u>	<u>-13.8618</u>	<u>-1.0741</u>	<u>1.3021</u>			<u>1.5358</u>
<u>Same Direction (SD) Crashes -- <math>N_{bisd}</math></u>							
<u>KABCO</u>	<u>A</u>	<u>-12.4690</u>		<u>1.0633</u>		<u>0.2661</u>	<u>1.1504</u>
<u>KABC</u>	<u>A</u>	<u>-5.9134</u>	<u>0.8168</u>			<u>0.4033</u>	<u>1.8464</u>
<u>KAB</u>	<u>A</u>	<u>-5.8261</u>	<u>0.3579</u>			<u>0.3360</u>	<u>1.8506</u>
<u>Opposite Direction (OD) Crashes -- <math>N_{bid}</math></u>							
<u>KABCO</u>	<u>B</u>	<u>-6.0829</u>		<u>0.4417</u>			<u>1.4996</u>
<u>KABC</u>	<u>B</u>	<u>-5.5548</u>		<u>0.2814</u>			<u>2.3460</u>
<u>Intersecting Direction (ID) Crashes -- <math>N_{bid}</math></u>							
Could not obtain useful models							



**Figure 12-12.** Graphical Form of the Intersection SPFs for Crashes on Four-Leg Intersections with Minor-Road Stop Control (4ST) (from Equations 12-21 and 12-22 and Table 12-16)

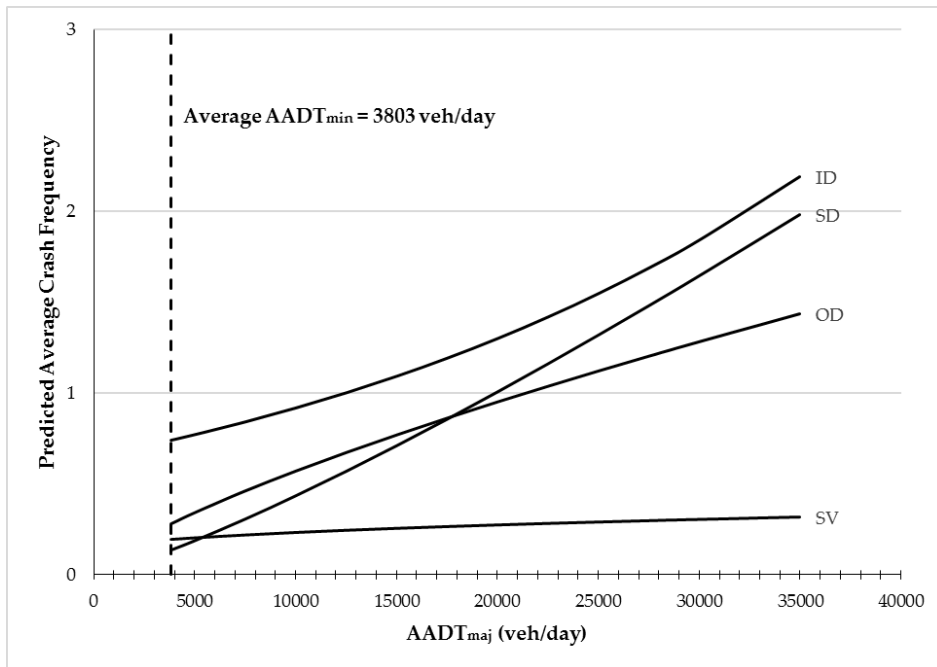
#### Four-Leg Signalized Intersections (4SG)

Table 12-17 identifies the model form used for each SPF and presents the values of the coefficients  $a$ ,  $b$ ,  $c$ ,  $d$  and  $e$  used in applying Equations 12-21 and 12-22 for each crash type at four-leg signalized intersections (4SG). The SPF overdispersion parameter,  $k$ , is also presented in Table 12-17.

Figure 12-13 presents a graphical form of the KABCO severity SPFs presented in Table 12-17. The plot shows predictions for the four crash types, i.e.  $N_{bisv}$ ,  $N_{bisd}$ ,  $N_{btod}$  and  $N_{btid}$  for increasing values of  $AADT_{maj}$  and average value of  $AADT_{min}$ .

**Table 12-17.** SPF Coefficients for Crashes at Four-Leg Signalized Intersections (4SG)

		Coefficients for 4SG Models					Overdispersion Parameter
Severity	Model Form	a	b	c	d	e	(k)
Total Crashes							
KABCO	B	-7.4359		0.9218			0.5514
KABC	B	-10.5443		1.0989			0.6386
KAB	B	-9.9857		0.9535			0.7440
KA	B	-9.6739		0.7511			0.6997
Single Vehicle (SV) Crashes -- $N_{bisv}$							
KABCO	B	-4.3216		0.3000			0.7818
KABC	B	-7.7339		0.5209			0.9105
KAB	B	-8.9332		0.6011			0.8532
Same Direction (SD) Crashes -- $N_{bisd}$							
KABCO	A	-8.2447		0.9424	0.6264		0.5800
KABC	A	-14.2230		1.2127		0.2693	0.6257
KAB	A	-15.2404		1.2210		0.2476	0.8485
KA	A	-14.3865		0.7926		0.4313	1.7976
Opposite Direction (OD) Crashes -- $N_{btod}$							
KABCO	A	-9.7053		0.7364		0.2867	1.1587
KABC	B	-13.5030		1.2228			1.8372
KAB	B	-12.7760		1.0838			2.2166
Intersecting Direction (ID) Crashes -- $N_{btid}$							
KABCO	A	-1.5214	0.3492			0.1316	0.8944
KABC	A	-5.6212		0.2977		0.1958	1.2440
KAB	A	-6.1898		0.4390			1.4297



**Figure 12-13.** Graphical Form of the Intersection SPFs for Crashes on Four-Leg Signalized Intersections (4SG) (from Equations 12-21 and 12-22 and Table 12-17)

**Commented [ST36]:** Deleted a bunch of graphs from here as they were from the first edition and do not correspond with the new models.

### Vehicle-Pedestrian Crashes

Separate SPFs are provided for estimation of the number of vehicle-pedestrian **crashes** at signalized and **stop controlled** intersections.

#### Signalized Intersections

The number of vehicle-pedestrian **crashes** per year at a signalized intersection is estimated with a SPF and a set of CMFs that apply specifically to vehicle-pedestrian **crashes**. The model for estimating vehicle-pedestrian **crashes** at signalized intersections is:

$$N_{pedi} = N_{pedbase} \times CMF_{lp} \times CMF_{2p} \times CMF_{3p} \quad (12-24)$$

Where:

$N_{pedbase}$  = predicted number of vehicle-pedestrian **crashes** per year for base conditions at signalized intersections; and

$CMF_{lp} \dots CMF_{3p}$  = crash modification factors for vehicle-pedestrian **crashes** at signalized intersections.

The SPF for vehicle-pedestrian **crashes** at signalized intersections is:

$$N_{pedbase} = \exp \left( a + b \times \ln(AADT_{total}) + c \times \ln \left( \frac{AADT_{min}}{AADT_{maj}} \right) + d \times \ln(PedVol) + e \times n_{lanesx} \right) \quad (12-25)$$

Where:

$AADT_{total}$  = sum of the average daily traffic volumes (vehicles per day) for the major and minor roads  
(=  $AADT_{maj} + AADT_{min}$ );

$PedVol$  = sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs;

$n_{lanesx}$  = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands; and

$a, b, c, d, e$  = regression coefficients.

Determination of values for  $AADT_{maj}$  and  $AADT_{min}$  is addressed in the discussion of Step 3. Only pedestrian crossing maneuvers immediately adjacent to the intersection (e.g., at a marked crosswalk or along the extended path of any sidewalk present) are considered in determining the pedestrian volumes. Table 12-18 presents the values of the coefficients  $a, b, c, d$ , and  $e$  used in applying Equation 12-25.

The coefficient values in Table 12-18 are intended for estimating total vehicle-pedestrian collisions. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes.

The application of Equation 12-25 requires data on the total pedestrian volumes crossing the intersection legs. Reliable estimates will be obtained when the value of  $PedVol$  in Equation 12-25 is based on actual pedestrian volume counts. Where pedestrian volume counts are not available, they may be estimated using Table 12-19. Replacing the values in Table 12-19 with locally derived values is encouraged.

The value of  $n_{lanesx}$  in Equation 12-25 represents the maximum number of traffic lanes that a pedestrian must cross in any crossing maneuver at the intersection. Both through and turning lanes that are crossed by a pedestrian along the crossing path are considered. If the crossing path is broken by an island that provides a suitable refuge for the pedestrian so that the crossing may be accomplished in two (or more) stages, then the number of lanes crossed in each stage is considered separately. To be considered as a suitable refuge, an island must be raised or depressed; a flush or painted island is not treated as a refuge for purposes of determining the value of  $n_{lanesx}$ .

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**Commented [SR37]:** The NCHRP 17-62 project team did not estimate predicted models for vehicle-pedestrian crashes. So, one option is to just keep this. The other option is to include prediction models from more recent studies on this topic.

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**Table 12-18.** SPFs for Vehicle-Pedestrian Crashes at Signalized Intersections

Intersection Type	Coefficients used in Equation 12-29					Overdispersion Parameter
	Intercept	AADT <sub>total</sub>	AADT <sub>min</sub> /AADT <sub>maj</sub>	PedVol	$n_{lanes}$	
	(a)	(b)	(c)	(d)	(e)	(k)
Total crashes						
3SG	-6.60	0.05	0.24	0.41	0.09	0.52
4SG	-9.53	0.40	0.26	0.45	0.04	0.24

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**Table 12-19.** Estimates of Pedestrian Crossing Volumes Based on General Level of Pedestrian Activity

General Level of Pedestrian Activity	Estimate of PedVol (pedestrians/day) for Use in Equation 12-29	
	3SG Intersections	4SG Intersections
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

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**Stop-Controlled Intersections**

The number of vehicle-pedestrian crashes per year for a stop-controlled intersection is estimated as:

$$N_{pedi} = N_{bi} \times f_{pedi}$$

(12-26)

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Where:

$f_{pedi}$  = pedestrian crash adjustment factor.

The value of  $N_{bi}$  used in Equation 12-26 is that determined with Equation 12-6.

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Table 12-20 presents the values of  $f_{pedi}$  for use in Equation 12-26. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of  $f_{pedi}$  are likely to depend on the climate and walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-20 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

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**Commented [ST38]:** Update with the correct Chapter reference for the calibration procedure.

**Table 12-20.** Pedestrian Crash Adjustment Factors for Stop-Controlled Intersections

Intersection Type	Pedestrian Crash Adjustment Factor ( $f_{pedi}$ )
3ST	0.021
4ST	0.022

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Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.  
Source: HSIS data for California (2002–2006)

**Vehicle-Bicycle Crashes**

The number of vehicle-bicycle crashes per year for an intersection is estimated as:

$$N_{bikel} = N_{bi} \times f_{bikel}$$

(12-27)

Where:

$f_{bikel}$  = bicycle crash adjustment factor.

The value of  $N_{bi}$  used in Equation 12-27 is determined with Equation 12-6.

Table 12-21 presents the values of  $f_{bikel}$  for use in Equation 12-31. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of  $f_{bikel}$  are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-17 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

**Table 12-21.** Bicycle Crash Adjustment Factors for Intersections

Intersection Type	Bicycle Crash Adjustment Factor ( $f_{bikel}$ )
3ST	0.016
3SG	0.011
4ST	0.018
4SG	0.015

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.

## 12.7. SOURCE: HSIS DATA FOR CALIFORNIA (2002–2006) CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 12.4, crash modification factors are applied to the selected safety performance function (SPF), which was selected in Step 9. SPFs provided in Chapter 12 are presented in Section 12.6. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the SPFs presented in Section 12.6.

Crash modification factors (CMFs) are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 12 shown in Equation 12-1. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has a CMF with a value greater than 1.00; any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 12 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions of the SPFs. The CMFs presented in Chapter 12 and the specific SPFs which they apply to are summarized in Table 12-18.

**Table 12-22.** Summary of CMFs in Chapter 12 and the Corresponding SPFs

Applicable SPF	CMF	CMF Description	CMF Equations and Tables
Roadway Segments	$CMF_{1r}$	On-Street Parking	Equation 12-32 and Table 12-19
	$CMF_{2r}$	Roadside Fixed Objects	Equation 12-33 and Tables 12-20 and 12-21

**Commented [SR39]:** The NCHRP 17-62 project team did not estimate prediction models for vehicle-bicycle crashes. However, since the publication of the 1<sup>st</sup> edition of the HSM, some studies have estimated prediction models for bicycle crashes at intersections. The production contractor may want to consider including results from these studies.

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	$CMF_{3r}$	Median Width	Table 12-22
	$CMF_{4r}$	Lighting	Equation 12-34 and Table 12-23
	$CMF_{5r}$	Automated Speed Enforcement	See text
Multiple-Vehicle Collisions and Single-Vehicle Crashes at Intersections	$CMF_{1i}$	Intersection Left-Turn Lanes	Table 12-24
	$CMF_{2i}$	Intersection Left-Turn Signal Phasing	Table 12-25
	$CMF_{3i}$	Intersection Right-Turn Lanes	Table 12-26
	$CMF_{4i}$	Right-Turn-on-Red	Equation 12-35
	$CMF_{5i}$	Lighting	Equation 12-36 and Table 12-27
	$CMF_{6i}$	Red-Light Cameras	Equations 12-37, 12-38, 12-39
Vehicle-Pedestrian Collisions at Signalized Intersections	$CMF_{1p}$	Bus Stops	Table 12-28
	$CMF_{2p}$	Schools	Table 12-29
	$CMF_{3p}$	Alcohol Sales Establishments	Table 12-30

### 12.7.1. Crash Modification Factors for Roadway Segments

The CMFs for geometric design and traffic control features of urban and suburban arterial roadway segments are presented below. These CMFs are determined in Step 10 of the predictive method and used in Equation 12-3 to adjust the SPF for urban and suburban arterial roadway segments to account for differences between the base conditions and the local site conditions.

#### $CMF_{1r}$ —On-Street Parking

The CMF for on-street parking, where present, is based on research by Bonneson (1). The base condition is the absence of on-street parking on a roadway segment. The CMF is determined as:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0) \quad (12-32)$$

Where:

$CMF_{1r}$  = crash modification factor for the effect of on-street parking on total crashes;

$f_{pk}$  = factor from Table 12-19;

$p_{pk}$  = proportion of curb length with on-street parking =  $(0.5 L_{pk}/L)$ ; and

$L_{pk}$  = sum of curb length with on-street parking for both sides of the road combined (miles); and

$L$  = length of roadway segment (miles).

This CMF applies to total roadway segment crashes.



The sum of curb length with on-street parking ( $L_{pk}$ ) can be determined from field measurements or video log review to verify parking regulations. Estimates can be made by deducting from twice the roadway segment length allowances for intersection widths, crosswalks, and driveway widths.

**Table 12-19.** Values of  $f_{pk}$  Used in Determining the Crash Modification Factor for On-Street Parking

Road Type	Type of Parking and Land Use			
	Parallel Parking		Angle Parking	
	Residential/Other	Commercial or Industrial/Institutional	Residential/Other	Commercial or Industrial/Institutional
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999

#### **$CMF_{2r}$ —Roadside Fixed Objects**

The base condition is the absence of roadside fixed objects on a roadway segment. The CMF for roadside fixed objects, where present, has been adapted from the work of Zegeer and Cynecki (15) on predicting utility pole crashes. The CMF is determined with the following equation:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo}) \quad (12-33)$$

Where:

$CMF_{2r}$  = crash modification factor for the effect of roadside fixed objects on total crashes;

$f_{\text{offset}}$  = fixed-object offset factor from Table 12-20;

$D_{fo}$  = fixed-object density (fixed objects/mi) for both sides of the road combined; and

$p_{fo}$  = fixed-object collisions as a proportion of total crashes from Table 12-21.

This CMF applies to total roadway segment crashes. If the computed value of  $CMF_{2r}$  is less than 1.00, it is set equal to 1.00. This can only occur for very low fixed object densities.

In estimating the density of fixed objects ( $D_{fo}$ ), only point objects that are 4 inches or more in diameter and do not have breakaway design are considered. Point objects that are within 70 ft of one another longitudinally along the road are counted as a single object. Continuous objects that are not behind point objects are counted as one point object for each 70 ft of length. The offset distance ( $O_{fo}$ ) shown in Table 12-20 is an estimate of the average distance from the edge of the traveled way to roadside objects over an extended roadway segment. If the average offset to fixed objects exceeds 30 ft, use the value of  $f_{\text{offset}}$  for 30 ft. Only fixed objects on the roadside on the right side of the roadway in each direction of travel are considered; fixed objects in the roadway median on divided arterials are not considered.

**Table 12-20.** Fixed-Object Offset Factor

Offset to Fixed Objects ( $O_{fo}$ ) (ft)	Fixed-Object Offset Factor ( $f_{\text{offset}}$ )
2	0.232

5	0.133
10	0.087
15	0.068
20	0.057
25	0.049
30	0.044

**Table 12-21.** Proportion of Fixed-Object Collisions

Road Type	Proportion of Fixed-Object Collisions ( <i>p<sub>f</sub></i> )
2U	0.059
3T	0.034
4U	0.037
4D	0.036
5T	0.016

**CMF<sub>3r</sub>—Median Width**

A CMF for median widths on divided roadway segments of urban and suburban arterials is presented in Table 12-22 based on the work of Harkey et al. (6). The base condition for this CMF is a median width of 15 ft. The CMF applies to total crashes and represents the effect of median width in reducing cross-median collisions; the CMF assumes that nonintersection collision types other than cross-median collisions are not affected by median width. The CMF in Table 12-22 has been adapted from the CMF in Table 13-12 based on the estimate by Harkey et al. (6) that cross-median collisions represent 12.0 percent of crashes on divided arterials.

This CMF applies only to traversable medians without traffic barriers; it is not applicable to medians serving as TWLTLs (a CMF for TWLTLs is provided in Chapter 16). The effect of traffic barriers on safety would be expected to be a function of barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers. The value of this CMF is 1.00 for undivided facilities.

**Table 12-22.** CMFs for Median Widths on Divided Roadway Segments without a Median Barrier (*CMF<sub>3r</sub>*)

Median Width (ft)	CMF
10	1.01
15	1.00
20	0.99
30	0.98
40	0.97
50	0.96
60	0.95
70	0.94
80	0.93
90	0.93

100

0.92

**CMF<sub>dr</sub>—Lighting**

The base condition for lighting is the absence of roadway segment lighting ( $CMF_{dr} = 1.00$ ). The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (3), as:

$$CMF_{dr} = 1.0 - \left( p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \right) \quad (12-34)$$

Where:

$CMF_{dr}$  = crash modification factor for the effect of roadway segment lighting on total crashes;

$p_{inr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

$p_{pnr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

$p_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

$CMF_{dr}$  applies to total roadway segment crashes. Table 12-23 presents default values for the nighttime crash proportions  $p_{inr}$ ,  $p_{pnr}$ , and  $p_{nr}$ . Replacement of the estimates in Table 12-23 with locally derived values is encouraged. If lighting installation increases the density of roadside fixed objects, the value of  $CMF_{2r}$  is adjusted accordingly.

**Table 12-23.** Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Segment Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury $p_{fi}$	PDO $p_{pdo}$	$p_n$
2U	0.424	0.576	0.316
3T	0.429	0.571	0.304
4U	0.517	0.483	0.365
4D	0.364	0.636	0.410
5T	0.432	0.568	0.274

**CMF<sub>5r</sub>—Automated Speed Enforcement**

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The base condition for automated speed enforcement is that it is absent. Chapter 17 presents a CMF of 0.83 for the reduction of all types of fatal-and-injury crashes from implementation of automated speed enforcement. This CMF is assumed to apply to roadway segments between intersections with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of the CMF for automated speed enforcement would be 0.95.

**12.7.2. Crash Modification Factors for Intersections**

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by CMFs.  $CMF_{fi}$  through  $CMF_{oi}$  are applied to multiple-vehicle collisions and single-vehicle crashes at intersections, but not to vehicle-pedestrian and vehicle-bicycle collisions.  $CMF_{fp}$  through  $CMF_{sp}$  are applied to vehicle-pedestrian collisions at four-leg signalized intersections (4SG), but not to multiple-vehicle collisions and single-vehicle crashes and not to other intersection types.

**CMF<sub>lt</sub>—Intersection Left-Turn Lanes**

The base condition for intersection left-turn lanes is the absence of left-turn lanes on the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 12-24. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes. There is no indication of any change in crash frequency for providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Table 12-24. The CMFs in the table apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). The CMFs for installation of left-turn lanes are based on research by Harwood et al. (7). A CMF of 1.00 is always used when no left-turn lanes are present.

**Table 12-24.** Crash Modification Factor ( $CMF_{lt}$ ) for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes <sup>a</sup>			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg intersection	Minor-road stop control <sup>b</sup>	0.67	0.45	—	—
	Traffic signal	0.93	0.86	0.80	—
Four-leg intersection	Minor-road stop control <sup>b</sup>	0.73	0.53	—	—
	Traffic signal	0.90	0.81	0.73	0.66

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes.

<sup>b</sup> Stop signs present on minor-road approaches only.

### $CMF_{2l}$ —Intersection Left-Turn Signal Phasing

The CMF for left-turn signal phasing is based on the results of work by Hauer (10), as modified in a study by Lyon et al. (11). Types of left-turn signal phasing considered include permissive, protected, protected/permissive, and permissive/protected. Protected/permissive operation is also referred to as a leading left-turn signal phase; permissive/protected operation is also referred to as a lagging left-turn signal phase. The CMF values are presented in Table 12-25. The base condition for this CMF is permissive left-turn signal phasing. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is always used for unsignalized intersections.

If several approaches to a signalized intersection have left-turn phasing, the values of  $CMF_{2l}$  for each approach are multiplied together.

**Table 12-25.** Crash Modification Factor ( $CMF_{2l}$ ) for Type of Left-Turn Signal Phasing

Type of Left-Turn Signal Phasing	$CMF_{2l}$
Permissive	1.00
Protected/permissive or permissive/protected	0.99
Protected	0.94

Note: Use  $CMF_{2l} = 1.00$  for all unsignalized intersections. If several approaches to a signalized intersection have left-turn phasing, the values of  $CMF_{2l}$  for each approach are multiplied together.

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### $CMF_{3l}$ —Intersection Right-Turn Lanes

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMFs for presence of right-turn lanes based on research by Harwood et al. (7) are presented in Table 12-26. These CMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes. There is no indication of any change in crash frequency for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Table 12-26.

The CMFs in Table 12-26 apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). A CMF value of 1.00 is always used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

**Table 12-26.** Crash Modification Factor ( $CMF_{3i}$ ) for Installation of Right-Turn Lanes on Intersection Approaches

Intersection Type	Type of Traffic Control	Number of Approaches with Right-Turn Lanes <sup>a</sup>			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg intersection	Minor-road stop control <sup>b</sup>	0.86	0.74	—	—
	Traffic signal	0.96	0.92	—	—
Four-leg intersection	Minor-road stop control <sup>b</sup>	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

<sup>a</sup> Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.

<sup>b</sup> Stop signs present on minor road approaches only.

#### $CMF_{4i}$ —Right-Turn-on-Red

The CMF for prohibiting right-turn-on-red on one or more approaches to a signalized intersection has been derived from a study by Clark (2) and from the CMFs for right-turn-on-red operation shown in Chapter 14. The base condition for  $CMF_{4i}$  is permitting a right-turn-on-red at all approaches to a signalized intersection. The CMF is determined as:

$$CMF_{4i} = 0.98^{(n_{prohib})} \quad (12-35)$$

Where:

$CMF_{4i}$  = crash modification factor for the effect of prohibiting right turns on red on total crashes; and

$n_{prohib}$  = number of signalized intersection approaches for which right-turn-on-red is prohibited.

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections.

#### $CMF_{5i}$ —Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (3), as:

$$CMF_{5i} = 1 - 0.38 \times p_{ni} \quad (12-36)$$

Where:

$CMF_{5i}$  = crash modification factor for the effect of intersection lighting on total crashes; and

$p_{ni}$  = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). Table 12-27 presents default values for the nighttime crash proportion,  $p_{ni}$ . HSM users are encouraged to replace the estimates in Table 12-27 with locally derived values.

**Table 12-27.** Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
	$p^{\text{ni}}$
3ST	0.238
4ST	0.229
3SG and 4SG	0.235

**CMF<sub>6i</sub>—Red-Light Cameras**

The base condition for red light cameras is their absence. The CMF for installation of a red light camera for enforcement of red signal violations at a signalized intersection is based on an evaluation by Persaud et al. (12). As shown in Chapter 14, this study indicates a CMF for red light camera installation of 0.74 for right-angle collisions and a CMF of 1.18 for rear-end collisions. In other words, red light cameras would typically be expected to reduce right-angle collisions and increase rear-end collisions. There is no evidence that red light camera installation affects other collision types. Therefore, a CMF for the effect of red light camera installation on total crashes can be computed with the following equations:

$$CMF_{6i} = 1 - p_{ra} \times (1 - 0.74) - p_{re} \times (1 - 1.18) \quad (12-37)$$

$$p_{ra} = \frac{p_{ramv(FI)} \times N_{bimv(FI)} + p_{ramv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \quad (12-38)$$

$$p_{re} = \frac{p_{remv(FI)} \times N_{bimv(FI)} + p_{remv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \quad (12-39)$$

Where:

$CMF_{6i}$  = crash modification factor for installation of red light cameras at signalized intersections;

$p_{ra}$  = proportion of crashes that are multiple-vehicle, right-angle collisions;

$p_{re}$  = proportion of crashes that are multiple-vehicle, rear-end collisions;

$p_{ramv(FI)}$  = proportion of multiple-vehicle fatal-and-injury crashes represented by right-angle collisions;

$p_{ramv(PDO)}$  = proportion of multiple-vehicle property-damage-only crashes represented by right-angle collisions;

$p_{remv(FI)}$  = proportion of multiple-vehicle fatal-and-injury crashes represented by rear-end collisions; and

$p_{remv(PDO)}$  = proportion of multiple-vehicle property-damage-only crashes represented by rear-end collisions.

The values of  $N_{bimv(FI)}$  is available from Equation 12-22, the value of  $N_{bimv(PDO)}$  is available from Equation 12-23, and the value of  $N_{bisv}$  is available from Equation 12-24. The values of  $p_{ramv(FI)}$ ,  $p_{ramv(PDO)}$ ,  $p_{remv(FI)}$ , and  $p_{remv(PDO)}$  can be determined from data for the applicable intersection type in Table 12-11. The values in Table 12-11 may be updated with data for a particular jurisdiction as part of the calibration process presented in Part C, Appendix A. The data in Table 12-11, by definition, represent average values for a broad range of signalized intersections. Because jurisdictions are likely to implement red-light cameras at intersections with higher than average proportions of right-angle collisions, it is acceptable to replace the values in Table 12-11 with estimate based on data for a specific intersection when determining the value of the red light camera CMF.

$$\text{Deleted: } p_{ra} = \frac{p_{ramv(FI)} \times N_{bimv(FI)} + p_{ramv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})}$$

Field Code Changed

### 12.7.3. Crash Modification Factors for Vehicle-Pedestrian Collisions at Signalized Intersections

The CMFs for vehicle-pedestrian collisions at signalized intersections are presented below.

#### $CMF_{1p}$ —Bus Stops

The CMFs for the number of bus stops within 1,000 ft of the center of the intersection are presented in Table 12-28. The base condition for bus stops is the absence of bus stops near the intersection. These CMFs apply to total vehicle-pedestrian collisions and are based on research by Harwood et al. (8).

**Table 12-28.** Crash Modification Factor ( $CMF_{1p}$ ) for the Presence of Bus Stops near the Intersection

Number of Bus Stops within 1,000 ft of the Intersection	$CMF_{1p}$
0	1.00
1 or 2	2.78
3 or more	4.15

In applying Table 12-28, multiple bus stops at the same intersection (i.e., bus stops in different intersection quadrants or located some distance apart along the same intersection leg) are counted separately. Bus stops located at adjacent intersections would also be counted as long as any portion of the bus stop is located within 1,000 ft of the intersection being evaluated.

#### $CMF_{2p}$ —Schools

The base condition for schools is the absence of a school near the intersection. The CMF for schools within 1,000 ft of the center of the intersection is presented in Table 12-29. A school may be counted if any portion of the school grounds is within 1,000 ft of the intersection. Where one or more schools are located near the intersection, the value of the CMF is independent of the number of schools present. This CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with a school nearby is likely to experience more vehicle-pedestrian collisions than an intersection without schools even if the traffic and pedestrian volumes at the two intersections are identical. Such increased crash frequencies indicate that school children are at higher risk than other pedestrians.

**Table 12-29.** Crash Modification Factor ( $CMF_{2p}$ ) for the Presence of Schools near the Intersection

Presence of Schools within 1,000 ft of the Intersection	$CMF_{2p}$
No school present	1.00
School present	1.35

#### $CMF_{3p}$ —Alcohol Sales Establishments

The base condition for alcohol sales establishments is the absence of alcohol sales establishments near the intersection. The CMF for the number of alcohol sales establishments within 1,000 ft of the center of an intersection is presented in Table 12-30. Any alcohol sales establishment wholly or partly within 1,000 ft of the intersection may be counted. The CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with alcohol sales establishments nearby is likely to experience more vehicle-pedestrian collisions than an intersection without alcohol sales establishments even if the traffic and pedestrian volumes at the two intersections are identical. This indicates the likelihood of higher risk behavior on the part of either pedestrians or drivers near alcohol sales establishments. The CMF includes any alcohol sales establishment which may include liquor stores, bars, restaurants, convenience stores, or grocery stores. Alcohol sales establishments are counted if they are on any intersection leg or even on another street, as long as they are within 1,000 ft of the intersection being evaluated.



**Table 12-30.** Crash Modification Factor ( $CMF_{3p}$ ) for the Number of Alcohol Sales Establishments near the Intersection

Number of Alcohol Sales Establishments within 1,000 ft of the Intersection	$CMF_{3p}$
0	1.00
1–8	1.12
9 or more	1.56

## 12.8. CALIBRATION OF THE SPFS TO LOCAL CONDITIONS

In Step 10 of the predictive method, presented in Section 12.4, the predictive model is calibrated to local state or geographic conditions. Crash frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes on urban and suburban arterial highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments and intersections (defined below as  $C_r$  and  $C_i$ , respectively) will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes on average than the roadways used in the development of the SPFs will have values less than 1.0. The calibration procedures are presented in Part C, Appendix A.

Calibration factors provide one method of incorporating local data to improve estimated crash frequencies for individual agencies or locations. Several other default values used in the methodology, such as collision type distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in Part C, Appendix A.

**Commented [ST41]:** Needs to be reviewed after the chapter on calibration is completed

## 12.9. INTERIM PREDICTIVE METHOD FOR ROUNDABOUTS

Sufficient research has not yet been conducted to form the basis for development of a predictive method for roundabouts. Since many jurisdictions are planning projects to convert existing intersections into modern roundabouts, an interim predictive method is presented here. This interim procedure is applicable to a location at which a modern roundabout has been constructed or is being planned to replace an existing intersection with minor-road stop control or an existing signalized intersection. The interim procedure is:

1. Apply the predictive method from Chapter 12 to estimate the crash frequency,  $N_{int}$ , for the existing intersection.
2. Multiply  $N_{int}$  by the appropriate CMF from Chapter 12 for conversion on an existing intersection to a modern roundabout. The applicable CMFs are:
  - 0.56 for conversion of a two-way stop-controlled intersection to a modern roundabout.
  - 0.52 for conversion of a signalized intersection to a modern roundabout.

These CMFs are applicable to all crash severities and collision types for both one- and two-lane roundabouts in all settings.

At present, there are no available SPFs to determine predicted average crash frequency of an existing or newly constructed roundabout where no intersection currently exists.

**Commented [I42]:** This section needs to be reviewed by 17-71 viz. results of the roundabout project.

12.10. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 12

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.8. This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 12.

Where urban and suburban arterials intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the arterial facility within the interchange area, cannot be addressed with the predictive method for urban and suburban arterials.

12.11. APPLICATION OF CHAPTER 12 PREDICTIVE METHOD

The predictive method presented in Chapter 12 applies to urban and suburban arterials. The predictive method is applied to by following the 18 steps presented in Section 12.4. Appendix 12A provides a series of worksheets for applying the predictive method and the predictive models detailed in this chapter. All computations within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed for consistency in computations. In the last stage of computation, rounding the final estimate expected average crash frequency to one decimal place.

12.12. SUMMARY

The predictive method is used to estimate the expected average crash frequency for a series of contiguous sites (entire urban or suburban arterial facility), or a single individual site. An urban or suburban facility is defined in Section 12.3.

The predictive method for urban and suburban arterial highways is applied by following the 18 steps of the predictive method presented in Section 12.4. Predictive models, developed for urban and suburban arterial facilities, are applied in Steps 9, 10, and 11 of the method. These models have been developed to estimate the predicted average crash frequency of an individual intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Where observed data are available, the EB Method may be applied in Step 13 or 15 of the predictive method to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Each predictive model in Chapter 12 consists of a safety performance function (SPF), crash modification factors (CMFs), a calibration factor, and pedestrian and bicyclist factors. The SPF is selected in Step 9 and is used to estimate the predicted average crash frequency for a site with base conditions. This estimate can be for either total crashes or and/or specific crash severities or collision types. In order to account for differences between the base conditions of the SPF and the actual conditions of the local site, CMFs are applied in Step 10 which adjust the predicted number of crashes according the geometric conditions of the site.

In order to account for the differences in state or regional crash frequencies, the SPF is calibrated to the specific state and or geographic region to which they apply. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 12.13 presents six sample problems which detail the application of the predictive method. A series of template worksheets have been developed to assist with applying the predictive method in Chapter 12. These worksheets are utilized to solve the sample problems in Section 12.13, and Appendix 12A contains blank versions of the worksheets.

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### 12.13. SAMPLE PROBLEMS

In this section, six sample problems are presented using the predictive method steps for urban and suburban arterials. Sample Problems 1 and 2 illustrate how to calculate the predicted average crash frequency for urban and suburban arterial roadway segments. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for a stop-controlled intersection. Sample Problem 4 illustrates a similar calculation for a signalized intersection. Sample Problem 5 illustrates how to combine the results from Sample Problems 1 through 4 in a case where site-specific observed crash data are available (i.e., using the site-specific EB Method). Sample Problem 6 illustrates how to combine the results from Sample Problems 1 through 4 in a case where site-specific observed crash data are not available (i.e., using the project-level EB Method).

**Commented [CL43]:** 2<sup>nd</sup> edition contractor to update as needed

**Commented [1J44R43]:** Or another party as assigned by AASHTO/TRB

**Table 12-31.** List of Sample Problems in Chapter 12

Problem No.	Page No.	Description
1	12-49	Predicted average crash frequency for a three-lane TWLTL arterial roadway segment
2	12-63	Predicted average crash frequency for a four-lane divided arterial roadway segment
3	12-74	Predicted average crash frequency for a three-leg stop-controlled intersection
4	12-86	Predicted average crash frequency for a four-leg signalized intersection
5	12-97	Expected average crash frequency for a facility when site-specific observed crash data are available
6	12-101	Expected average crash frequency for a facility when site-specific observed crash data are not available

#### 12.13.1. Sample Problem 1

##### The Site/Facility

A three-lane urban arterial roadway segment with a center two-way left-turn lane (TWLTL).

##### The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

##### The Facts

- 1.5-mi length
- 11,000 veh/day
- 1.0 mi of parallel on-street commercial parking on each side of street
- 30 driveways (10 minor commercial, 2 major residential, 15 minor residential, 3 minor industrial/institutional)
- 10 roadside fixed objects per mile
- 6-ft offset to roadside fixed objects
- Lighting present
- 35-mph posted speed

##### Assumptions

Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

##### Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 7.0 crashes per year (rounded to one decimal place).

## Steps

### Step 1 through 8

To determine the predicted average crash frequency of the roadway segment in Sample Problem 1, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

### Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

For a three-lane urban arterial roadway segment with TWLTL, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

#### Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$\begin{aligned}
 N_{brmv} &= \exp(a + b \times \ln(AADT) + \ln(L)) \\
 N_{brmv(\text{total})} &= \exp(-12.40 + 1.41 \times \ln(11,000) + \ln(1.5)) \\
 &= 3.805 \text{ crashes/year} \\
 N_{brmv(FI)} &= \exp(-16.45 + 1.69 \times \ln(11,000) + \ln(1.5)) \\
 &= 0.728 \text{ crashes/year} \\
 N_{brmv(PDO)} &= \exp(-11.95 + 1.33 \times \ln(11,000) + \ln(1.5)) \\
 &= 2.298 \text{ crashes/year}
 \end{aligned}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-11 and 12-12 to assure that they sum to the value for total crashes as follows:

$$\begin{aligned}
 N_{brmv(FI)} &= N_{brmv(\text{total})} \left( \frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}} \right) \\
 &= 3.805 \left( \frac{0.728}{0.728 + 2.298} \right) \\
 &= 0.742 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{brmv(PDO)} &= N_{brmv(\text{total})} - N_{brmv(FI)} \\
 &= 3.805 - 0.742 \\
 &= 2.343 \text{ crashes/year}
 \end{aligned}$$

#### Single-Vehicle Crashes

The SFP for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$\begin{aligned}
 N_{brmv} &= \exp(a + b \times \ln(AADT) + \ln(L)) \\
 N_{brmv(\text{total})} &= \exp(-12.40 + 1.41 \times \ln(11,000) + 1) \\
 &= 3.805 \text{ crashes/year} \\
 \text{Deleted: } N_{brmv(FI)} &= \exp(-16.45 + 1.69 \times \ln(11,000) + 1) \\
 &= 0.728 \text{ crashes/year} \\
 N_{brmv(PDO)} &= \exp(-11.95 + 1.33 \times \ln(11,000) + 1) \\
 &= 2.298 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{brmv(FI)} &= N_{brmv(\text{total})} \left( \frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}} \right) \\
 \text{Deleted: } &= 3.805 \left( \frac{0.728}{0.728 + 2.298} \right) \\
 &= 0.742 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{brsv} &= \exp(a + b \times \ln(AADT) + \ln(L)) \\
 N_{brsv(\text{total})} &= \exp(-5.74 + 0.54 \times \ln(11,000) + \ln(1.5)) \\
 &= 0.734 \text{ crashes/year} \\
 N_{brsv(FI)} &= \exp(-6.37 + 0.47 \times \ln(11,000) + \ln(1.5)) \\
 &= 0.204 \text{ crashes/year} \\
 N_{brsv(PDO)} &= \exp(-6.29 + 0.56 \times \ln(11,000) + \ln(1.5)) \\
 &= 0.510 \text{ crashes/year}
 \end{aligned}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-14 and 12-15 to assure that they sum to the value for total crashes as follows:

$$\begin{aligned}
 N_{brsv(FI)} &= N_{brsv(\text{total})} \left( \frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}} \right) \\
 &= 0.734 \times \left( \frac{0.204}{0.204 + 0.510} \right) \\
 &= 0.210 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{brsv(PDO)} &= N_{brsv(\text{total})} - N_{brsv(FI)} \\
 &= 0.734 - 0.210 \\
 &= 0.524 \text{ crashes/year}
 \end{aligned}$$

#### Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdvy(\text{total})} = \sum_{\text{all driveway types}} n_j \times N_j \times \left( \frac{AADT}{15,000} \right)^{(t)}$$

The number of driveways within the roadway segment,  $n_j$ , for Sample Problem 1 is 10 minor commercial, two major residential, 15 minor residential, and three minor industrial/institutional.

The number of driveway-related collisions,  $N_j$ , and the regression coefficient for AADT,  $t$ , for a three-lane arterial are provided in Table 12-7.

$$\begin{aligned}
 N_{brdvy(\text{total})} &= 10 \times 0.032 \times \left( \frac{11,000}{15,000} \right)^{(1.0)} + 2 \times 0.053 \times \left( \frac{11,000}{15,000} \right)^{(1.0)} \\
 &\quad + 15 \times 0.010 \times \left( \frac{11,000}{15,000} \right)^{(1.0)} + 3 \times 0.015 \times \left( \frac{11,000}{15,000} \right)^{(1.0)} \\
 &= 0.455 \text{ crashes/year}
 \end{aligned}$$

Driveway-related collisions can be separated into components by severity level using Equations 12-17 and 12-18 as follows:

From Table 12-7, for a three-lane arterial the proportion of driveway-related collisions that involve fatalities and injuries,  $f_{dwy} = 0.243$

$$\begin{aligned}
 N_{brsv(FI)} &= N_{brsv(\text{total})} \left( \frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}} \right) \\
 \text{Deleted:} \quad &= 0.734 \times \left( \frac{0.204}{0.204 + 0.510} \right) \\
 &= 0.210 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{brdwy(FI)} &= N_{brdwy(total)} \times f_{dwy} \\
 &= 0.455 \times 0.243 \\
 &= 0.111 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{brdwy(PDO)} &= N_{brdwy(total)} - N_{brdwy(FI)} \\
 &= 0.455 - 0.111 \\
 &= 0.344 \text{ crashes/year}
 \end{aligned}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.**

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

**On-Street Parking ( $CMF_{1r}$ )**

$CMF_{1r}$  is calculated from Equation 12-32 as follows:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0)$$

The proportion of curb length with on-street parking,  $p_{pk}$ , is determined as follows:

$$p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Since 1.0 mile of on-street parking on each side of the road is provided, the sum of curb length with on-street parking for both sides of the road combined,  $L_{pk} = 2$ .

$$p_{pk} = 0.5 \times \frac{2}{1.5} = 0.66$$

From Table 12-19,  $f_{pk} = 2.074$ .

$$\begin{aligned}
 CMF_{1r} &= 1 + 0.66 \times (2.074 - 1.0) \\
 &= 1.71
 \end{aligned}$$

**Roadside Fixed Objects ( $CMF_{2r}$ )**

$CMF_{2r}$  is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-20, for a roadside fixed object with a 6-ft offset, the fixed-object offset factor,  $f_{offset}$ , is interpolated as 0.124.

From Table 12-21, for a three-lane arterial the proportion of total crashes,  $p_{fo} = 0.034$ .

$$\begin{aligned}
 CMF_{2r} &= 0.124 \times 10 \times 0.034 + (1.0 - 0.034) \\
 &= 1.01
 \end{aligned}$$

**Median Width ( $CMF_{3r}$ )**

The value of  $CMF_{3r}$  is 1.00 for undivided facilities (see Section 12.7.1). It is assumed that a roadway with TWLTL is undivided.

$$N_{brdwy(FI)} = N_{brdwy(total)} \times f_{dwy}$$

$$\begin{aligned}
 \text{Deleted: } &= 0.455 \times 0.243 \\
 &= 0.111 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{brdwy(PDO)} &= N_{brdwy(total)} - N_{brdwy(FI)} \\
 &= 0.455 - 0.111 \\
 &= 0.344 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

Field Code Changed

$$\text{Deleted: } p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Field Code Changed

$$\text{Deleted: } p_{pk} = 0.5 \times \frac{2}{1.5} = 0.66$$

Field Code Changed

$$\text{Deleted: } p_{fo} = 0.034$$

**Lighting ( $CMF_{dr}$ )**

$CMF_{dr}$  is calculated from Equation 12-34 as follows:

$$CMF_{dr} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}))$$

For a three-lane arterial,  $p_{inr} = 0.429$ ,  $p_{pnr} = 0.571$ , and  $p_{nr} = 0.304$  (see Table 12-23).

$$\begin{aligned} CMF_{dr} &= 1.0 - (0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571)) \\ &= 0.93 \end{aligned}$$

**Automated Speed Enforcement ( $CMF_{sr}$ )**

Since there is no automated speed enforcement in Sample Problem 1,  $CMF_{sr} = 1.00$  (i.e., the base condition for  $CMF_{sr}$  is the absent of automated speed enforcement).

The combined CMF value for Sample Problem 1 is calculated below.

$$\begin{aligned} CMF_{comb} &= 1.71 \times 1.01 \times 0.93 \\ &= 1.61 \end{aligned}$$

**Vehicle-Pedestrian and Vehicle-Bicycle Collisions**

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions,  $N_{brs}$  is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes.  $N_{brs}$  is determined from Equation 12-3 as follows:

$$N_{br} = N_{spf\ rs} \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{nr})$$

From Equation 12-4,  $N_{spf\ rs}$  can be calculated as follows:

$$\begin{aligned} N_{spf\ rs} &= N_{brmv} + N_{brsv} + N_{brdwy} \\ &= 3.085 + 0.734 + 0.455 \\ &= 4.274 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 1 is 1.61.

$$\begin{aligned} N_{br} &= 4.274 \times (1.61) \\ &= 6.881 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed greater than 30 mph on three-lane arterials the pedestrian crash adjustment factor,  $f_{pedr} = 0.013$ .

$$\begin{aligned} N_{pedr} &= 6.881 \times 0.013 \\ &= 0.089 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

Deleted:  $p_{inr} = 0.429$ ,  $p_{pnr} = 0.571$ , and  $p_{nr} = 0.304$

Field Code Changed

Field Code Changed

Field Code Changed

Deleted:  $CMF_{sr} = 1.00$

Field Code Changed

Deleted:  $CMF_{comb} = 1.71 \times 1.01 \times 0.93$   
= 1.61 ¶

Field Code Changed

Deleted:  $N_{br} = N_{spf\ rs} \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{nr})$  ¶

Field Code Changed

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$   
Deleted: = 3.085 + 0.734 + 0.455 ¶  
= 4.274 crashes/year

Field Code Changed

From Table 12-9, for a posted speed greater than 30 mph on three-lane arterials the bicycle crash adjustment factor,  $f_{biker} = 0.007$ .

$$\begin{aligned} N_{biker} &= 6.881 \times 0.007 \\ &= 0.048 \text{ crashes/year} \end{aligned}$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in that a calibration factor,  $C_r$ , of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } rs} &= C_r \times (N_{br} + N_{pedr} + N_{biker}) \\ &= 1.00 \times (6.881 + 0.089 + 0.048) \\ &= 7.018 \text{ crashes/year} \end{aligned}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments



Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

### Worksheet SP1A—General Information and Input Data for Urban and Suburban Roadway Segments

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1.

#### Worksheet SP1A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Road type (2U, 3T, 4U, 4D, 5T)		—	3T
Length of segment, L (mi)		—	1.5
AADT (veh/day)		—	11,000
Type of on-street parking (none/parallel/angle)		none	parallel-commercial
Proportion of curb length with on-street parking		—	0.66
Median width (ft)		15	not present
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	not present
Major commercial driveways (number)		—	0
Minor commercial driveways (number)		—	10
Major industrial/institutional driveways (number)		—	0
Minor industrial/institutional driveways (number)		—	3
Major residential driveways (number)		—	2
Minor residential driveways (number)		—	15
Other driveways (number)		—	0
Speed Category		—	intermediate or high speed (>30 mph)
Roadside fixed object density (fixed objects/mi)		not present	10
Offset to roadside fixed objects (ft)		not present	6
Calibration Factor, $C_r$		1.0	1.0

#### Worksheet SP1B. Crash Modification Factors for Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP1B which indicates the combined CMF value.

**Worksheet SP1B.** Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	CMF for Roadside Fixed Objects	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{comb}$
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	$(1)*(2)*(3)*(4)*(5)$
1.71	1.01	1.00	0.93	1.00	1.61

**Worksheet SP1C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments**

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 1 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP1C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{brw}$	Proportion of Total Crashes	Adjusted $N_{brw}$	Combined CMFs	Calibration Factor	Predicted $N_{brw}$
	from Table 12-3		from Table 12-3	from Equation 12-10					
	a	b				(4) <sub>total</sub> *(5)	(6) from Worksheet SP1B	$C_r$	(6)*(7)*(8)
Total	-12.40	1.41	0.66	3.085	1.000	3.085	1.61	1.00	4.967
Fatal and injury (FI)	-16.45	1.69	0.59	0.728	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$	0.743	1.61	1.00	1.196
					0.241				
Property damage only (PDO)	-11.95	1.33	0.59	2.298	$(5)_{total}-(5)_{FI}$	2.342	1.61	1.00	3.771
					0.759				

### Worksheet SP1D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP1D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP1C) into components by crash severity and collision type.

### Worksheet SP1D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $P_{ij}$	Predicted $N_{injury\ FI}$ (crashes/year)	Proportion of Collision Type $P_{PDO}$	Predicted $N_{injury\ PDO}$ (crashes/year)	Predicted $N_{injury\ Total}$ (crashes/year)
Collision Type	from Table 12-4	(9) <sub>FI</sub> from Worksheet SP1C	from Table 12-4	(9) <sub>PDO</sub> from Worksheet SP1C	(9) <sub>Total</sub> from Worksheet SP1C
Total	1.000	1.196 (2)*(3) <sub>FI</sub>	1.000	3.771 (4)*(5) <sub>PDO</sub>	4.967 (3)+(5)
Rear-end collision	0.845	1.011	0.842	3.175	4.186
Head-on collision	0.034	0.041	0.020	0.075	0.116
Angle collision	0.069	0.083	0.020	0.075	0.158
Sideswipe, same direction	0.001	0.001	0.078	0.294	0.295
Sideswipe, opposite direction	0.017	0.020	0.020	0.075	0.095
Other multiple-vehicle collision	0.034	0.041	0.020	0.075	0.116

### Worksheet SP1E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 1 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP1E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP1E.** Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{base}$	Proportion of Total Crashes	Adjusted $N_{base}$	Combined CMFs	Calibration Factor	Predicted $N_{base}$
	from Table 12-5		from Table 12-5	from Equation 12-13		(4) <sub>total</sub> *(5)	(6) from Worksheet SP1B	$C_r$	(6)*(7)*(8)
	a	b							
Total	-5.74	0.54	1.37	0.734	1.000	0.734	1.61	1.00	1.182
Fatal and injury (FI)	-6.37	0.47	1.06	0.204	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$	0.210	1.61	1.00	0.338
					0.286				
Property damage only (PDO)	-6.29	0.56	1.93	0.510	$(5)_{total}-(5)_{FI}$	0.524	1.61	1.00	0.844
					0.714				

**Worksheet SP1F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments**

Worksheet SP1F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP1E) into components by crash severity and collision type.

**Worksheet SP1F.** Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $(P_i)$	Predicted $N_{Insv} (FI)$ (crashes/year)	Proportion of Collision Type $(PDO)$	Predicted $N_{Insv} (PDO)$ (crashes/year)	Predicted $N_{Insv} (total)$ (crashes/year)
Collision Type	from Table 12-6	(9) $_{FI}$ from Worksheet SP1E	from Table 12-6	(9) $_{PDO}$ from Worksheet SP1E	(9) $_{total}$ from Worksheet SP1E
Total	1.000	0.338 (2)*(3) $_{FI}$	1.000	0.844 (4)*(5) $_{PDO}$	1.182 (3)+(5)
Collision with animal	0.001	0.000	0.001	0.001	0.001
Collision with fixed object	0.688	0.233	0.963	0.813	1.046
Collision with other object	0.001	0.000	0.001	0.001	0.001
Other single-vehicle collision	0.310	0.105	0.035	0.030	0.135

**Worksheet SP1G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments**

Worksheet SP1G determines and presents the number of driveway-related multiple-vehicle collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized).

**Worksheet SP1G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)
Driveway Type	Number of Driveways, $n_i$	Crashes per Driveway per Year, $N_i$	Coefficient for Traffic Adjustment, $t$	Initial $N_{inday}$	Overdispersion Parameter, $k$
		from Table 12-7	from Table 12-7	Equation 12-16 $n_i * N_i / (AADT/15,000)t$	from Table 12-7
Major commercial	0	0.102	1.000	0.000	—
Minor commercial	10	0.032	1.000	0.235	
Major industrial/institutional	0	0.110	1.000	0.000	
Minor industrial/institutional	3	0.015	1.000	0.033	
Major residential	2	0.053	1.000	0.078	
Minor residential	15	0.010	1.000	0.110	
Other	0	0.016	1.000	0.000	
Total	—	—	—	0.456	1.10

**Worksheet SP1H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments**

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP1G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7 and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

**Worksheet SP1H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Initial $N_{inday}$	Proportion of Total Crashes ( $f_{sev}$ )	Adjusted $N_{inday}$	Combined CMFs	Calibration Factor, $C_r$	Predicted $N_{inday}$
	(5) <sub>total</sub> from Worksheet SP1G	from Table 12-7	(2) <sub>total</sub> * (3)	(6) from Worksheet SP1B		(4) * (5) * (6)
Total	0.456	1.000	0.456	1.61	1.00	0.734
Fatal and injury (FI)	—	0.243	0.111	1.61	1.00	0.179
Property damage only (PDO)	—	0.757	0.345	1.61	1.00	0.555

**Worksheet SP1I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments**

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4,

respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP1I. Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted $N_{\text{nonv}}$	Predicted $N_{\text{inv}}$	Predicted $N_{\text{brday}}$	Predicted $N_{\text{br}}$	$f_{\text{ped}}$		Predicted $N_{\text{ped}}$
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, $C_c$	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.013	1.00	0.089
Fatal and injury (FI)	—	—	—	—	—	1.00	0.089

**Worksheet SP1J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments**

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP1J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted $N_{\text{nonv}}$	Predicted $N_{\text{inv}}$	Predicted $N_{\text{brday}}$	Predicted $N_{\text{br}}$	$f_{\text{biker}}$		Predicted $N_{\text{biker}}$
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, $C_c$	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.007	1.00	0.048
Fatal and injury	—	—	—	—	—	1.00	0.048

**Worksheet SP1K—Crash Severity Distribution for Urban and Suburban Roadway Segments**

Worksheet SP1K provides a summary of all collision types by severity level. Values from Worksheets SP1C, SP1E, SP1H, SP1I, and SP1J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)



**Worksheet SP1K. Crash Severity Distribution for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J	(5) from Worksheets SP1D and SP1F; and (7) from Worksheet SP1H	(6) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J
<b>MULTIPLE-VEHICLE</b>			
Rear-end collisions (from Worksheet SP1D)	1.011	3.175	4.186
Head-on collisions (from Worksheet SP1D)	0.041	0.075	0.116
Angle collisions (from Worksheet SP1D)	0.083	0.075	0.158
Sideswipe, same direction (from Worksheet SP1D)	0.001	0.294	0.295
Sideswipe, opposite direction (from Worksheet SP1D)	0.020	0.075	0.095
Driveway-related collisions (from Worksheet SP1H)	0.179	0.555	0.734
Other multiple-vehicle collision (from Worksheet SP1D)	0.041	0.075	0.116
Subtotal	1.376	4.324	5.700
<b>SINGLE-VEHICLE</b>			
Collision with animal (from Worksheet SP1F)	0.000	0.001	0.001
Collision with fixed object (from Worksheet SP1F)	0.233	0.813	1.046
Collision with other object (from Worksheet SP1F)	0.000	0.001	0.001
Other single-vehicle collision (from Worksheet SP1F)	0.105	0.030	0.135
Collision with pedestrian (from Worksheet SP1I)	0.089	0.000	0.089
Collision with bicycle (from Worksheet SP1J)	0.048	0.000	0.048
Subtotal	0.475	0.845	1.320
Total	1.851	5.169	7.020

**Worksheet SP1L—Summary Results for Urban and Suburban Roadway Segments**

Worksheet SP1L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

**Worksheet SP1L.** Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency, $N_{\text{predicted } rs}$ (crashes/year)	Roadway Segment Length, $L$ (mi)	Crash Rate (crashes/mi/year)
	(Total) from Worksheet SP1K		(2)/(3)
Total	7.020	1.5	4.7
Fatal and injury (FI)	1.851	1.5	1.2
Property damage only (PDO)	5.169	1.5	3.4

**12.13.2. Sample Problem 2****The Highway**

A four-lane divided urban arterial roadway segment.

**The Question**

What is the predicted average crash frequency of the roadway segment for a particular year?

**The Facts**

- 0.75-mi length
- 23,000 veh/day
- On-street parking not permitted
- 8 driveways (1 major commercial, 4 minor commercial, 1 major residential, 1 minor residential, 1 minor industrial/institutional)
- 20 roadside fixed objects per mile
- 12-ft offset to roadside fixed objects
- 40-ft median
- Lighting present
- 30-mph posted speed

**Assumptions**

Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 3.4 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

For a four-lane divided urban arterial roadway segment, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 1. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

#### Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{brmv(\text{total})} = \exp(-12.34 + 1.36 \times \ln(23,000) + \ln(0.75))$$

$$= 2.804 \text{ crashes/year}$$

#### Single-Vehicle Crashes

The SPF for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{brsv(\text{total})} = \exp(-5.05 + 0.47 \times \ln(23,000) + \ln(0.75))$$

$$= 0.539 \text{ crashes/year}$$

#### Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdwy(\text{total})} = \sum_{\text{all driveway types}} n_j \times N_j \times \left( \frac{AADT}{15,000} \right)^{(t)}$$

The number of driveways within the roadway segment,  $n_j$ , for Sample Problem 1 is one major commercial, four minor commercial, one major residential, one minor residential, and one minor industrial/institutional.

The number of driveway-related collisions,  $N_j$ , and the regression coefficient for AADT,  $t$ , for a four-lane divided arterial, are provided in Table 12-7.

$$N_{brdwy(\text{total})} = 1 \times 0.033 \times \left( \frac{23,000}{15,000} \right)^{(1.106)} + 4 \times 0.011 \times \left( \frac{23,000}{15,000} \right)^{(1.106)} + 1 \times 0.018 \times \left( \frac{23,000}{15,000} \right)^{(1.106)}$$

$$+ 1 \times 0.003 \times \left( \frac{23,000}{15,000} \right)^{(1.106)} + 1 \times 0.005 \times \left( \frac{23,000}{15,000} \right)^{(1.106)}$$

$$= 0.165 \text{ crashes/year}$$

The fatal-and-injury (FI) and property-damage-only (PDO) SPF values for multiple-vehicle nondriveway collisions, single-vehicle crashes and multiple-vehicle driveway-related collisions can be determined by using the same procedure presented in Sample Problem 1.

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.**

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$\text{Deleted: } N_{brmv(\text{total})} = \exp(-12.34 + 1.36 \times \ln(23,000) + \ln(0.75))$$

$$= 2.804 \text{ crashes/year}$$

Field Code Changed

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$\text{Deleted: } N_{brsv(\text{total})} = \exp(-5.05 + 0.47 \times \ln(23,000) + \ln(0.75))$$

$$= 0.539 \text{ crashes/year}$$

Field Code Changed

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

#### On-Street Parking ( $CMF_{1r}$ )

Since on-street parking is not permitted,  $CMF_{1r} = 1.00$  (i.e., the base condition for  $CMF_{1r}$  is the absence of on-street parking).

Deleted:  $CMF_{1r} = 1.00$

Field Code Changed

#### Roadside Fixed Objects ( $CMF_{2r}$ )

$CMF_{2r}$  is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-20, for a roadside fixed object with a 12-ft offset, the fixed-object offset factor,  $f_{\text{offset}}$ , is interpolated as 0.079.

From Table 12-21, for a four-lane divided arterial the proportion of total crashes,  $p_{fo} = 0.036$ .

Deleted:  $p_{fo} = 0.036$

$$\begin{aligned} CMF_{2r} &= 0.079 \times 20 \times 0.036 + (1.0 - 0.036) \\ &= 1.02 \end{aligned}$$

#### Median Width ( $CMF_{3r}$ )

From Table 12-22, for a four-lane divided arterial with a 40-ft median,  $CMF_{3r} = 0.97$ .

Deleted:  $CMF_{3r} = 0.97$

#### Lighting ( $CMF_{4r}$ )

$CMF_{4r}$  can be calculated from Equation 12-34 as follows:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{mr} - 0.83 \times p_{pnr}))$$

For a four-lane divided arterial,  $p_{mr} = 0.364$ ,  $p_{pnr} = 0.636$ , and  $p_{nr} = 0.410$  (see Table 12-23).

$$\begin{aligned} CMF_{4r} &= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)) \\ &= 0.91 \end{aligned}$$

#### Automated Speed Enforcement ( $CMF_{5r}$ )

Since there is no automated speed enforcement in Sample Problem 2,  $CMF_{5r} = 1.00$  (i.e., the base condition for  $CMF_{5r}$  is the absence of automated speed enforcement).

Deleted:  $CMF_{5r} = 1.00$

Field Code Changed

The combined CMF value for Sample Problem 2 is calculated below.

$$\begin{aligned} CMF_{\text{comb}} &= 1.02 \times 0.97 \times 0.91 \\ &= 0.90 \end{aligned}$$

#### Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions,  $N_{br}$ , is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes.  $N_{br}$  is determined from Equation 12-3 as follows:

$$N_{br} = N_{\text{spf rs}} \times (CMF_{1r} \times CMF_{2r} \times \dots \times CMF_{nr})$$

From Equation 12-4,  $N_{\text{spf rs}}$  can be calculated as follows:

$$\begin{aligned}
 N_{spf\ rs} &= N_{brmv} + N_{brsv} + N_{brdwy} \\
 &= 2.804 + 0.539 + 0.165 \\
 &= 3.508 \text{ crashes/year}
 \end{aligned}$$

The combined CMF value for Sample Problem 2 is 0.90.

$$\begin{aligned}
 N_{br} &= 3.508 \times (0.90) \\
 &= 3.157 \text{ crashes/year}
 \end{aligned}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed of 30 mph on four-lane divided arterials, the pedestrian crash adjustment factor  $f_{pedr} = 0.067$ .

$$\begin{aligned}
 N_{pedr} &= 3.157 \times 0.067 \\
 &= 0.212 \text{ crashes/year}
 \end{aligned}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-9, for a posted speed of 30 mph on four-lane divided arterials, the bicycle crash adjustment factor  $f_{biker} = 0.013$ .

$$\begin{aligned}
 N_{biker} &= 3.157 \times 0.013 \\
 &= 0.041 \text{ crashes/year}
 \end{aligned}$$

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in that a calibration factor,  $C_r$ , of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

#### Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned}
 N_{\text{predicted } rs} &= C_r \times (N_{br} + N_{pedr} + N_{biker}) \\
 &= 1.00 \times (3.157 + 0.212 + 0.041) \\
 &= 3.410
 \end{aligned}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments

- *Worksheet SP2C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

#### **Worksheet SP2A—General Information and Input Data for Urban and Suburban Roadway Segments**

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2a

**Worksheet SP2A. General Information and Input Data for Urban and Suburban Roadway Segments**

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Road type (2U, 3T, 4U, 4D, 5T)		—	4D
Length of segment, L (mi)		—	0.75
AADT (veh/day)		—	23,000
Type of on-street parking (none/parallel/angle)		none	None
Proportion of curb length with on-street parking		—	N/A
Median width (ft)		15	40
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	not present
Major commercial driveways (number)		—	1
Minor commercial driveways (number)		—	4
Major industrial/institutional driveways (number)		—	—
Minor industrial/institutional driveways (number)		—	1
Major residential driveways (number)		—	1
Minor residential driveways (number)		—	1
Other driveways (number)		—	—
Speed Category		—	Low (30mph)
Roadside fixed object density (fixed objects/mi)		not present	20
Offset to roadside fixed objects (ft)		not present	12
Calibration Factor, $C_r$		1.0	1.0

**Worksheet SP2B—Crash Modification Factors for Urban and Suburban Roadway Segments**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP2B which indicates the combined CMF value.

**Worksheet SP2B. Crash Modification Factors for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	CMF for Roadside Fixed Objects	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{comb}$
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	$(1)*(2)*(3)*(4)*(5)$
1.00	1.02	0.97	0.91	1.00	0.90

**Worksheet SP2C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments**

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 2 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP2C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP2C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments**

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{base}$	Proportion of Total Crashes	Adjusted $N_{base}$	Combined CMFs	Calibration Factor	Predicted $N_{base}$
	from Table 12-3		from Table 12-3	from Equation 12-10		(4) <sub>total</sub> *(5)	(6) from Worksheet SP2B	$C_r$	(6)*(7)*(8)
	a	b							
Total	-12.34	1.36	1.32	2.804	1.000	2.804	0.90	1.00	2.524
Fatal and injury (FI)	-12.76	1.28	1.31	0.825	(4) <sub>FI</sub> /((4) <sub>FI</sub> +(4) <sub>PDO</sub> )	0.780	0.90	1.00	0.702
				0.278					
Property damage only (PDO)	-12.81	1.38	1.34	2.143	(5) <sub>total</sub> -(5) <sub>FI</sub>	2.024	0.90	1.00	1.822
				0.722					

**Worksheet SP2D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments**

Worksheet SP2D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).



These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP2C) into components by crash severity and collision type.

**Worksheet SP2D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{FI}$	Predicted $N_{\text{brms}} (FI)$ (crashes/year)	Proportion of Collision Type $_{PDO}$	Predicted $N_{\text{brms}} (PDO)$ (crashes/year)	Predicted $N_{\text{brms}} (\text{total})$ (crashes/year)
Collision Type	from Table 12-4	(9) $_{FI}$ from Worksheet SP2C	from Table 12-4	(9) $_{PDO}$ from Worksheet SP2C	(9) $_{\text{total}}$ from Worksheet SP2C
Total	1.000	0.702 (2)*(3) $_{FI}$	1.000	1.822 (4)*(5) $_{PDO}$	2.524 (3)+(5)
Rear-end collision	0.832	0.584	0.662	1.206	1.790
Head-on collision	0.020	0.014	0.007	0.013	0.027
Angle collision	0.040	0.028	0.036	0.066	0.094
Sideswipe, same direction	0.050	0.035	0.223	0.406	0.441
Sideswipe, opposite direction	0.010	0.007	0.001	0.002	0.009
Other multiple-vehicle collision	0.048	0.034	0.071	0.129	0.163

**Worksheet SP2E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments**

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 2 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP2E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP2E.** Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{base}$	Proportion of Total Crashes	Adjusted $N_{base}$	Combined CMFs	Calibration Factor	Predicted $N_{base}$
	from Table 12-5		from Table 12-5	from Equation 12-13		(4) <sub>total</sub> *(5)	(6) from worksheet SP2B	$C_r$	(6)*(7)*(8)
	a	b							
Total	-5.05	0.47	0.86	0.539	1.000	0.539	0.90	1.00	0.485
Fatal and injury (FI)	-8.71	0.66	0.28	0.094	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.174	0.094	0.90	1.00	0.085
Property damage only (PDO)	-5.04	0.45	1.06	0.446	$(5)_{total}-(5)_{FI}$ 0.826	0.445	0.90	1.00	0.401

**Worksheet SP2F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments**

Worksheet SP2F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP2E) into components by crash severity and collision type.

**Worksheet SP2F.** Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
Collision Type	Proportion of Collision Type (FI)	Predicted $N_{base}$ (FI) (crashes/year)	Proportion of Collision Type (PDO)	Predicted $N_{base}$ (PDO) (crashes/year)	Predicted $N_{base}$ (total) (crashes/year)
	from Table 12-6	(9) <sub>FI</sub> from Worksheet SP2E	from Table 12-6	(9) <sub>PDO</sub> from Worksheet SP2E	(9) <sub>total</sub> from Worksheet SP2E
		(2)*(3) <sub>FI</sub>		(4)*(5) <sub>PDO</sub>	(3)+(5)
Total	1.000	0.085	1.000	0.401	0.485
Collision with animal	0.001	0.000	0.063	0.025	0.025
Collision with fixed object	0.500	0.043	0.813	0.326	0.369
Collision with other object	0.028	0.002	0.016	0.006	0.008
Other single-vehicle collision	0.471	0.040	0.108	0.043	0.083

**Worksheet SP2G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments**

Worksheet SP2G determines and presents the number of multiple-vehicle driveway-related collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized).

**Worksheet SP2G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, $N_i$	Coefficient for Traffic Adjustment, $t$	Initial $N_{\text{driveway}}$	Overdispersion Parameter, $k$
Driveway Type	Number of Driveways, $n_i$	from Table 12-7	from Table 12-7	Equation 12-16 $n_i^* N_i^* (\text{AADT}/15,000)^t$	from Table 12-7
Major commercial	1	0.033	1.106	0.053	—
Minor commercial	4	0.011	1.106	0.071	
Major industrial/institutional	0	0.036	1.106	0.000	
Minor industrial/institutional	1	0.005	1.106	0.008	
Major residential	1	0.018	1.106	0.029	
Minor residential	1	0.003	1.106	0.005	
Other	0	0.005	1.106	0.000	
Total	—	—	—	0.166	1.39

**Worksheet SP2H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments**

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP2G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7, and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

**Worksheet SP2H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Initial $N_{ndrwy}$	Proportion of Total Crashes ( $f_{drwy}$ )	Adjusted $N_{ndrwy}$	Combined CMFs	Calibration Factor, $C_r$	Predicted $N_{ndrwy}$
	(5) <sub>total</sub> from Worksheet SP2G	from Table 12-7	(2) <sub>total</sub> * (3)	(6) from Worksheet SP2B		(4)*(5)*(6)
Total	0.166	1.000	0.166	0.90	1.00	0.149
Fatal and injury (FI)	—	0.284	0.047	0.90	1.00	0.042
Property damage only (PDO)	—	0.716	0.119	0.90	1.00	0.107

**Worksheet SP2I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments**

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP2I. Vehicle-Pedestrian Collisions**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	Predicted $N_{hmc}$	Predicted $N_{hmv}$	Predicted $N_{ndrwy}$	Predicted $N_{lv}$	$f_{pedr}$	Calibration Factor, $C_r$	Predicted $N_{pedr}$
	(9) from Worksheet SP2C	(9) from Worksheet SP2E	(7) from Worksheet SP2H	(2)+(3)+(4)	from Table 12-8		(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.067	1.000	0.212
Fatal and injury (FI)	—	—	—	—	—	1.00	0.212

**Worksheet SP2J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments**

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP2J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted $N_{bicycle}$	Predicted $N_{bicycle}$	Predicted $N_{bicycle}$	Predicted $N_{bicycle}$	$f_{bicycle}$		Predicted $N_{bicycle}$
Crash Severity Level	(9) from Worksheet SP2C	(9) from Worksheet SP2E	(7) from Worksheet SP2H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, $C_r$	(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.013	1.00	0.041
Fatal and injury	—	—	—	—	—	1.00	0.041

**Worksheet SP2K—Crash Severity Distribution for Urban and Suburban Roadway Segments**

Worksheet SP2K provides a summary of all collision types by severity level. Values from Worksheets SP2C, SP2E, SP2H, SP2I, and SP2J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

**Worksheet SP2K. Crash Severity Distribution for Urban and Suburban Roadway Segments**

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J	(5) from Worksheet SP2D and SP2F; and (7) from Worksheet SP2H	(6) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J
<b>MULTIPLE-VEHICLE</b>			
Rear-end collisions (from Worksheet SP2D)	0.584	1.206	1.790
Head-on collisions (from Worksheet SP2D)	0.014	0.013	0.027
Angle collisions (from Worksheet SP2D)	0.028	0.066	0.094
Sideswipe, same direction (from Worksheet SP2D)	0.035	0.406	0.441
Sideswipe, opposite direction (from Worksheet SP2D)	0.007	0.002	0.009
Driveway-related collisions (from Worksheet SP2H)	0.042	0.107	0.149
Other multiple-vehicle collision (from Worksheet SP2D)	0.034	0.129	0.163
Subtotal	0.744	1.929	2.673
<b>SINGLE-VEHICLE</b>			
Collision with animal (from Worksheet SP2F)	0.000	0.025	0.025
Collision with fixed object (from Worksheet SP2F)	0.043	0.326	0.369
Collision with other object (from Worksheet SP2F)	0.002	0.006	0.008
Other single-vehicle collision (from Worksheet SP2F)	0.040	0.043	0.083
Collision with pedestrian (from Worksheet SP2I)	0.212	0.000	0.212
Collision with bicycle (from Worksheet SP2J)	0.041	0.000	0.041
Subtotal	0.338	0.400	0.738
Total	1.082	2.329	3.411

**Worksheet SP2L—Summary Results for Urban and Suburban Roadway Segments**

Worksheet SP2L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

**Worksheet SP2L.** Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency, $N_{\text{predicted}}$ (crashes/year)	Roadway Segment Length, $L$ (mi)	Crash Rate (crashes/mi/year)
	(Total) from Worksheet SP2K		(2)/(3)
Total	3.411	0.75	4.5
Fatal and injury (FI)	1.082	0.75	1.4
Property damage only (PDO)	2.329	0.75	3.1

**12.13.3. Sample Problem 3**

The Site/Facility

A three-leg stop-controlled intersection located on an urban arterial.

**The Question**

What is the predicted crash frequency of the unsignalized intersection for a particular year?

**The Facts**

- 1 left-turn lane on one major road approach
- No right-turn lanes on any approach
- AADT of major road is 14,000 veh/day
- AADT of minor road is 4,000 veh/day

**Assumptions**

Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem 3 is determined to be 1.6 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the roadway segment in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

For a three-leg stop-controlled intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

**Multiple-Vehicle Crashes**

The SPF for multiple-vehicle collisions for a single three-leg stop-controlled intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$\begin{aligned}
 N_{bimv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 N_{bimv(total)} &= \exp(-13.63 + 1.11 \times \ln(14,000) + 0.41 \times \ln(4,000)) \\
 &= 1.892 \text{ crashes/year} \\
 \cancel{N_{bimv(FI)}} &= \exp(-14.01 + 1.16 \times \ln(14,000) + 0.30 \times \ln(4,000)) \\
 &= 0.639 \text{ crashes/year} \\
 N_{bimv(PDO)} &= \exp(-15.38 + 1.20 \times \ln(14,000) + 0.51 \times \ln(4,000)) \\
 &= 1.358 \text{ crashes/year}
 \end{aligned}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-22 and 12-23 to assure that they sum to the value for total crashes as follows:

$$\begin{aligned}
 N_{bimv(FI)} &= N_{bimv(total)} \left( \frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}} \right) \\
 &= 1.892 \times \left( \frac{0.639}{0.639 + 1.358} \right) \\
 &= 0.605 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{bimv(PDO)} &= N_{bimv(total)} - N_{bimv(FI)} \\
 &= 1.892 - 0.605 \\
 &= 1.287 \text{ crashes/year}
 \end{aligned}$$

#### Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single three-leg stop-controlled intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$\begin{aligned}
 N_{bisv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 N_{bisv(total)} &= \exp(-6.81 + 0.16 \times \ln(14,000) + 0.51 \times \ln(4,000)) \\
 &= 0.349 \text{ crashes/year} \\
 N_{bisv(PDO)} &= \exp(-8.36 + 0.25 \times \ln(14,000) + 0.55 \times \ln(4,000)) \\
 &= 0.244 \text{ crashes/year}
 \end{aligned}$$

Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections,  $N_{bisv(FI)}$  is calculated using Equation 12-27 (in place of Equation 12-25), and the initial value for  $N_{bisv(PDO)}$  calculated above is then adjusted using Equation 12-26 to assure that fatal-and-injury and property-damage-only crashes sum to the value for total crashes as follows:

$$N_{bisv(FI)} = N_{bisv(total)} \times f_{bisv}$$

For a three-leg stop-controlled intersection, the default proportion of fatal-and-injury crashes,  $f_{bisv} = 0.31$  (see Section 12.6.2, Single-Vehicle Crashes)

$$\begin{aligned}
 N_{bimv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 N_{bimv(total)} &= \exp(-13.63 + 1.11 \times \ln(14,000) + 0.41 \times \ln(4,000)) \\
 &= 1.892 \text{ crashes/year} \\
 \text{Deleted: } N_{bimv(FI)} &= \exp(-14.01 + 1.16 \times \ln(14,000) + 0.30 \times \ln(4,000)) \\
 &= 0.639 \text{ crashes/year} \\
 N_{bimv(PDO)} &= \exp(-15.38 + 1.20 \times \ln(14,000) + 0.51 \times \ln(4,000)) \\
 &= 1.358 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{bimv(FI)} &= N_{bimv(total)} \left( \frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}} \right) \\
 \text{Deleted: } &= 1.892 \times \left( \frac{0.639}{0.639 + 1.358} \right) \\
 &= 0.605 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{bisv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 N_{bisv(total)} &= \exp(-6.81 + 0.16 \times \ln(14,000) + 0.51 \times \ln(4,000)) \\
 &= 0.349 \text{ crashes/year} \\
 \text{Deleted: } N_{bisv(PDO)} &= \exp(-8.36 + 0.25 \times \ln(14,000) + 0.55 \times \ln(4,000)) \\
 &= 0.244 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed



$$\begin{aligned}
 N_{biv(FI)} &= 0.349 \times 0.31 \\
 &= 0.108 \text{ crashes/year} \\
 \cancel{N_{biv(PDO)} = N_{biv(total)} - N_{biv(FI)}} \\
 &= 0.349 - 0.108 \\
 &= 0.241 \text{ crashes/year}
 \end{aligned}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.**  
Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

#### Intersection Left-Turn Lanes ( $CMF_{1i}$ )

From Table 12-24, for a three-leg stop-controlled intersection with one left-turn lane on the major road,  $CMF_{1i} = 0.67$ .

#### Intersection Left-Turn Signal Phasing ( $CMF_{2i}$ )

For unsignalized intersections,  $CMF_{2i} = 1.00$ .

#### Intersection Right-Turn Lanes ( $CMF_{3i}$ )

Since no right-turn lanes are present,  $CMF_{3i}$  is 1.00 (i.e., the base condition for  $CMF_{3i}$  is the absent of right-turn lanes on the intersection approaches).

#### Right-Turn-on-Red ( $CMF_{4i}$ )

For unsignalized intersections,  $CMF_{4i} = 1.00$ .

#### Lighting ( $CMF_{5i}$ )

Since there is no lighting at this intersection,  $CMF_{5i}$  is 1.00 (i.e., the base condition for  $CMF_{5i}$  is the absence of intersection lighting).

#### Red-Light Cameras ( $CMF_{6i}$ )

For unsignalized intersections,  $CMF_{6i}$  is always 1.00.

The combined CMF value for Sample Problem 3 is 0.67.

#### Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions,  $N_{bi}$ , must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes.  $N_{bi}$  is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{6i})$$

From Equation 12-7,  $N_{spf\ int}$  can be calculated as follows:

$$\begin{aligned}
 N_{spf\ int} &= N_{bimv} + N_{biv} \\
 &= 1.892 + 0.349 \\
 &= 2.241 \text{ crashes/year}
 \end{aligned}$$

The combined CMF value for Sample Problem 3 is 0.67.

$$\begin{aligned}
 N_{bi} &= 2.241 \times (0.67) \\
 &= 1.501 \text{ crashes/year}
 \end{aligned}$$

$$\begin{aligned}
 N_{biv(FI)} &= 0.349 \times 0.31 \\
 &= 0.108 \text{ crashes/year} \\
 \text{Deleted: } N_{biv(PDO)} &= N_{biv(total)} - N_{biv(FI)} \quad \P \\
 &= 0.349 - 0.108 \\
 &= 0.241 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{spf\ int} &= N_{bimv} + N_{biv} \\
 \text{Deleted: } &= 1.892 + 0.349 \quad \P \\
 &= 2.241 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{bi} &= 2.241 \times (0.67) \\
 \text{Deleted: } &= 1.501 \text{ crashes/year} \quad \P
 \end{aligned}$$

Field Code Changed

The SPF for vehicle-pedestrian collisions for a three-leg stop-controlled intersection is calculated from Equation 12-30 as follows:

$$N_{pedi} = N_{bi} \times f_{pedi}$$

From Table 12-16, for a three-leg stop-controlled intersection the pedestrian crash adjustment factor,  $f_{pedi} = 0.211$ .

$$\begin{aligned} N_{pedi} &= 1.501 \times 0.021 \\ &= 0.032 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikei} = N_{pedi} \times f_{bikei}$$

From Table 12-17, for a three-leg stop-controlled intersection, the bicycle crash adjustment factor  $f_{bikei} = 0.016$ .

$$\begin{aligned} N_{bikei} &= 1.501 \times 0.016 \\ &= 0.024 \text{ crashes/year} \end{aligned}$$

Deleted:  $f_{bikei} = 0.016$ .

Field Code Changed

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in Sample Problem 3 that a calibration factor,  $C_i$ , of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

#### **Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 12-5 based on results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted int}} &= C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \\ &= 1.00 \times (1.501 + 0.032 + 0.024) \\ &= 1.557 \text{ crashes/year} \end{aligned}$$

## **WORKSHEETS**

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 12 worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

- *Worksheet SP3G (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections
- *Worksheet SP3J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP3K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SP3L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

#### **Worksheet SP3A—General Information and Input Data for Urban and Suburban Arterial Intersections**

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 3.

**Worksheet SP3A. General Information and Input Data for Urban and Suburban Arterial Intersections**

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)	—	3ST
AADT <sub>maj</sub> (veh/day)	—	14,000
AADT <sub>min</sub> (veh/day)	—	4,000
Intersection lighting (present/not present)	not present	not present
Calibration factor, $C_i$	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	1
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	0
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian ( $n_{lanes}$ )	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

**Worksheet SP3B—Crash Modification Factors for Urban and Suburban Arterial Intersections**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 7 of Worksheet SP3B which indicates the combined CMF value.

**Worksheet SP3B. Crash Modification Factors for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	CMF for Left-Turn Signal Phasing	CMF for Right-Turn Lanes	CMF for Right-Turn-on-Red	CMF for Lighting	CMF for Red-Light Cameras	Combined CMF
$CMF_{li}$	$CMF_{2i}$	$CMF_{3i}$	$CMF_{4i}$	$CMF_{5i}$	$CMF_{6i}$	$CMF_{comb}$
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	$(1)*(2)*(3)*(4)*(5)*(6)$
0.67	1.00	1.00	1.00	1.00	1.00	0.67

**Worksheet SP3C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections**

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 3 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP3C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP3B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP3C.** Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, $k$	Initial $N_{bimv}$	Proportion of Total Crashes	Adjusted $N_{bimv}$	Combined CMFs	Calibration Factor, $C_i$	Predicted $N_{bimv}$
	from Table 12-10			from Table 12-10	from Equation 12-22		(4) <sub>total</sub> *(5)	(7) from Worksheet SP3B		(6)*(7)*(8)
	a	b	c							
Total	−13.36	1.11	0.41	0.80	1.892	1.000	1.892	0.67	1.00	1.268
Fatal and injury (FI)	−14.01	1.16	0.30	0.69	0.639	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$	0.605	0.67	1.00	0.405
						0.320				
Property damage only (PDO)	−15.38	1.20	0.51	0.77	1.358	$(5)_{total}-(5)_{FI}$	1.287	0.67	1.00	0.862
						0.680				

**Worksheet SP3D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

Worksheet SP3D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP3C) into components by crash severity and collision type.

**Worksheet SP3D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $p_{FI}$	Predicted $N_{biv(FI)}$ (crashes/year)	Proportion of Collision Type $p_{PDO}$	Predicted $N_{biv(PDO)}$ (crashes/year)	Predicted $N_{biv(total)}$ (crashes/year)
Collision Type	from Table 12-11	(9) $n$ from Worksheet SP3C	from Table 12-11	(9) $p_{PDO}$ from Worksheet SP3C	(9) $p_{PDO}$ from Worksheet SP3C
Total	1.000	0.405 (2)*(3) $_{FI}$	1.000	0.862 (4)*(5) $_{PDO}$	1.268 (3)+(5)
Rear-end collision	0.421	0.171	0.440	0.379	0.550
Head-on collision	0.045	0.018	0.023	0.020	0.038
Angle collision	0.343	0.139	0.262	0.226	0.365
Sideswipe	0.126	0.051	0.040	0.034	0.085
Other multiple-vehicle collision	0.065	0.026	0.235	0.203	0.229

**Worksheet SP3E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections**

The SPF for single-vehicle crashes at the intersection in Sample Problem 3 is calculated using Equation 12-25 for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP3E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections,  $N_{biv(FI)}$  is calculated using Equation 12-27 (in place of Equation 12-25), and the value is entered into Column 4 and 6 since no further adjustment is required. Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP3B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP3E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections**

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, $k$	Initial $N_{base}$	Proportion of Total Crashes	Adjusted $N_{base}$	Combined CMFs	Calibration Factor, $C_i$	Predicted $N_{base}$
	from Table 12-12				from Equation 12-25; (FI) from Equation 12-25 or 12-27					(7) from Worksheet SP3B
	a	b	c							
Total	-6.81	0.16	0.51	1.14	0.349	1.000	0.349	0.67	1.00	0.234
Fatal and injury (FI)	N/A	N/A	N/A	N/A	0.108	$(4)_{FI} / ((4)_{FI} + (4)_{PDO})$	0.108	0.67	1.00	0.072
						N/A				
Property damage only (PDO)	-8.36	0.25	0.55	1.29	0.244	$(5)_{total} - (5)_{FI}$	0.242	0.67	1.00	0.162
						0.693				

**Worksheet SP3F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections**

Worksheet SP3F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP3E) into components by crash severity and collision type.



**Worksheet SP3F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type (FI)	Predicted $N_{\text{base}}^{\text{FI}}$ (crashes/year)	Proportion of Collision Type (PDO)	Predicted $N_{\text{base}}^{\text{PDO}}$ (crashes/year)	Predicted $N_{\text{base}}^{\text{total}}$ (crashes/year)
Collision Type	Table 12-13	(9) <sub>FI</sub> from Worksheet SP3E	Table 12-13	(9) <sub>PDO</sub> from Worksheet SP3E	(9) <sub>PDO</sub> from Worksheet SP3E
Total	1.000	0.072 (2)*(3) <sub>FI</sub>	1.000	0.162 (4)*(5) <sub>PDO</sub>	0.234 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.003	0.000	0.000
Collision with animal	0.003	0.000	0.018	0.003	0.003
Collision with fixed object	0.762	0.055	0.834	0.135	0.190
Collision with other object	0.090	0.006	0.092	0.015	0.021
Other single-vehicle collision	0.039	0.003	0.023	0.004	0.007
Single-vehicle noncollision	0.105	0.008	0.030	0.005	0.013

**Worksheet SP3G—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections**

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP3G. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted $N_{\text{base}}^{\text{mv}}$	Predicted $N_{\text{base}}^{\text{sv}}$	Predicted $N_{\text{base}}^{\text{total}}$	$f_{\text{ped}}$		Predicted $N_{\text{ped}}$
Crash Severity Level	(9) from Worksheet SP3C	(9) from Worksheet SP3E	(2)+(3)	from Table 12-16	Calibration Factor, $C_i$	(4)*(5)*(6)
Total	1.268	0.234	1.502	0.021	1.00	0.032
Fatal and injury (FI)	—	—	—	—	1.00	0.032

**Worksheet SP3J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections**

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP3J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted $N_{bimv}$	Predicted $N_{bivv}$	Predicted $N_{bt}$	$f_{biket}$		Predicted $N_{pedt}$
Crash Severity Level	(9) from Worksheet SP3C	(9) from Worksheet SP3E	(2)+(3)	from Table 12-17	Calibration Factor, $C_i$	(4)*(5)*(6)
Total	1.268	0.234	1.502	0.016	1.000	0.024
Fatal and injury (FI)	—	—	—	—	1.000	0.024

**Worksheet SP3K—Crash Severity Distribution for Urban and Suburban Arterial Intersections**

Worksheet SP3K provides a summary of all collision types by severity level. Values from Worksheets SP3D, SP3F, SP3G, and SP3J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

**Worksheet SP3K. Crash Severity Distribution for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)
Collision Type	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
	(3) from Worksheets SP3D and SP3F; (7) from SP3G and SP3J	(5) from Worksheets SP3D and SP3F	(6) from Worksheets SP3D and SP3F; (7) from SP3G and SP3J
<b>MULTIPLE-VEHICLE COLLISIONS</b>			
Rear-end collisions (from Worksheet SP3D)	0.171	0.379	0.550
Head-on collisions (from Worksheet SP3D)	0.018	0.020	0.038
Angle collisions (from Worksheet SP3D)	0.139	0.226	0.365
Sideswipe (from Worksheet SP3D)	0.051	0.034	0.085
Other multiple-vehicle collision (from Worksheet SP3D)	0.026	0.203	0.229
Subtotal	0.405	0.862	1.267
<b>SINGLE-VEHICLE COLLISIONS</b>			
Collision with parked vehicle (from Worksheet SP3F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP3F)	0.000	0.003	0.003
Collision with fixed object (from Worksheet SP3F)	0.055	0.135	0.190
Collision with other object (from Worksheet SP3F)	0.006	0.015	0.021
Other single-vehicle collision (from Worksheet SP3F)	0.003	0.004	0.007
Single-vehicle noncollision (from Worksheet SP3F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP3G)	0.032	0.000	0.032
Collision with bicycle (from Worksheet SP3J)	0.024	0.000	0.024
Subtotal	0.128	0.162	0.290
Total	0.533	1.024	1.557

**Worksheet SP3L—Summary Results for Urban and Suburban Arterial Intersections**

Worksheet SP3L presents a summary of the results.

**Worksheet SP3L. Summary Results for Urban and Suburban Arterial Intersections**

(1)	(2)
Crash Severity Level	Predicted Average Crash Frequency, $N_{\text{predicted int}}$ (crashes/year)
	(Total) from Worksheet SP3K
Total	1.557
Fatal and injury (FI)	0.533
Property damage only (PDO)	1.024

**12.13.4. Sample Problem 4****The Intersection**

A four-leg signalized intersection located on an urban arterial.

**The Question**

What is the predicted crash frequency of the signalized intersection for a particular year?

**The Facts**

- 1 left-turn lane on each of the two major road approaches
- 1 right-turn lane on each of the two major road approaches
- Protected/permissive left-turn signal phasing on major road
- AADT of major road is 15,000 veh/day
- AADT of minor road is 9,000 veh/day
- Lighting is present
- No approaches with prohibited right-turn-on-red
- Four-lane divided major road
- Two-lane undivided minor road
- Pedestrian volume is 1,500 peds/day
- The number of bus stops within 1,000 ft of intersection is 2
- A school is present within 1,000 ft of intersection
- The number of alcohol establishments within 1,000 ft of intersection is 6

**Assumptions**

Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-28 and 12-31.

The calibration factor is assumed to be 1.00.

The maximum number of lanes crossed by a pedestrian is assumed to be four (crossing two through lanes, one left-turn lane, and one right-turn lane across one side of the divided major road).

**Results**

Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem 4 is determined to be 3.4 crashes per year (rounded to one decimal place).

**Steps****Step 1 through 8**

To determine the predicted average crash frequency of the roadway segment in Sample Problem 4, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year and the EB Method is not applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.**

For a four-leg signalized intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple- and single-vehicle collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 3 (for fatal-and-injury base crashes at a four-leg signalized intersection, Equation 12-25 in place of Equation 12-27 is used). The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

**Multiple-Vehicle Collisions**

The SPF for multiple-vehicle collisions for a single four-leg signalized intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$\begin{aligned}
 N_{bimv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 \cancel{N_{bimv(total)}} &= \cancel{\exp(-10.99 + 1.07 \times \ln(15,000) + c \times \ln(9,000))} \\
 &= 4.027 \text{ crashes/year}
 \end{aligned}$$

**Single-Vehicle Crashes**

The SPF for single-vehicle crashes for a single four-leg signalized intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$\begin{aligned}
 N_{bisv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 \cancel{N_{bisv(total)}} &= \cancel{\exp(-10.21 + 0.68 \times \ln(15,000) + 0.27 \times \ln(9,000))} \\
 &= 0.297 \text{ crashes/year}
 \end{aligned}$$

**Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.**

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below.  $CMF_{li}$  through  $CMF_{2i}$  are applied to multiple-vehicle collisions and single-vehicle crashes, while  $CMF_{lp}$  through  $CMF_{3p}$  are applied to vehicle-pedestrian collisions.

**Intersection Left-Turn Lanes ( $CMF_{li}$ )**

From Table 12-24, for a four-leg signalized intersection with one left-turn lane on each of two approaches,  $CMF_{li} = 0.81$ .

**Intersection Left-Turn Signal Phasing ( $CMF_{2i}$ )**

From Table 12-25, for a four-leg signalized intersection with protected/permissive left-turn signal phasing for two approaches,  $CMF_{2i} = 0.98(0.99 \times 0.99)$ .

**Intersection Right-Turn Lanes ( $CMF_{3i}$ )**

From Table 12-26, for a four-leg signalized intersection with one right-turn lane on each of two approaches,  $CMF_{3i} = 0.92$ .

**Right-Turn-on-Red ( $CMF_{4i}$ )**

Since right-turn-on-red (RTOR) is not prohibited on any of the intersection legs,  $CMF_{4i} = 1.00$  (i.e., the base condition for  $CMF_{4i}$  is permitting a RTOR at all approaches to a signalized intersection).

**Lighting ( $CMF_{5i}$ )**

$CMF_{5i}$  is calculated from Equation 12-36.

$$CMF_{5i} = 1 - 0.38 \times p_{ni}$$

From Table 12-27, the proportion of crashes that occur at night,  $p_{ni} = 0.235$ .

$$\begin{aligned}
 CMF_{5i} &= 1 - 0.38 \times 0.235 \\
 &= 0.91
 \end{aligned}$$

**Red-Light Cameras ( $CMF_{6i}$ )**

Since no red light cameras are present at this intersection,  $CMF_{6i} = 1.00$  (i.e., the base condition for  $CMF_{6i}$  is the absence of red light cameras).

$$\begin{aligned}
 N_{bimv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 \text{Deleted: } N_{bimv(total)} &= \exp(-10.99 + 1.07 \times \ln(15,000) + c \times \ln(9,000)) \\
 &= 4.027 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{bisv} &= \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \\
 \text{Deleted: } N_{bisv(total)} &= \exp(-10.21 + 0.68 \times \ln(15,000) + 0.27 \times \ln(9,000)) \\
 &= 0.297 \text{ crashes/year}
 \end{aligned}$$

Field Code Changed

The combined CMF value applied to multiple- and single-vehicle crashes in Sample Problem 4 is calculated below.

$$\begin{aligned} CMF_{comb} &= 0.81 \times 0.98 \times 0.92 \times 0.91 \\ &= 0.66 \end{aligned}$$

#### Bus Stop ( $CMF_{1p}$ )

From Table 12-28, for two bus stops within 1,000 ft of the center of the intersection,  $CMF_{1p} = 2.78$ .

#### Schools ( $CMF_{2p}$ )

From Table 12-29, for one school within 1,000 ft of the center of the intersection,  $CMF_{2p} = 1.35$ .

#### Alcohol Sales Establishments ( $CMF_{3p}$ )

From Table 12-30, for six alcohol establishments within 1,000 ft of the center of the intersection,  $CMF_{3p} = 1.12$ .

#### Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The SPF for vehicle-pedestrian collisions for a four-leg signalized intersection is calculated from Equation 12-28 as follows:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p}$$

$N_{pedbase}$  is calculated from Equation 12-29 using the coefficients from Table 12-14.

$$\begin{aligned} N_{pedbase} &= \exp \left( a + b \times \ln(AADT_{total}) + c \times \ln \left( \frac{AADT_{min}}{AADT_{maj}} \right) + d \times \ln(PedVol) + e \times n_{laness} \right) \\ &= \exp \left( -9.53 + 0.40 \times \ln(24,000) + 0.26 \times \ln \left( \frac{9,000}{15,000} \right) + 0.45 \times \ln(1,500) + 0.04 \times 4 \right) \\ &= 0.113 \text{ crashes/year} \end{aligned}$$

The CMF vehicle-pedestrian collision values calculated above are  $CMF_{1p} = 2.78$ ,  $CMF_{2p} = 1.35$ , and  $CMF_{3p} = 1.12$ .

$$\begin{aligned} N_{pedi} &= 0.113 \times 2.78 \times 1.35 \times 1.12 \\ &= 0.475 \text{ crashes/year} \end{aligned}$$

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions,  $N_{bi}$ , must be calculated in order to determine vehicle-bicycle crashes.  $N_{bi}$  is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \dots \times CMF_{6i})$$

From Equation 12-7,  $N_{spf\ int}$  can be calculated as follows:

$$\begin{aligned} N_{spf\ int} &= N_{bimv} + N_{bisv} \\ &= 4.027 + 0.297 \\ &= 4.324 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 4 is 0.66.

$$\begin{aligned} N_{bi} &= 4.324 \times (0.66) \\ &= 2.854 \text{ crashes/year} \end{aligned}$$

$$\begin{aligned} \text{Deleted: } CMF_{comb} &= 0.81 \times 0.98 \times 0.92 \times 0.91 \\ &= 0.66 \end{aligned}$$

Field Code Changed

$$\begin{aligned} \text{Deleted: } N_{pedbase} &= \exp \left( a + b \times \ln(AADT_{total}) + c \times \ln \left( \frac{A_{min}}{A_{maj}} \right) + d \times \ln(PedVol) + e \times n_{laness} \right) \\ &= \exp \left( -9.53 + 0.40 \times \ln(24,000) + 0.26 \times \ln \left( \frac{9,000}{15,000} \right) + 0.45 \times \ln(1,500) + 0.04 \times 4 \right) \\ &= 0.113 \text{ crashes/year} \end{aligned}$$

Field Code Changed

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikel} = N_{bi} \times f_{bikel}$$

From Table 12-17, for a four-leg signalized intersection the bicycle crash adjustment factor,  $f_{bikel} = 0.015$ .

$$\begin{aligned} N_{bikel} &= 2.854 \times 0.015 \\ &= 0.043 \text{ crashes/year} \end{aligned}$$

Deleted:  $N_{bikel} = 2.854 \times 0.015$   
= 0.043 crashes/year ¶

Field Code Changed

**Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.**

It is assumed in Sample Problem 4 that a calibration factor,  $C_i$ , of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

#### Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated from Equation 12-5 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted int}} &= C_i \times (N_{bi} + N_{pedi} + N_{bikel}) \\ &= 1.00 \times (2.854 + 0.475 + 0.043) \\ &= 3.372 \text{ crashes/year} \end{aligned}$$

## WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 12 worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP4B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP4C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4H (Corresponds to Worksheet 2H)*—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SP4I (Corresponds to Worksheet 2I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SP4J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP4K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections

- *Worksheet SP4L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

### Worksheet SP4A—General Information and Input Data for Urban and Suburban Arterial Intersections

Worksheet SP4A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4.

#### Worksheet SP4A. General Information and Input Data for Urban and Suburban Arterial Intersections

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)		—	4SG
AADT <sub>maj</sub> (veh/day)		—	15,000
AADT <sub>min</sub> (veh/day)		—	9,000
Intersection lighting (present/not present)		not present	present
Calibration factor, $C_i$		1.00	1.00
Data for unsignalized intersections only:		—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)		0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)		0	N/A
Data for signalized intersections only:		—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)		0	2
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)		0	2
Number of approaches with left-turn signal phasing		—	2
Number of approaches with right-turn-on-red prohibited		0	0
Type of left-turn signal phasing		permissive	protected/permissive
Intersection red-light cameras (present/not present)		not present	not present
Sum of all pedestrian crossing volumes (PedVol)		—	1,500
Maximum number of lanes crossed by a pedestrian ( $n_{lanes}$ )		—	4
Number of bus stops within 300 m (1,000 ft) of the intersection		0	2
Schools within 300 m (1,000 ft) of the intersection (present/not present)		not present	present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection		0	6



**Worksheet SP4B—Crash Modification Factors for Urban and Suburban Arterial Intersections**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 7 of Worksheet SP4B which indicates the combined CMF value.

**Worksheet SP4B.** Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	CMF for Left-Turn Signal Phasing	CMF for Right-Turn Lanes	CMF for Right-Turn-on-Red	CMF for Lighting	CMF for Red-Light Cameras	Combined CMF
$CMF_{1i}$	$CMF_{2i}$	$CMF_{3i}$	$CMF_{4i}$	$CMF_{5i}$	$CMF_{6i}$	$CMF_{comb}$
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	$(1)*(2)*(3)*(4)*(5)*(6)$
0.81	0.98	0.92	1.00	0.91	1.00	0.66

**Worksheet SP4C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections**

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 4 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP4C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP4B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP4C.** Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, <i>k</i>	Initial <i>N<sub>bimv</sub></i>	Proportion of Total Crashes	Adjusted <i>N<sub>bimv</sub></i>	Combined CMFs	Calibration Factor, <i>C<sub>i</sub></i>	Predicted <i>N<sub>bimv</sub></i>
	from Table 12-10			from Table 12-10	from Equation 12-22		(4) <sub>total</sub> *(5)	(7) from Worksheet SP4B		(6)*(7)*(8)
a	b	c	from Table 12-10	from Equation 12-22	Proportion of Total Crashes	(4) <sub>total</sub> *(5)	(7) from Worksheet SP4B	Calibration Factor, <i>C<sub>i</sub></i>	(6)*(7)*(8)	
Total	−10.99	1.07	0.23	0.39	4.027	1.000	4.027	0.66	1.00	2.658
Fatal and injury (FI)	−13.14	1.18	0.22	0.33	1.233	(4) <sub>FI</sub> /((4) <sub>FI</sub> + (4) <sub>PDO</sub> )	1.281	0.66	1.00	0.845
						0.318				
Property damage only (PDO)	−11.02	1.02	0.24	0.44	2.647	(5) <sub>total</sub> −(5) <sub>FI</sub>	2.746	0.66	1.00	1.812
						0.682				

**Worksheet SP4D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

Worksheet SP4D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP4C) into components by crash severity and collision type.

**Worksheet SP4D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $(P_i)$	Predicted $N_{\text{fi}} (FI)$ (crashes/year)	Proportion of Collision Type $(P_{PDO})$	Predicted $N_{\text{PDO}} (PDO)$ (crashes/year)	Predicted $N_{\text{fi}} (total)$ (crashes/year)
Collision Type	from Table 12-11	(9) <sub>FI</sub> from Worksheet SP4C	from Table 12-11	(9) <sub>PDO</sub> from Worksheet SP4C	(9) <sub>PDO</sub> from Worksheet SP4C
Total	1.000	0.845 (2)*(3) <sub>FI</sub>	1.000	1.812 (4)*(5) <sub>PDO</sub>	2.658 (3)+(5)
Rear-end collision	0.450	0.380	0.483	0.875	1.255
Head-on collision	0.049	0.041	0.030	0.054	0.095
Angle collision	0.347	0.293	0.244	0.442	0.735
Sideswipe	0.099	0.084	0.032	0.058	0.142
Other multiple-vehicle collision	0.055	0.046	0.211	0.382	0.428

**Worksheet SP4E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections**

The SPF for single-vehicle crashes at the intersection in Sample Problem 4 is calculated using Equation 12-25 for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP4E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2, and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP4B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

**Worksheet SP4E.** Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, $k$	Initial $N_{bisev}$	Proportion of Total Crashes	Adjusted $N_{bisev}$	Combined CMFs	Calibration Factor, $C_i$	Predicted $N_{bisev}$
	from Table 12-12			from Table 12-12	from Equation 12-25; (FI) from Equation 12-25 or 12-27		(4) <sub>total</sub> *(5)	(7) from Worksheet SP4B		(6)*(7)*(8)
	a	b	c							
Total	-10.21	0.68	0.27	0.36	0.297	1.000	0.297	0.66	1.000	0.196
Fatal and injury (FI)	-9.25	0.43	0.29	0.09	0.084	$(4)_{FI} / ((4)_{FI} + (4)_{PDO})$ 0.287	0.085	0.66	1.000	0.056
Property damage only (PDO)	-11.34	0.78	0.25	0.44	0.209	$(5)_{total} - (5)_{FI}$ 0.713	0.212	0.66	1.000	0.140

**Worksheet SP4F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections**

Worksheet SP4F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP4E) into components by crash severity and collision type.

**Worksheet SP4F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $(P)$	Predicted $N_{\text{base}}$ (FI) (crashes/year)	Proportion of Collision Type $(PDO)$	Predicted $N_{\text{base}}$ (PDO) (crashes/year)	Predicted $N_{\text{base}}$ (total) (crashes/year)
Collision Type	Table 12-13	(9) <sub>FI</sub> from Worksheet SP4E	Table 12-13	(9) <sub>PDO</sub> from Worksheet SP4E	(9) <sub>PDO</sub> from Worksheet SP4E
Total	1.000	0.056 (2)*(3) <sub>FI</sub>	1.000	0.140 (4)*(5) <sub>PDO</sub>	0.196 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.001	0.000	0.000
Collision with animal	0.002	0.000	0.002	0.000	0.000
Collision with fixed object	0.744	0.042	0.870	0.122	0.164
Collision with other object	0.072	0.004	0.070	0.010	0.014
Other single-vehicle collision	0.040	0.002	0.023	0.003	0.005
Single-vehicle noncollision	0.141	0.008	0.034	0.005	0.013

**Worksheet SP4H—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections**

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values for vehicle-pedestrian collision. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 4 of Worksheet SP4H which indicates the combined CMF value for vehicle-pedestrian collisions.

**Worksheet SP4H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections**

(1)	(2)	(3)	(4)
CMF for Bus Stops	CMF for Schools	CMF for Alcohol Sales Establishments	Combined CMF
$CMF_{lp}$	$CMF_{2p}$	$CMF_{3p}$	(1)*(2)*(3)
from Table 12-28	from Table 12-29	from Table 12-30	
2.78	1.35	1.12	4.20

**Worksheet SP4I—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections**

The predicted number of vehicle-pedestrian collisions per year for base conditions at a signalized intersection,  $N_{pedbase}$ , is calculated using Equation 12-30 and entered into Column 4 of Worksheet SP4I. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 represents the combined CMF for vehicle-pedestrian collisions (from Column 4 in Worksheet SP4H), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of vehicle-pedestrian collisions using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP4I. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections**

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients					Overdispersion Parameter, <i>k</i>	<i>N<sub>pedbase</sub></i>	Combined CMF	Calibration Factor, <i>C<sub>i</sub></i>	Predicted <i>N<sub>pedi</sub></i>
	from Table 12-14						from Equation 12-30	(4) from Worksheet SP4H		(8)*(9)*(10)
	a	b	c	d	e					
Total	−9.53	0.40	0.26	0.45	0.04	0.24	0.113	4.20	1.00	0.475
Fatal and injury (FI)	—	—	—	—	—	—	—	—	1.00	0.475

**Worksheet SP4J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections**

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP4C and SP4E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

**Worksheet SP4J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted $N_{bimv}$	Predicted $N_{biov}$	Predicted $N_{bi}$	$f_{bikel}$		Predicted $N_{pedi}$
Crash Severity Level	(9) from Worksheet SP4C	(9) from Worksheet SP4E	(2)+(3)	from Table 12-17	Calibration Factor, $C_i$	(4)*(5)*(6)
Total	2.658	0.196	2.854	0.015	1.00	0.043
Fatal and injury (FI)	—	—	—	—	1.00	0.043

**Worksheet SP4K—Crash Severity Distribution for Urban and Suburban Arterial Intersections**

Worksheet SP4K provides a summary of all collision types by severity level. Values from Worksheets SP4D, SP4F, SP4I, and SP4J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

**Worksheet SP4K. Crash Severity Distribution for Urban and Suburban Arterial Intersections**

(1)	(2)	(3)	(4)
Collision Type	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
	(3) from Worksheets SP4D and SP4F; (7) from SP4I and SP4J	(5) from Worksheets SP4D and SP4F	(6) from Worksheets SP4D and SP4F; (7) from SP4I and SP4J
<b>MULTIPLE-VEHICLE COLLISIONS</b>			
Rear-end collisions (from Worksheet SP4D)	0.380	0.875	1.255
Head-on collisions (from Worksheet SP4D)	0.041	0.054	0.095
Angle collisions (from Worksheet SP4D)	0.293	0.442	0.735
Sideswipe (from Worksheet SP4D)	0.084	0.058	0.142
Other multiple-vehicle collision (from Worksheet SP4D)	0.046	0.382	0.428
Subtotal	0.844	1.811	2.655
<b>SINGLE-VEHICLE COLLISIONS</b>			
Collision with parked vehicle (from Worksheet SP4F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP4F)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SP4F)	0.042	0.122	0.164
Collision with other object (from Worksheet SP4F)	0.004	0.010	0.014
Other single-vehicle collision (from Worksheet SP4F)	0.002	0.003	0.005
Single-vehicle noncollision (from Worksheet SP4F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP4I)	0.475	0.000	0.475
Collision with bicycle (from Worksheet SP4J)	0.043	0.000	0.043
Subtotal	0.574	0.140	0.714
Total	1.418	1.951	3.369

**Worksheet SP4L—Summary Results for Urban and Suburban Arterial Intersections**

Worksheet SP4L presents a summary of the results.



**Worksheet SP4L.** Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{\text{predicted int}}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SP4K
Total	3.369
Fatal and injury (FI)	1.418
Property damage only (PDO)	1.951

**12.13.5. Sample Problem 5****The Project**

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

**The Question**

What is the expected crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1 through 4 and the observed crash frequencies using the site-specific EB Method?

**The Facts**

- 2 roadway segments (3T segment, 4D segment)
- 2 intersections (3ST intersection, 4SG intersection)
- 34 observed crashes (3T segment: 7 multiple-vehicle nondriveway, 4 single-vehicle, 2 multiple-vehicle driveway related; 4D: 6 multiple-vehicle nondriveway, 3 single-vehicle, 1 multiple-vehicle driveway related; 3ST: 2 multiple-vehicle, 3 single-vehicle; 4SG 6 multiple-vehicle, 0 single-vehicle)

**Outline of Solution**

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted crash frequencies for the project using the site-specific EB Method (i.e., observed crashes are assigned to specific intersections or roadway segments) presented in Part C, Appendix A.2.4.

**Results**

The expected average crash frequency for the project is 25.4 crashes per year (rounded to one decimal place).

**WORKSHEETS**

To apply the site-specific EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- Worksheet SP5A (Corresponds to Worksheet 3A)*—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.
- Worksheet SP5B (Corresponds to Worksheet 3B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials.
- Worksheet SP5C (Corresponds to Worksheet 3C)*—Site-Specific EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

**Worksheets SP5A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.**

The predicted average crash frequencies by severity level and collision type determined in Sample Problems 1 through 4 are entered into Columns 2 through 4 of Worksheet SP5A. Column 5 presents the observed crash frequencies by site and collision type, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from Part C, Appendix A is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8. Detailed calculation of Columns 7 and 8 are provided below.

**Worksheet SP5A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	Weighted Adjustment, $w$	Expected Average Crash Frequency, $N_{\text{expected (vehicle)}}$
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FI)}}$	$N_{\text{predicted (PDO)}}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1	4.967	1.196	3.771	7	0.66	0.234	6.524
Segment 2	2.524	0.702	1.822	6	1.32	0.231	5.197
Single-Vehicle							
Segment 1	1.182	0.338	0.844	4	1.37	0.382	2.924
Segment 2	0.485	0.085	0.401	3	0.86	0.706	1.224
Multiple-Vehicle Driveway-Related							
Segment 1	0.734	0.179	0.555	2	1.10	0.553	1.300
Segment 2	0.149	0.042	0.107	1	1.39	0.828	0.295
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1	1.268	0.405	0.862	2	0.80	0.496	1.637
Intersection 2	2.658	0.845	1.812	6	0.39	0.491	4.359
Single-Vehicle							
Intersection 1	0.234	0.072	0.162	3	1.14	0.789	0.818
Intersection 2	0.196	0.056	0.140	0	0.36	0.934	0.183
Combined (Sum of Column)	14.397	3.920	10.476	34	—	—	24.461

**Column 7—Weighted Adjustment**

The weighted adjustment,  $w$ , to be placed on the predictive model estimate is calculated using Equation A-5 as follows:

$$w = \frac{1}{1 + k \times \left( \sum_{\substack{\text{all study} \\ \text{years}}} N_{\text{predicted}} \right)}$$

***Multiple-Vehicle Nondriveway Collisions***

Segment 1

$$w = \frac{1}{1 + 0.66 \times (4.967)} = 0.234$$

Segment 2

$$w = \frac{1}{1 + 1.32 \times (2.524)} = 0.231$$

***Single-Vehicle Crashes***

Segment 1

$$w = \frac{1}{1 + 1.37 \times (1.182)} = 0.382$$

Segment 2

$$w = \frac{1}{1 + 0.86 \times (0.485)} = 0.706$$

***Multiple-Vehicle Driveway Related Collisions***

Segment 1

$$w = \frac{1}{1 + 1.10 \times (0.734)} = 0.553$$

Segment 2

$$w = \frac{1}{1 + 1.39 \times (0.149)} = 0.828$$

***Multiple-Vehicle Collisions***

Intersection 1

$$w = \frac{1}{1 + 0.80 \times (1.268)} = 0.496$$

Intersection 2

$$w = \frac{1}{1 + 0.39 \times (2.658)} = 0.491$$

#### *Single-Vehicle Crashes*

Intersection 1

$$w = \frac{1}{1 + 1.149 \times (0.234)} = 0.789$$

Intersection 2

$$w = \frac{1}{1 + 0.36 \times (0.196)} = 0.934$$

#### **Column 8—Expected Average Crash Frequency**

The estimate of expected average crash frequency,  $N_{\text{expected}}$ , is calculated using Equation A-4 as follows:

$$N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}}$$

#### *Multiple-Vehicle Nondriveway Collisions*

$$\text{Segment 1 } N_{\text{expected}} = 0.234 \times 4.967 + (1 - 0.234) \times 7 = 6.524$$

$$\text{Segment 2 } N_{\text{expected}} = 0.231 \times 2.524 + (1 - 0.231) \times 6 = 5.197$$

#### *Single-Vehicle Crashes*

$$\text{Segment 1 } N_{\text{expected}} = 0.382 \times 1.182 + (1 - 0.382) \times 4 = 2.924$$

$$\text{Segment 2 } N_{\text{expected}} = 0.706 \times 0.485 + (1 - 0.706) \times 3 = 1.224$$

**Deleted:**  $N_{\text{expected}} = 0.706 \times 0.485 + (1 - 0.706) \times 3 = 1.224$

#### *Multiple-Vehicle Driveway Related Collisions*

$$\text{Segment 1 } N_{\text{expected}} = 0.553 \times 0.734 + (1 - 0.553) \times 2 = 1.300$$

$$\text{Segment 2 } N_{\text{expected}} = 0.828 \times 0.149 + (1 - 0.828) \times 1 = 0.295$$

**Deleted:**  $N_{\text{expected}} = 0.828 \times 0.149 + (1 - 0.828) \times 1 = 0.295$

#### *Multiple-Vehicle Collisions*

$$\text{Intersection 1 } N_{\text{expected}} = 0.496 \times 1.268 + (1 - 0.496) \times 2 = 1.637$$

$$\text{Intersection 2 } N_{\text{expected}} = 0.491 \times 2.658 + (1 - 0.491) \times 6 = 4.359$$

**Single-Vehicle Crashes**

Intersection 1  $N_{\text{expected}} = 0.789 \times 0.234 + (1 - 0.789) \times 3 = 0.818$

Intersection 2  $N_{\text{expected}} = 0.934 \times 0.196 + (1 - 0.934) \times 0 = 0.183$

**Worksheets SP5B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials**

Worksheet SP5B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

**Worksheet SP5B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials**

(1)	(2)	(3)
Site Type	$N_{\text{pred}}$	$N_{\text{site}}$
<b>ROADWAY SEGMENTS</b>		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
<b>INTERSECTIONS</b>		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

**Worksheets SP5C—Site-Specific EB Method Summary Results for Urban and Suburban Arterials**

Worksheet SP5C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the site-specific EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

**Worksheet SP5C.** Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	$N_{proj}$	$N_{site}$	$N_{expected} \text{ (vehicle)}$	$N_{expected}$
Total	(2) <sub>comb</sub> Worksheet SP5A	(2) <sub>comb</sub> Worksheet SP5B	(3) <sub>comb</sub> Worksheet SP5B	(13) <sub>comb</sub> Worksheet SP5A	(3)+(4)+(5)
	14.397	0.808	0.156	24.461	25.4
Fatal and injury (FI)	(3) <sub>comb</sub> Worksheet SP5A	(2) <sub>comb</sub> Worksheet SP5B	(3) <sub>comb</sub> Worksheet SP5B	(5) <sub>total</sub> *(2) <sub>FI</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
	3.920	0.808	0.156	6.660	7.6
Property damage only (PDO)	(4) <sub>comb</sub> Worksheet SP5A	—	—	(5) <sub>total</sub> *(2) <sub>PDO</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
	10.476	0.000	0.000	17.800	17.8

**12.13.6. Sample Problem 6****The Project**

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

**The Question**

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1 through 4 and the observed crash frequencies using the **project-level EB Method**?

**The Facts**

- 2 roadway segments (3T segment, 4D segment)
- 2 intersection (3ST intersection, 4SG intersection)
- 34 observed crashes (but no information is available to attribute specific crashes to specific sites)

**Outline of Solution**

Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e., observed crash data for individual roadway segments and intersections are not available, but observed crashes are assigned to a facility as a whole) presented in Part C, Appendix A.2.5.

**Results**

The expected average crash frequency for the project is 26.0 crashes per year (rounded to one decimal place).

**WORKSHEETS**

To apply the project-level EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- Worksheet SP6A (Corresponds to Worksheet 4A)*—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

- *Worksheet SP6B (Corresponds to Worksheet 4B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials
- *Worksheet SP6C (Corresponds to Worksheet 4C)*—Project-EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

**Worksheets SP6A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials**

The predicted average crash frequencies by severity level and collision type, excluding vehicle-pedestrian and vehicle-bicycle collisions, determined in Sample Problems 1 through 4 are entered in Columns 2 through 4 of Worksheet SP6A. Column 5 presents the total observed crash frequencies combined for all sites, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates  $N_{w0}$ , and Column 8 calculates  $N_{w1}$ . Equations A-10 through A-14 from Part C, Appendix A are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

**Worksheet SP6A.** Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Collision Type/Site Type	Predicted Crashes			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	$N_{\text{predicted } w=0}$	$N_{\text{predicted } w=1}$	$w_0$	$N_0$	$w_1$	$N_1$	$N_{\text{expected/cumulative (vehicle)}}$
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (EB)}}$	$N_{\text{predicted (PDO)}}$			Equation A-8 $(6)^*(2)^2$	Equation A-9 $(\text{sqrt}((6)^*(2)))$	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
ROADWAY SEGMENTS												
Multiple-Vehicle Nondriveway												
Segment 1	4.967	1.196	3.771	—	0.66	16.283	1.811	—	—	—	—	—
Segment 2	2.524	0.702	1.822	—	1.32	8.409	1.825	—	—	—	—	—
Single-Vehicle												
Segment 1	1.182	0.338	0.844	—	1.37	1.914	1.273	—	—	—	—	—
Segment 2	0.485	0.085	0.401	—	0.86	0.202	0.646	—	—	—	—	—
Multiple-Vehicle Driveway-Related												
Segment 1	0.734	0.179	0.555	—	1.10	0.593	0.899	—	—	—	—	—
Segment 2	0.149	0.042	0.107	—	1.39	0.031	0.455	—	—	—	—	—
INTERSECTIONS												
Multiple-Vehicle												
Intersection 1	1.268	0.405	0.862	—	0.80	1.286	1.007	—	—	—	—	—
Intersection 2	2.658	0.845	1.812	—	0.39	2.755	1.018	—	—	—	—	—
Single-Vehicle												
Intersection 1	0.234	0.072	0.162	—	1.14	0.062	0.516	—	—	—	—	—
Intersection 2	0.196	0.056	0.140	—	0.36	0.014	0.266	—	—	—	—	—
Combined (Sum of Column)	14.397	3.920	10.476	34	—	31.549	9.716	0.313	27.864	0.597	22.297	25.080



Note:  $N_{\text{predicted } w0}$  = Predicted number of total crashes assuming that crash frequencies are statistically independent

$$N_{\text{predicted } w_0} = \sum_{j=1}^5 k_{rmj} N_{rmj}^2 + \sum_{j=1}^5 k_{rsj} N_{rsj}^2 + \sum_{j=1}^5 k_{rdj} N_{rdj}^2 + \sum_{j=1}^4 k_{lmj} N_{lmj}^2 + \sum_{j=1}^4 k_{lsj} N_{lsj}^2 \quad (\text{A-8})$$

$N_{\text{predicted } w_1}$  = Predicted number of total crashes assuming that crash frequencies are perfectly correlated

$$N_{\text{predicted } w_1} = \sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}} + \sum_{j=1}^5 \sqrt{k_{rdj} N_{rdj}} + \sum_{j=1}^4 \sqrt{k_{lmj} N_{lmj}} + \sum_{j=1}^4 \sqrt{k_{lsj} N_{lsj}} \quad (\text{A-9})$$

#### Column 9— $w_0$

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent,  $w_0$ , is calculated using Equation A-10 as follows:

$$\begin{aligned} w_0 &= \frac{1}{1 + \frac{N_{\text{predicted } w_0}}{N_{\text{predicted (total)}}}} \\ &= \frac{1}{1 + \frac{31.549}{14.397}} \\ &= 0.313 \end{aligned}$$

#### Column 10— $N_0$

The expected crash frequency based on the assumption that different roadway elements are statistically independent,  $N_0$ , is calculated using Equation A-11 as follows:

$$\begin{aligned} N_0 &= w_0 \times N_{\text{predicted (total)}} + (1 - w_0) \times N_{\text{observed (total)}} \\ &= 0.313 \times 14.397 + (1 - 0.313) \times 34 \\ &= 27.864 \end{aligned}$$

#### Column 11— $w_1$

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated,  $w_1$ , is calculated using Equation A-12 as follows:

$$\begin{aligned} w_1 &= \frac{1}{1 + \frac{N_{\text{predicted } w_1}}{N_{\text{predicted (total)}}}} \\ &= \frac{1}{1 + \frac{9.716}{14.397}} \\ &= 0.597 \end{aligned}$$

#### Column 12— $N_1$

The expected crash frequency based on the assumption that different roadway elements are perfectly correlated,  $N_1$ , is calculated using Equation A-13 as follows:

$$\begin{aligned} N_1 &= w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}} \\ &= 0.597 \times 14.397 + (1 - 0.597) \times 34 \\ &= 22.297 \end{aligned}$$

#### Column 13— $N_{\text{expected/comb}}$

The expected average crash frequency based of combined sites,  $N_{\text{expected/comb}}$ , is calculated using Equation A-14 as follows:

$$\text{Deleted: } N_{\text{predicted } w_0} = \sum_{j=1}^5 k_{rmj} N_{rmj}^2 + \sum_{j=1}^5 k_{rsj} N_{rsj}^2 + \sum_{j=1}^5 k_{rdj} N_{rdj}^2$$

Field Code Changed

$$\text{Deleted: } N_{\text{predicted } w_1} = \sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}} + \sum_{j=1}^5 \sqrt{k_{rdj} N_{rdj}} + \sum_{j=1}^4 \sqrt{k_{lmj} N_{lmj}} + \sum_{j=1}^4 \sqrt{k_{lsj} N_{lsj}}$$

Field Code Changed

$$\begin{aligned} N_0 &= w_0 \times N_{\text{predicted (total)}} + (1 - w_0) \times N_{\text{observed (total)}} \\ \text{Deleted: } &= 0.313 \times 14.397 + (1 - 0.313) \times 34 \\ &= 27.864 \end{aligned}$$

Field Code Changed

$$\begin{aligned} \text{Deleted: } N_1 &= w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}} \\ &= 0.597 \times 14.397 + (1 - 0.597) \times 34 \\ &= 22.297 \end{aligned}$$

Field Code Changed

$$\begin{aligned}
 N_{\text{expected/comb}} &= \frac{N_0 + N_1}{2} \\
 &= \frac{27.864 + 22.297}{2} \\
 &= 25.080
 \end{aligned}$$

### Worksheets SP6B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

Worksheet SP6B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

#### Worksheet SP6B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	$N_{ped}$	$N_{bik}$
<b>ROADWAY SEGMENTS</b>		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
<b>INTERSECTIONS</b>		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

### Worksheets SP6C—Project-Level EB Method Summary Results for Urban and Suburban Arterials

Worksheet SP6C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the project-level EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

**Worksheet SP6C. Project-Level EB Method Summary Results for Urban and Suburban Arterials**

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	$N_{ped}$	$N_{bike}$	$N_{expected(comb vehicle)}$	$N_{expected}$
Total	(2) <sub>comb</sub> Worksheet SP6A	(2) <sub>comb</sub> Worksheet SP6B	(3) <sub>comb</sub> Worksheet SP6B	(13) <sub>comb</sub> Worksheet SP6A	(3)+(4)+(5)
	14.397	0.808	0.156	25.080	26.0
Fatal and injury (FI)	(3) <sub>comb</sub> Worksheet SP6A	(2) <sub>comb</sub> Worksheet SP6B	(3) <sub>comb</sub> Worksheet SP6B	(5) <sub>total</sub> *(2) <sub>FI</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
	3.920	0.808	0.156	6.829	7.8
Property damage only (PDO)	(4) <sub>comb</sub> Worksheet SP6A	—	—	(5) <sub>total</sub> *(2) <sub>PDO</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
	10.476	0.000	0.000	18.250	18.3

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## APPENDIX 12A. WORKSHEETS FOR PREDICTIVE METHOD FOR URBAN AND SUBURBAN ARTERIALS

### Worksheet 1A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	Base Conditions	Site Conditions
Road type (2U, 3T, 4U, 4D, 5T)	—	
Length of segment, $L$ (mi)	—	
AADT (veh/day)	—	
Type of on-street parking (none/parallel/angle)	none	
Proportion of curb length with on-street parking	—	
Median width (ft)	15	
Lighting (present / not present)	not present	
Auto speed enforcement (present/not present)	not present	
Major commercial driveways (number)	—	
Minor commercial driveways (number)	—	
Major industrial/institutional driveways (number)	—	
Minor industrial/institutional driveways (number)	—	
Major residential driveways (number)	—	
Minor residential driveways (number)	—	
Other driveways (number)	—	
Speed Category	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration Factor, $C_r$	1.0	

**Worksheet 1B.** Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	CMF for Roadside Fixed Objects	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
$CMF_{1r}$	$CMF_{2r}$	$CMF_{3r}$	$CMF_{4r}$	$CMF_{5r}$	$CMF_{comb}$
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	$(1)*(2)*(3)*(4)*(5)$

**Worksheet 1C.** Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{brmo}$	Proportion of Total Crashes	Adjusted $N_{brmo}$	Combined CMFs	Calibration Factor	Predicted $N_{brmo}$
	from Table 12-3		from Table 12-3	from Equation 12-10		$(4)_{total}*(5)$	(6) from Worksheet 1B	$C_r$	$(6)*(7)*(8)$
	a	b							
Total									
Fatal and injury (FI)					$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)					$(5)_{total}-(5)_{FI}$				

**Worksheet 1D.** Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
Collision Type	Proportion of Collision Type $(P_i)$	Predicted $N_{brwy} (FI)$ (crashes/year)	Proportion of Collision Type $(PDO_i)$	Predicted $N_{brwy} (PDO)$ (crashes/year)	Predicted $N_{brwy} (total)$ (crashes/year)
	from Table 12-4	(9) <sub>FI</sub> from Worksheet 1C	from Table 12-4	(9) <sub>PDO</sub> from Worksheet 1C	(9) <sub>total</sub> from Worksheet 1C
Total	1.000	(2)*(3) <sub>FI</sub>	1.000	(4)*(5) <sub>PDO</sub>	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

**Worksheet 1E.** Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, $k$	Initial $N_{brwy}$	Proportion of Total Crashes	Adjusted $N_{brwy}$	Combined CMFs	Calibration Factor	Predicted $N_{brwy}$
	from Table 12-5		from Table 12-5	from Equation 12-13					
	a	b				(4) <sub>total</sub> *(5)	(6) from Worksheet 1B	$C_r$	(6)*(7)*(8)
Total									
Fatal and injury (FI)					$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)					$(5)_{total}-(5)_{FI}$				



**Worksheet 1F.** Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
Collision Type	Proportion of Collision Type $(P_C)$	Predicted $N_{SVI} (P_C)$ (crashes/year)	Proportion of Collision Type $(P_{PDO})$	Predicted $N_{SVI} (P_{PDO})$ (crashes/year)	Predicted $N_{SVI} (total)$ (crashes/year)
	from Table 12-6	(9) $n_i$ from Worksheet 1E	from Table 12-6	(9) $P_{PDO}$ from Worksheet 1E	(9) $n_{total}$ from Worksheet 1E
Total	1.000	(2)*(3) $P_C$	1.000	(4)*(5) $P_{PDO}$	(3)+(5)
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					

**Worksheet 1G.** Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
Driveway Type	Number of Driveways, $n_i$	Crashes per Driveway per Year, $N_i$	Coefficient for Traffic Adjustment, $t$	Initial $N_{MDR}$	Overdispersion Parameter, $k$
		from Table 12-7	from Table 12-7	Equation 12-16 $n_i * N_i / (AADT/15,000)t$	from Table 12-7
Major commercial					—
Minor commercial					
Major industrial/institutional					
Minor industrial/institutional					
Major residential					
Minor residential					
Other					
Total	—	—	—		

**Worksheet 1H.** Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Initial $N_{drwy}$	Proportion of Total Crashes ( $f_{drwy}$ )	Adjusted $N_{drwy}$	Combined CMFs	Calibration Factor, $C_r$	Predicted $N_{drwy}$
	(5) total from Worksheet 1G	from Table 12-7	(2) total * (3)	(6) from Worksheet 1B		(4)*(5)*(6)
Total						
Fatal and injury (FI)	—					
Property damage only (PDO)	—					

**Worksheet 1I.** Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	Predicted $N_{bussv}$	Predicted $N_{bussv}$	Predicted $N_{bdrwy}$	Predicted $N_{bdr}$	$f_{pedr}$	Calibration Factor, $C_r$	Predicted $N_{pedr}$
	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-8		(5)*(6)*(7)
Total							
Fatal and injury (FI)	—	—	—	—	—		

**Worksheet 1J.** Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	Predicted $N_{bussv}$	Predicted $N_{bussv}$	Predicted $N_{bdrwy}$	Predicted $N_{bdr}$	$f_{biker}$	Calibration Factor, $C_r$	Predicted $N_{biker}$
	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-9		(5)*(6)*(7)
Total							
Fatal and injury	—	—	—	—	—		

**Worksheet 1K.** Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
Collision Type	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
	(3) from Worksheets 1D and 1E; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J	(5) from Worksheets 1D and 1E; and (7) from Worksheet 1H	(6) from Worksheets 1D and 1E; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J
<b>MULTIPLE-VEHICLE</b>			
Rear-end collisions (from Worksheet 1D)			
Head-on collisions (from Worksheet 1D)			
Angle collisions (from Worksheet 1D)			
Sideswipe, same direction (from Worksheet 1D)			
Sideswipe, opposite direction (from Worksheet 1D)			
Driveway-related collisions (from Worksheet 1H)			
Other multiple-vehicle collision (from Worksheet 1D)			
Subtotal			
<b>SINGLE-VEHICLE</b>			
Collision with animal (from Worksheet 1F)			
Collision with fixed object (from Worksheet 1F)			
Collision with other object (from Worksheet 1F)			
Other single-vehicle collision (from Worksheet 1F)			
Collision with pedestrian (from Worksheet 1I)			
Collision with bicycle (from Worksheet 1J)			
Subtotal			
Total			

**Worksheet 1L.** Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency, $N_{\text{predicted } rs}$ (crashes/year)	Roadway Segment Length, $L$ (mi)	Crash Rate (crashes/mi/year)
	(total) from Worksheet 1K		(2)/(3)
Total			
Fatal and injury (FI)			
Property damage only (PDO)			

**Worksheet 2A.** General Information and Input Data for Urban and Suburban Arterial Intersections

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)		—	
AADT <sub>maj</sub> (veh/day)		—	
AADT <sub>min</sub> (veh/day)		—	
Intersection lighting (present/not present)		not present	
Calibration factor, $C_i$		1.00	
Data for unsignalized intersections only:		—	
Number of major-road approaches with left-turn lanes (0, 1, 2)		0	
Number of major-road approaches with right-turn lanes (0, 1, 2)		0	
Data for signalized intersections only:		—	
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)		0	
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)		0	
Number of approaches with left-turn signal phasing		—	
Number of approaches with right-turn-on-red prohibited		0	
Type of left-turn signal phasing		permissive	
Intersection red-light cameras (present/not present)		not present	
Sum of all pedestrian crossing volumes (PedVol)		—	
Maximum number of lanes crossed by a pedestrian ( $n_{\text{lanes}}$ )		—	
Number of bus stops within 300 m (1,000 ft) of the intersection		0	
Schools within 300 m (1,000 ft) of the intersection (present/not present)		not present	
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection		0	

**Worksheet 2B.** Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	CMF for Left-Turn Signal Phasing	CMF for Right-Turn Lanes	CMF for Right-Turn-on-Red	CMF for Lighting	CMF for Red-Light Cameras	Combined CMF
$CMF_{li}$	$CMF_{2i}$	$CMF_{3i}$	$CMF_{4i}$	$CMF_{5i}$	$CMF_{6i}$	$CMF_{comb}$
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	$(1)*(2)*(3)*(4)*(5)*(6)$

Worksheet 2C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, <i>k</i>	Initial <i>N</i> <sub>obsrv</sub>	Proportion of Total Crashes	Adjusted <i>N</i> <sub>obsrv</sub>	Combined CMFs	Calibration Factor, <i>C<sub>i</sub></i>	Predicted <i>N</i> <sub>obsrv</sub>
	from Table 12-10			from Table 12-10	from Equation 12-22					(6)*(7)*(8)
	a	b	c				(4) <sub>total</sub> *(5)	(7) from Worksheet 2B		
Total										
Fatal and injury (FI)						(4) <sub>FI</sub> /((4) <sub>FI</sub> +(4) <sub>PDO</sub> )				
Property damage only (PDO)						(5) <sub>total</sub> -(5) <sub>FI</sub>				

**Worksheet 2D.** Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $(P_T)$	Predicted $N_{\text{minor}}^{(T)}$ (crashes/year)	Proportion of Collision Type $(P_{DO})$	Predicted $N_{\text{minor}}^{(PDO)}$ (crashes/year)	Predicted $N_{\text{minor}}^{(\text{total})}$ (crashes/year)
Collision Type	from Table 12-11	(9) $n$ from Worksheet 2C	from Table 12-11	(9) $P_{DO}$ from Worksheet 2C	(9) $P_{DO}$ from Worksheet 2C
Total	1.000	(2)*(3) $_{FI}$	1.000	(4)*(5) $_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					

**Worksheet 2E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections**

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, $k$	Initial $N_{obs}$	Proportion of Total Crashes	Adjusted $N_{obs}$	Combined CMFs	Calibration Factor, $C_i$	Predicted $N_{obs}$
	from Table 12-12			from Table 12-12	from Equation 12-25; (FI) from Equation 12-25 or 12-27					
	a	b	c				(4) <sub>total</sub> *(5)	(7) from Worksheet 2B		(6)*(7)*(8)
Total										
Fatal and injury (FI)						$(4)_{FI} / ((4)_{FI} + (4)_{PDO})$				
Property damage only (PDO)						$(5)_{total} - (5)_{FI}$				



**Worksheet 2F.** Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
Collision Type	Proportion of Collision Type $(P_D)$	Predicted $N_{bisc} (FI)$ (crashes/year)	Proportion of Collision Type $(PDO)$	Predicted $N_{bisc} (PDO)$ (crashes/year)	Predicted $N_{bisc} (total)$ (crashes/year)
	Table 12-13	(9) $_{FI}$ from Worksheet 2E	Table 12-13	(9) $_{PDO}$ from Worksheet 2E	(9) $_{PDO}$ from Worksheet 2E
Total	1.000	(2)*(3) $_{FI}$	1.000	(4)*(5) $_{PDO}$	(3)+(5)
Collision with parked vehicle					
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					
Single-vehicle noncollision					

**Worksheet 2G.** Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted $N_{bisc}$	Predicted $N_{bisc}$	Predicted $N_{bisc}$	$f_{pedi}$	Calibration Factor, $C_i$	Predicted $N_{pedi}$
	(9) from Worksheet 2C	(9) from Worksheet 2E	(2)+(3)	from Table 12-16		(4)*(5)*(6)
Total						
Fatal and injury (FI)	—	—	—	—		

**Worksheet 2H.** Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)	(3)	(4)
CMF for Bus Stops	CMF for Schools	CMF for Alcohol Sales Establishments	Combined CMF
$CMF_{1p}$	$CMF_{2p}$	$CMF_{3p}$	
from Table 12-28	from Table 12-29	from Table 12-30	(1)*(2)*(3)

**Worksheet 2I.** Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients					Overdispersion Parameter, $k$	$N_{pedbase}$	Combined CMF	Calibration Factor, $C_i$	Predicted $N_{pedi}$
	from Table 12-14						from Equation 12-30	(4) from Worksheet 2H		(8)*(9)*(10)
	a	b	c	d	e					
Total										
Fatal and injury (FI)	—	—	—	—	—	—	—	—		

**Worksheet 2J.** Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)		(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted $N_{bino}$		Predicted $N_{biso}$	Predicted $N_{bi}$	$f_{biket}$	Calibration Factor, $C_i$	Predicted $N_{pedi}$
	(9) from Worksheet 2C		(9) from Worksheet 2E	(2)+(3)	from Table 12-17		(4)*(5)*(6)
Total							
Fatal and injury (FI)	—		—	—	—		

**Worksheet 2K.** Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
Collision Type	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
	(3) from Worksheets 2D and 2F; (7) from Worksheets 2G or 2I and 2J	(5) from Worksheets 2D and 2F	(6) from Worksheets 2D and 2F; (7) from Worksheets 2G or 2I and 2J
<b>MULTIPLE-VEHICLE COLLISIONS</b>			
Rear-end collisions (from Worksheet 2D)			
Head-on collisions (from Worksheet 2D)			
Angle collisions (from Worksheet 2D)			
Sideswipe (from Worksheet 2D)			
Other multiple-vehicle collision (from Worksheet 2D)			
Subtotal			
<b>SINGLE-VEHICLE COLLISIONS</b>			
Collision with parked vehicle (from Worksheet 2F)			
Collision with animal (from Worksheet 2F)			
Collision with fixed object (from Worksheet 2F)			
Collision with other object (from Worksheet 2F)			
Other single-vehicle collision (from Worksheet 2F)			
Single-vehicle noncollision (from Worksheet 2F)			
Collision with pedestrian (from Worksheet 2G or 2I)			
Collision with bicycle (from Worksheet 2J)			
Subtotal			
Total			

**Worksheet 2L.** Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
Crash Severity Level	Predicted Average Crash Frequency, $N_{\text{predicted int}}$ (crashes/year)
	(Total) from Worksheet 2K
Total	
Fatal and injury (FI)	
Property damage only (PDO)	

**Worksheet 3A.** Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	Weighted Adjustment, $w$	Expected Average Crash Frequency, $N_{\text{expected}}$ (vehicle)
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FB)}}$	$N_{\text{predicted (PDO)}}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Multiple-Vehicle Driveway-Related							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Single-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)					—	—	

**Worksheet 3B.** Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	$N_{ped}$	$N_{bike}$
<b>ROADWAY SEGMENTS</b>		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
<b>INTERSECTIONS</b>		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

**Worksheet 3C.** Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	$N_{ped}$	$N_{bike}$	$N_{expected (vehicle)}$	$N_{expected}$
Total	(2) <sub>comb</sub> Worksheet 3A	(2) <sub>comb</sub> Worksheet 3B	(3) <sub>comb</sub> Worksheet 3B	(13) <sub>comb</sub> Worksheet 3A	(3)+(4)+(5)
Fatal and injury (FI)	(3) <sub>comb</sub> Worksheet 3A	(2) <sub>comb</sub> Worksheet 3B	(3) <sub>comb</sub> Worksheet 3B	(5) <sub>total</sub> *(2) <sub>FI</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
Property damage only (PDO)	(4) <sub>comb</sub> Worksheet 3A	— 0.000	— 0.000	(5) <sub>total</sub> *(2) <sub>PDO</sub> /(2) <sub>total</sub>	(3)+(4)+(5)

**Worksheet 4A.** Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)		
Collision Type/Site Type	Predicted Crashes			Observed Crashes, $N_{\text{observed}}$ (crashes/year)	Overdispersion Parameter, $k$	$N_{\text{predicted } w_0}$	$N_{\text{predicted } w_1}$	$w_0$	$N_o$	$w_1$	$N_1$	$N_{\text{expected(comb (vehicle))}}$		
	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FD)}}$	$N_{\text{predicted (PDOB)}}$			Equation A-8 $(6)*(2)^2$	Equation A-9 $(\text{sqrt}((6)*(2)))$	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14		
<b>ROADWAY SEGMENTS</b>														
<b>Multiple-Vehicle Nondriveway</b>														
Segment 1				—				—	—	—	—	—		
Segment 2				—				—	—	—	—	—		
Segment 3				—				—	—	—	—	—		
Segment 4				—				—	—	—	—	—		
<b>Single-Vehicle</b>														
Segment 1				—				—	—	—	—	—		
Segment 2				—				—	—	—	—	—		
Segment 3				—				—	—	—	—	—		
Segment 4				—				—	—	—	—	—		
<b>Multiple-Vehicle Driveway-Related</b>														
Segment 1				—				—	—	—	—	—		
Segment 2				—				—	—	—	—	—		
Segment 3				—				—	—	—	—	—		
Segment 4				—				—	—	—	—	—		
<b>INTERSECTIONS</b>														
<b>Multiple-Vehicle</b>														
Intersection 1				—				—	—	—	—	—		
Intersection 2				—				—	—	—	—	—		
Intersection 3				—				—	—	—	—	—		

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**Worksheet 4B.** Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	$N_{ped}$	$N_{bike}$
<b>ROADWAY SEGMENTS</b>		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
<b>INTERSECTIONS</b>		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

**Worksheet 4C.** Project-Level EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	$N_{ped}$	$N_{bike}$	$N_{expected/comb} \text{ (vehicle)}$	$N_{expected}$
Total	(2) <sub>comb</sub> Worksheet 4A	(2) <sub>comb</sub> Worksheet 4B	(3) <sub>comb</sub> Worksheet 4B	(13) <sub>comb</sub> Worksheet 4A	(3)+(4)+(5)
Fatal and injury (FI)	(3) <sub>comb</sub> Worksheet 4A	(2) <sub>comb</sub> Worksheet 4B	(3) <sub>comb</sub> Worksheet 4B	(5) <sub>total</sub> *(2) <sub>FI</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
Property damage only (PDO)	(4) <sub>comb</sub> Worksheet 4A	—	—	(5) <sub>total</sub> *(2) <sub>PDO</sub> /(2) <sub>total</sub>	(3)+(4)+(5)
		0.000	0.000		



## APPENDIX A. SPECIALIZED PROCEDURES COMMON TO ALL PART C CHAPTERS

This Appendix presents two specialized procedures intended for use with the predictive method presented in Chapters 10, 11, and 12. These include the procedure for calibrating the predictive models presented in the Part C chapters to local conditions and the Empirical Bayes (EB) Method for combining observed crash frequencies with the estimate provided by the predictive models in Part C. Both of these procedures are an integral part of the predictive method in Chapters 10, 11, and 12, and are presented in this Appendix only to avoid repetition across the chapters.

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### A.1. CALIBRATION OF THE PART C PREDICTIVE MODELS

The Part C predictive method in Chapters 10, 11, and 12 include predictive models which consist of safety performance functions (SPFs), crash modification factors (CMFs) and calibration factors and have been developed for specific roadway segment and intersection types. The SPF functions are the basis of the predictive models and were developed in HSM-related research from the most complete and consistent available data sets. However, the general level of crash frequencies and crash severity may vary substantially from one jurisdiction to another, and even from time to time in a given jurisdiction, for a variety of reasons including climate, driver population characteristics, including rates of seat belt use, animal populations, crash reporting thresholds, and crash reporting system procedures. Therefore, for the Part C predictive models to provide results that are meaningful and accurate for each jurisdiction on a continuing basis, it is important that the SPFs be calibrated for application in each jurisdiction and from time to time. A procedure for determining the calibration factors for the Part C predictive models is presented below in Appendix A.1.1.

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Some HSM users may prefer to develop SPFs with data from their own jurisdiction for use in the Part C predictive models rather than calibrating the Part C SPFs. Calibration of the Part C SPFs will generally provide satisfactory results. However, SPFs developed directly with data for a specific jurisdiction may provide more reliable estimates for that jurisdiction than calibration of Part C SPFs. Therefore, jurisdictions that have the capability, and wish to develop their own models, are encouraged to do so. The calibration procedure provides tools for comparing a user-developed SPF for a specific jurisdiction to a calibrated Part C SPF. Guidance on development of jurisdiction-specific SPFs that are suitable for use in the Part C predictive method is presented in Appendix A.1.2.

Most of the regression coefficients and distribution values used in the Part C predictive models in Chapters 10, 11, and 12 have been determined through research and, therefore, modification by users is not recommended. However, a few specific quantities, such as the distribution of crashes by collision type or the proportion of crashes occurring during nighttime conditions, are known to vary substantially from jurisdiction to jurisdiction. Where appropriate local data are available, users are encouraged to replace these default values with locally derived values. The values in the predictive models that may be updated by users to fit local conditions are explicitly identified in Chapters 10, 11, and 12. Unless explicitly identified, values in the predictive models should not be modified by the user. A procedure for deriving jurisdiction-specific values to replace these selected parameters is presented below in Appendix A.1.3.

### A.1.1. Calibration of Predictive Models

The purpose of the Part C calibration procedure is to adjust the predictive models, which were developed with data from one jurisdiction in one time period, for application in another jurisdiction and another time period. Calibration provides a method to account for differences between jurisdictions and over time in factors such as climate, driver populations, animal populations, crash reporting thresholds, and crash reporting system procedures.

The calibration procedure is used to derive the values of the calibration factors for roadway segments and for intersections that are used in the Part C predictive models. The calibration factor for roadway segments,  $C_r$ , is used in Equations 10-2, 11-2, 11-3, and 12-2. The calibration factor for intersections,  $C_i$ , is used in Equations 10-3, 11-4, and 12-5. The calibration factors,  $C_r$  and  $C_i$ , may be constant for a specific facility type, crash type and crash severity or it may more generally vary according to a calibration function. are based on the ratio of the total observed crash frequencies for a selected set of sites to the total expected average crash frequency estimated for the same sites, during the same time period, using the applicable Part C predictive method. Thus, the nominal value of the calibration factor, when the observed and predicted crash frequencies happen to be equal, is 1.00. When there are more crashes observed than are predicted by the Part C predictive method, the computed calibration factor will be greater than 1.00. When there are fewer crashes observed than are predicted by the Part C predictive method, the computed calibration factor will be less than 1.00.

It is recommended that new values of the calibration factors be updated at least every two to three years, and some HSM users may prefer to develop calibration factors perform these updates on an annual basis. Calibration factors for the most recent available period are to be used for all assessment of proposed future projects. If available, calibration factors for the specific time periods included in the evaluation periods before and after a project or treatment implementation are to be used in effectiveness evaluations that use the procedures presented in Chapter 9.

If the procedures in Appendix A.1.3 are used to calibrate any default values in the Part C predictive models to local conditions, the locally-calibrated values should be used in the calibration process described below.

The calibration procedure, which is illustrated in Figure xx, involves up to eight basic steps:

- Step 1—Identify facility type, and crash type and crash severity for which the applicable Part C predictive model is to be calibrated.
- Step 2—Select sites for initial calibration of the predictive model.
- Step 3—Obtain data applicable to a specific calibration period.
- Step 4—Apply the applicable Part C predictive model to predict total crash frequency for each site during the calibration period as a whole.
- Step 5—Compute calibration factors.
- Step 6—Assess success of the calibration, i.e., the adequacy of the calibration sample. If insufficient then add additional sites (if available) and return to Step 3. If additional sites are not available, then assume calibration factor for similar facility/crash type if available, otherwise adopt the uncalibrated SPF with caution.
- Step 7—(Calibration factor successfully estimated). Estimate a calibration function.
- Step 8—Assess if a calibration function or factor is better and adopt as appropriate for use in the Part C predictive model.

The Federal Highway Administration has developed a software tool, “The Calibrator”<sup>1</sup> that can be used, and may be regarded as essential, in performing Steps 4 to 8.

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<sup>1</sup> Lyon C., Persaud B. and F. Gross. The Calibrator: An SPF Calibration and Assessment Tool User Guide.

Each of the [above](#) steps is described below.

**A.1.1.1. Step 1—Identify Facility Type [and Crash type and Crash Severity](#) for Which the Applicable Part C SPFs are to be Calibrated.**

Calibration is performed separately for each facility type, [crash type and crash severity](#) addressed in each Part C chapter. Table A-1 identifies all of the facility types, [crash types and crash severities](#) included in the Part C chapters for which calibration factors need to be derived. The Part C SPFs for each of these [are to be calibrated before use](#), but HSM users may choose not to calibrate the SPFs for particular [ones](#), [if they do not plan to apply the Part C SPFs](#) for those.

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**Table A-1.** SPFs in the Part C Predictive Models that Need Calibration

**Commented [IJ5]:** Needs to be updated for the final 17-62 SPFs and for SPFs developed in other projects, including freeways. We are leaving this for the production contractor because we do not know yet how to most efficiently format the information due to the different arrays of SPFs in each chapter

Facility, Segment, or Intersection Type	Calibration Factor to be Derived	
	Symbol	Equation Number(s)
<b>ROADWAY SEGMENTS</b>		
Rural Two-Lane, Two-Way Roads		
Two-lane undivided segments	$C_r$	10-2
Rural Multilane Highways		
Undivided segments	$C_r$	11-2
Divided segments	$C_r$	11-3
Urban and Suburban Arterials		
Two-lane undivided segments	$C_r$	12-2
Three-lane segments with center two-way left-turn lane	$C_r$	12-2
Four-lane undivided segments	$C_r$	12-2
Four-lane divided segments	$C_r$	12-2
Five-lane segments with center two-way left-turn lane	$C_r$	12-2
<b>INTERSECTIONS</b>		
Rural Two-Lane, Two-Way Roads		
Three-leg intersections with minor-road stop control	$C_i$	10-3
Four-leg intersections with minor-road stop control	$C_i$	10-3
Four-leg signalized intersections	$C_i$	10-3
Rural Multilane Highways		
Three-leg intersections with minor-road stop control	$C_i$	11-4
Four-leg intersections with minor-road stop control	$C_i$	11-4
Four-leg signalized intersections	$C_i$	11-4
Urban and Suburban Arterials		
Three-leg intersections with minor-road stop control	$C_i$	12-5
Three-leg signalized intersections	$C_i$	12-5
Four-leg intersections with minor-road stop control	$C_i$	12-5
Four-leg signalized intersections	$C_i$	12-5

#### A.1.1.2. Step 2—Select Sites for Initial Calibration of the SPF<sub>*r*</sub>

**Deleted:** for Each Facility Type

For each facility type, crash type and crash severity, the desirable minimum sample size for the calibration data set is 30 to 50 sites, with each site long enough to adequately represent physical and safety conditions for the facility. Calibration sites should be selected without regard to the number of crashes on individual sites; in other words, calibration sites should not be selected to intentionally limit the calibration data set to include only sites with either high or low crash frequencies. Where practical, this may be accomplished by selecting calibration sites randomly from a larger set of candidate sites. Following site selection, the entire group of calibration sites should represent a total of at least 100 crashes per year. These calibration sites will be either roadway segments or intersections, as appropriate to the facility type being addressed. If the required data discussed in Step 3 are readily available for a larger number of sites, that larger number of sites should be used for calibration. If a jurisdiction has fewer than 30 sites for a particular facility type and/or an available sample with less than 100 crashes per year, then it is desirable

to use all of those available sites for calibration and adopt the calibration factor or function if successfully estimated. For large jurisdictions, such as entire states, with a variety of topographical and climate conditions, it may be desirable to assemble a separate set of sites and develop separate calibration factors for each specific terrain type or geographical region. For example, a state with distinct plains and mountains regions, or with distinct dry and wet regions, might choose to develop separate calibration factors for those regions. On the other hand, a state that is relatively uniform in terrain and climate might choose to perform a single calibration for the entire state. Where separate calibration factors are developed by terrain type or region, this needs to be done consistently for all applicable facility types in those regions.

It is desirable that the calibration sites for each facility type be reasonably representative of the range of site characteristics to which the predictive model will be applied. However, no formal stratification by traffic volume or other site characteristics is needed in selecting the calibration sites, so the sites can be selected in a manner to make the data collection needed for Step 3 as efficient as practical. There is no need to develop a new data set if an existing data set with sites suitable for calibration is already available. If no existing data set is available so that a calibration data set consisting entirely of new data needs to be developed, or if some new sites need to be chosen to supplement an existing data set, it is desirable to choose the new calibration sites by random selection from among all sites of the applicable facility type.

Step 2 only needs to be performed the first time that calibration is performed for a given facility type. For calibration in subsequent years, the same sites may be used again.

#### A.1.1.3. Step 3—Obtain Data Applicable to a Specific Calibration Period.

Once the calibration sites have been selected, the next step is to assemble the calibration data set if a suitable data set is not already available. For each site in the calibration data set, the calibration data set should include:

- Total crash frequency for the applicable crash type and severity for a period of one or more years in duration.
- All site characteristics data needed to apply the applicable Part C predictive model.

~~Observed crashes for all severity levels should be included in calibration.~~ The duration of crash frequency data should correspond to the period for which the resulting calibration factor,  $C_r$  or  $C_i$ , will be applied in the Part C predictive models. Thus, if an annual calibration factor is being developed, the duration of the calibration period should include just that one year. If the resulting calibration factor will be employed for two or three years, the duration of the calibration period should include only those years. Since crash frequency is likely to change over time, calibration periods longer than three years are not recommended. All calibration periods should have durations that are multiples of 12 months to avoid seasonal effects. For ease of application, it is recommended that the calibration periods consist of one, two, or three full calendar years. It is recommended to use the same calibration period for all sites, but exceptions may be made where necessary.

The observed crash data used for calibration should include all crashes related to each roadway segment or intersection selected for the calibration data set. Crashes should be assigned to specific roadway segments or intersections based on the guidelines presented below in [Appendix A.2.3](#).

Table A-2 identifies the site characteristics data that are needed to apply the Part C predictive models for each facility type for which most CMFs are available to apply the models. (For several crash types and severities, less than 50% of the CMFs required may be available; in such cases, the base model is calibrated without applying CMFs.) The table classifies each data element as either required or desirable for the calibration procedure in accordance with the CMFs required to apply the Part C predictive models or the base conditions if the base model is being calibrated. Data for each of the required elements are needed for calibration of the predictive model or to identify base condition sites if the base model is being calibrated. If data for some required elements are not readily available for calibration of the predictive model, it may be possible to select sites in Step 2 for which these data are available. For example, in calibrating the predictive models for roadway segments on rural two-lane, two-way roads, if data on the radii of horizontal curves are not readily available, the calibration data set could be limited to tangent roadways. Decisions of this type should be made, as needed, to keep the effort required to assemble the calibration data set within reasonable bounds. For the data elements identified in Table A-2 as desirable, but not required, it is recommended that actual data be used if available, but assumptions are suggested in the table for application where data are not available.

Deleted: for Each Facility Type

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Commented [BP6]: Need specific guidance on which sites to select for base model calibration. Table A-2 will need a separate column for this.

**Table A-2.** Data Needs for Calibration of Part C Predictive Models by Facility Type

**Commented [BP7]:** Needs updating for 17-62 SPFs and those developed in other projects for other facility types. Also needs to identify conditions for base models if less than 50% of CMFs are available in the HSM. It may be sometime before we know which site/crash/severity types will need base model calibration. [NCHRP 17-78 will determine this]

Chapter	Data Element	Data Need		Default Assumption
		Required	Desirable	
ROADWAY SEGMENTS				
10—Rural Two-Lane, Two-Way Roads	Segment length	X		Need actual data
	Annual average daily traffic (AADT)	X		Need actual data
	Lengths of horizontal curves and tangents	X		Need actual data
	Radii of horizontal curves	X		Need actual data
	Presence of spiral transition for horizontal curves		X	Base default on agency design policy
	Superelevation variance for horizontal curves		X	No superelevation variance
	Percent grade		X	Base default on terrain <sup>a</sup>
	Lane width	X		Need actual data
	Shoulder type	X		Need actual data
	Shoulder width	X		Need actual data
	Presence of lighting		X	Assume no lighting
	Driveway density		X	Assume 5 driveways per mile
	Presence of passing lane		X	Assume not present
	Presence of short four-lane section		X	Assume not present
	Presence of center two-way left-turn lane	X		Need actual data
	Presence of centerline rumble strip		X	Base default on agency design policy
	Roadside hazard rating		X	Assume roadside hazard rating = 3
	Use of automated speed enforcement		X	Base default on current practice
11—Rural Multilane Highways	For all rural multilane highways:			
	Segment length	X		Need actual data
	Annual average daily traffic (AADT)	X		Need actual data
	Lane width	X		Need actual data
	Shoulder width	X		Need actual data
	Presence of lighting		X	Assume no lighting
	Use of automated speed enforcement		X	Base default on current practice
	For undivided highways only:			
	Sideslope	X		Need actual data
	For divided highways only:			
Median width	X		Need actual data	
12—Urban and Suburban Arterials	Segment length	X		Need actual data
	Number of through traffic lanes	X		Need actual data

	Presence of median	X	Need actual data
	Presence of center two-way left-turn lane	X	Need actual data
	Annual average daily traffic (AADT)	X	Need actual data
	Number of driveways by land-use type	X	Need actual data <sup>b</sup>
	Posted speed limit	X	Need actual data
	Presence of on-street parking	X	Need actual data
	Type of on-street parking	X	Need actual data
	Roadside fixed object density	X	database default on fixed-object offset and density categories <sup>c</sup>
	Presence of lighting	X	Base default on agency practice
	Presence of automated speed enforcement	X	Base default on agency practice
<b>INTERSECTIONS</b>			
10—Rural Two-Lane, Two-Way Roads	Number of intersection legs	X	Need actual data
	Type of traffic control	X	Need actual data
	Annual average daily traffic (AADT) for major road	X	Need actual data
	Annual average daily traffic (AADT) for minor road	X	Need actual data or best estimate
	Intersection skew angle	X	Assume no skew <sup>d</sup>
	Number of approaches with left-turn lanes	X	Need actual data
	Number of approaches with right-turn lanes	X	Need actual data
	Presence of lighting	X	Need actual data
11—Rural Multilane Highways	<i>For all rural multilane highways:</i>		
	Number of intersection legs	X	Need actual data
	Type of traffic control	X	Need actual data
	Annual average daily traffic (AADT) for major road	X	Need actual data
	Annual average daily traffic (AADT) for minor road	X	Need actual data or best estimate
	Presence of lighting	X	Need actual data
	Intersection skew angle	X	Assume no skew <sup>d</sup>
	Number of approaches with left-turn lanes	X	Need actual data
	Number of approaches with right-turn lanes	X	Need actual data
12—Urban and Suburban Arterials	<i>For all intersections on arterials:</i>		
	Number of intersection legs	X	Need actual data
	Type of traffic control	X	Need actual data
	Average annual daily traffic (AADT) for major road	X	Need actual data
	Average annual daily traffic (AADT) for minor road	X	Need actual data or best estimate

Number of approaches with left-turn lanes	X	Need actual data
Number of approaches with right-turn lanes	X	Need actual data
Presence of lighting	X	Need actual data
<i>For signalized intersections only:</i>		
Presence of left-turn phasing	X	Need actual data
Type of left-turn phasing	X	Prefer actual data, but agency practice may be used as a default
Use of right-turn-on-red signal operation	X	Need actual data
Use of red-light cameras	X	Need actual data
Pedestrian volume	X	Estimate with Table 12-15
Maximum number of lanes crossed by pedestrians on any approach	X	Estimate from number of lanes and presence of median on major road
Presence of bus stops within 1,000 ft	X	Assume not present
Presence of schools within 1,000 ft	X	Assume not present
Presence of alcohol sales establishments within 1,000 ft	X	Assume not present

<sup>a</sup> Suggested default values for calibration purposes:  $CMF = 1.00$  for level terrain;  $CMF = 1.06$  for rolling terrain;  $CMF = 1.14$  for mountainous terrain

<sup>b</sup> Use actual data for number of driveways, but simplified land-use categories may be used (e.g., commercial and residential only).

<sup>c</sup> CMFs may be estimated based on two categories of fixed-object offset ( $O_{fo}$ )—either 5 or 20 ft—and three categories of fixed-object density ( $D_{fo}$ )—0, 50, or 100 objects per mile.

<sup>d</sup> If measurements of intersection skew angles are not available, the calibration should preferably be performed for intersections with no skew.

#### A.1.1.4. Step 4—Apply the Applicable Part C Predictive Method to Predict Total Crash Frequency for Each Site During the Calibration Period as a Whole

The site characteristics data assembled in Step 3 should be used to apply the applicable predictive method from Chapter 10, 11, or 12 to each site in the calibration data set. For this application, the predictive method should be applied without using the EB Method and, of course, without employing a calibration factor (i.e., a calibration factor of 1.00 is assumed). Using the predictive models, the expected average crash frequency is obtained for either one, two, or three years, depending on the duration of the calibration period selected.

#### A.1.1.5. Step 5—Compute Calibration Factors for Use in Part C Predictive Models

The final step is to compute the calibration factor as:

$$C_r \text{ (or } C_i) = \frac{\sum_{\text{all sites}} \text{observed crashes}}{\sum_{\text{all sites}} \text{predicted crashes}} \quad (\text{A-1})$$

The computation is performed separately for each applicable facility type, crash type and crash severity. The computed calibration factor is rounded to two decimal places for application in the appropriate Part C predictive model.

#### Example Calibration Factor Calculation

The SPF for four-leg signalized intersections on rural two-lane, two-way roads from Equation 10-10 is:

**Commented [BP8]:** Updated with new SPF for total crashes – which is predicting far fewer crashes because it was estimated with data from Ohio rather than Minnesota.



$$N_{spf\ int} = e^{\left[-8.163 + 0.877 \ln(AADT_{tot})\right]}$$

Where:

$N_{spf\ int}$  = predicted number of total intersection-related crashes per year for base conditions;

$AADT_{tot}$  = total of average annual daily entering traffic volumes (vehicles/day) on the major and minor road;

$AADT_{min}$  = average annual daily entering traffic volumes (vehicles/day) on the minor road.

The base conditions are:

- No left-turn lanes on any approach
- No right-turn lanes on any approach

The CMF values from Chapter 10 are:

- CMF for one approach with a left-turn lane = 0.82
- CMF for one approach with a right-turn lane = 0.96
- CMF for two approaches with right-turn lanes = 0.92
- No lighting present (so lighting CMF = 1.00 for all cases)

Typical data for eight intersections are shown in an example calculation below. Note that for an actual calibration, the recommended minimum sample size would be 30 to 50 sites that experience at least 100 crashes per year. Thus, the number of sites used here is smaller than recommended, and is intended solely to illustrate the calculations.

For the first intersection in the example the predicted crash frequency for base conditions is:

$$N_{base} = e^{\left(-8.163 + 0.877 \ln(4000 + 2000)\right)} = 0.587 \text{ crashes/year}$$

The intersection has a left-turn lane on the major road, for which  $CMF_{li}$  is 0.82, and a right-turn lane on one approach, a feature for which  $CMF_{ri}$  is 0.96. There are three years of data, during which four crashes were observed (shown in Column 10 of Table Ex-1). The predicted average crash frequency from the Chapter 10 for this intersection without calibration is from Equation 10-2:

$$N_{br} = (N_{base}) \times (CMF_{li}) \times (CMF_{ri}) \times (\text{number of years of data})$$

$$= 0.587 \times 0.82 \times 0.96 \times 3 = 1.385 \text{ crashes in three years, shown in Column 9.}$$

Similar calculations were done for each intersection in the table shown below. The sum of the observed crash frequencies in Column 10 (23) is divided by the sum of the predicted average crash frequencies in Column 9 (13.722) to obtain the calibration factor,  $C_i$ , equal to 1.676. It is recommended that calibration factors be rounded to two decimal places, so calibration factor equal to 1.68 should be used in the Chapter 10 predictive model for four-leg signalized intersections.

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**Table Ex-1.** Example of Calibration Factor Computation

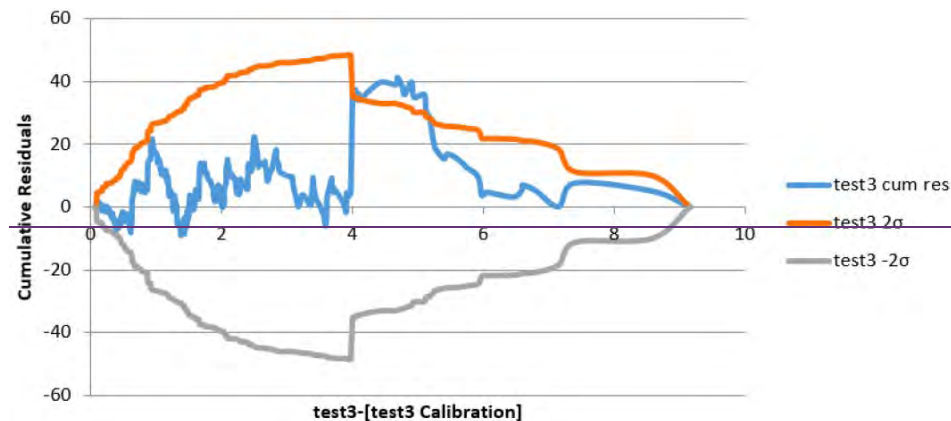
1	2	3	4	5	6	7	8	9	10
<i>AADT<sub>maj</sub></i>	<i>AADT<sub>min</sub></i>	SPF Prediction	Intersection Approaches with Left-Turn Lanes	<i>CMF<sub>LT</sub></i>	Intersection Approaches with Right-Turn Lane	<i>CMF<sub>RT</sub></i>	Years of Data	Predicted Average Crash Frequency	Observed Crash Frequency
4000	2000	0.587	1	0.82	1	0.96	3	1.385	1
3000	1500	0.456	0	1.00	2	0.92	2	0.839	2
5000	3400	0.788	0	1.00	2	0.92	3	2.174	3
6500	3000	0.878	0	1.00	2	0.92	3	2.422	5
3600	2300	0.578	1	0.82	1	0.96	3	1.365	2
4600	4500	0.845	0	1.00	2	0.92	3	2.333	3
5700	3300	0.837	1	0.82	1	0.96	3	1.977	5
6800	1500	0.780	1	0.82	1	0.96	2	1.227	2
Sum								13.722	23
Calibration Factor ( <i>C<sub>i</sub></i> )								1.676	

**A1.1.6 Step 6—Assess success of the calibration, i.e., the adequacy of the calibration sample.**

It is recommended that the FHWA Calibrator tool be used for this assessment. The user guide for that tool provides guidance on how success can be assessed with Cumulative Residual (CURE) plots and the coefficient of variation (CV) of the calibration factor. The calibration is successful if either:

- 1) Five percent or less of CURE plot ordinates for *fitted* values (after applying the calibration factor) exceed the  $2\sigma$  limits, or
- 2) The CV of the calibration factor is less than 0.15.

Exhibit xx, taken from the Calibrator User Guide, is an example of a CURE plot for fitted values of an SPF denoted as “test3”. The Calibrator tool has estimated that 4% of the ordinates (those between fitted values of 4 and 5 crashes) exceed the  $2\sigma$  limits.



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If the calibration factor is assessed to be successfully estimated, then the process moves on to Step 7.

If the sample is assessed to be insufficient then additional sites (if available) are selected using the guidance in Step 2 and added to the calibration sample and the process is taken back to Step 3.

If additional sites are not available and the calibration factor of interest is for total crashes (all types and severities combined) then the calibration factor for a similar facility/crash type, if available, may be assumed; otherwise the uncalibrated SPF may be adopted with due caution.

If additional sites are not available and the calibration is being done for a specific crash type and/or severity then the calibration factor for total crashes, if available, may be assumed; otherwise the uncalibrated SPF may be adopted with due caution. The calibration process is now complete.

#### **A1.1.7 Step 7—Estimate a calibration function (if calibration factor is successfully estimated)**

It is again recommended that the Calibrator Tool be used for estimating Calibration Function using the approach developed by Srinivasan et al. (2016)<sup>2</sup>. In that approach, the calibration factor is a function of the predicted value of the uncalibrated model and is of the form:

$$\text{Calibration Factor} = \alpha(N_{\text{uncalibrated}})^{\beta}$$

where  $N_{\text{uncalibrated}}$  is the predicted number of crashes from the uncalibrated SPF.

If a function cannot be successfully estimated, i.e., the parameter  $\beta$  is statistically insignificant at the 90% confidence level as assessed by the Calibrator tool, then the process is complete and the calibration factor estimated in Step 5 is adopted.

If a function is successfully estimated as assessed by the Calibrator tool, the process moves on to Step 8.

#### **A1.1.8 Step 8—Assess if a calibration function or factor is better**

The Calibrator tool is again used for this assessment. Whichever is better is adopted for use in the Part C predictive process.

Optional Extension of Step 8 (where base models are being calibrated as determined in Step 3)

If appropriate skills are available or could be acquired, it is recommended to try to directly estimate an SPF with the final calibration dataset and adopt the model if successfully estimated and performs better than the calibration factor and calibration function. The FHWA Calibrator tool can be used in this performance assessment.

#### **Example Application of Steps 6, 7, and 8**

Suppose the example initial calibration provided for Step 4 was based on an extended sample of 40 sites with 100 crashes per year and the Calibrator tool provided the following measures for assessing the success of the calibration:

Calibration Factor = 1.98

Coefficient of Variation of the Calibration Factor = 0.18

Percent of CURE Plot ordinates for *fitted* values exceeding the  $2\sigma$  limits = 15%

In this case, the calibration is not successful since both measures exceed the threshold for success (0.15

<sup>2</sup> Srinivasan, R., M. Colety, G. Bahar, B. Crowther and M. Farmen. 2016. Estimation of Calibration Functions for Predicting Crashes on Rural Two-Lane Roads in Arizona. *Transportation Research Record: Journal of the Transportation Research Board Annual Meeting*, No. 2583, pp. 17-24.

for the CV and 5% for percent of CURE Plot ordinates exceeding the  $2\sigma$  limits.

Suppose the analyst assembles data for another 10 sites for a total of 50 sites and finds after applying the Calibrator that the calibration is successful, i.e., one of the two measures is below the upper threshold. The Calibration process then proceeds to Step 7.

The 50 calibration sites are then used to estimate a calibration function of the form:

$$\text{Calibration Factor} = \alpha(N_{\text{uncalibrated}})^{\beta}$$

Suppose the estimated parameter  $\beta$  is deemed to be statistically significant at the 90% confidence level, then the calibration function is assessed to be successfully estimated, and the process moves to Step 8.

In Step 8, the Calibrator tool can be used to assess whether it is better to use the Calibration function or a single calibration factor. It is anticipated that this step is mainly a confirmation that the function logically provides better predictions. However, in some cases, a user may opt for the convenience of a single calibration factor if the improvement achieved by using a function is immaterial. However, at this time there is no guidance on what constitutes an immaterial improvement.

#### A.1.2. **Guidance for Development of Jurisdiction-Specific Safety Performance Functions for Use in the Part C Predictive Method**

Satisfactory results from the Part C predictive method can be obtained by calibrating the predictive model for each facility type, as explained in Appendix A.1.1. However, some users may prefer to develop jurisdiction-specific SPFs using their agency's own data, and this is likely to enhance the reliability of the Part C predictive method. While there is no requirement that this be done, HSM users are welcome to use local data to develop their own SPFs, or if they wish, replace some SPFs with jurisdiction-specific models and retain other SPFs from the Part C chapters. Within the first two to three years after a jurisdiction-specific SPF is developed, calibration of the jurisdiction-specific SPF using the procedure presented in Appendix A.1.1 may not be necessary, particularly if other default values in the Part C models are replaced with locally-derived values, as explained in Appendix A.1.3.

If jurisdiction-specific SPFs are used in the Part C predictive method, they need to be developed with methods that are statistically valid and developed in such a manner that they fit into the applicable Part C predictive method. The following guidelines for development of jurisdiction-specific SPFs that are acceptable for use in Part C include:

- In preparing the crash data to be used for development of jurisdiction-specific SPFs, crashes are assigned to roadway segments and intersections following the definitions explained in Appendix A.2.3 and illustrated in Figure A-1.
- The jurisdiction-specific SPF should be developed with a statistical technique such as negative binomial regression that accounts for the overdispersion typically found in crash data and quantifies an overdispersion parameter so that the model's predictions can be combined with observed crash frequency data using the EB Method.
- The jurisdiction-specific SPF should use the same base conditions as the corresponding SPF in Part C or should be capable of being converted to those base conditions.
- The jurisdiction-specific SPF should include the effects of the following traffic volumes: average annual daily traffic volume for roadway segment and major- and minor-road average annual daily traffic volumes for intersections.
- The jurisdiction-specific SPF for any roadway segment facility type should have a functional form in which predicted average crash frequency is directly proportional to segment length.

These guidelines are not intended to stifle creativity and innovation in model development. However, a model that does not account for overdispersed data or that cannot be integrated with the rest of the Part C predictive method will not be useful.

Two types of data sets may be used for SPF development. First, SPFs may be developed using only data that represent the base conditions, which are defined for each SPF in Chapters 10, 11, and 12. Second, it is also acceptable to develop models using data for a broader set of conditions than the base conditions. In this approach, all variables that are part of the applicable base-condition definition, but have non-base-condition values, should be included in an initial model. Then, the initial model should be made applicable to the base conditions by substituting values that correspond to those base conditions into the model. Several examples of this process are presented in Appendix 10A.

### **A1.3 Guidance for Crash Predictions where SPFs could not be Reliably Estimated or are Otherwise not Available**

There are 2 types of cases where SPFs could not be reliably estimated. These were especially evident in developing SPFs for various crash types and severities. A third type of case pertains to crash types and severities for which estimation of SPFs was not considered.

Case A: Models did not converge or were illogical (e.g., AADT exponents were negative or statistically insignificant at the 10% level) and as such there are no recommended SPFs.

Case B: There is low confidence in a SPF because it did not validate well or had poor Goodness of Fit statistics.

Case C: For numerous crash types and severities estimation of SPFs was not considered either because they were not of primary interest generally (e.g., nighttime crashes) or because there are typically too few crashes to attempt SPF development (e.g., bicycle and pedestrian crashes).

In all cases, a reliable “parent” SPF is available to which a crash type/severity proportion using the application jurisdiction’s data can be applied. A “parent” SPF would be the one with the lowest crash frequency that includes the crash type/severity of interest. For example, a KAB parent SPF, if reliable, would be considered for KA crashes. Otherwise, a KABC parent SPF, if reliable, would be considered for both KA and KAB crashes, and so on.

If Case A or Case C pertains, a crash type/severity proportion developed from the jurisdiction’s data is applied to a prediction from the recommended and calibrated “parent” SPF. It is recommended that the validity of the resulting SPF be assessed using the Calibrator tool before adopting it and due caution be exercised in applying it should the assessment indicate that it may be unreliable.

If Case B pertains, the question for the analyst is which of two potential approaches and SPFs produces the most reliable crash predictions.

Approach 1: A case B uncalibrated SPF that did not validate well or has poor GOF statistics.

Approach 2: A modified SPF in which a crash type/severity proportion developed from the jurisdiction’s data is applied to a prediction from the recommended and uncalibrated “parent” SPF.

To perform this assessment it is recommended that a formal procedure be applied with the FHWA Calibrator tool. In the process, a calibration factor is estimated for the SPF considered in each approach. To do so, the final data used for applying the calibration procedure is assembled, including counts pertaining to the crash type/severity of interest. Then Goodness of Fit measures are estimated for each of the two SPFs applying the Calibrator tool to the final calibration data. A recommendation is made on the basis of a comparison of these measures. That recommendation will include an assessment of the validity of the results from the selected approach that should be considered in applying the selected SPF.

### **A.1.3. Replacement of Selected Default Values in the Part C Predictive Models to Local Conditions**

The Part C predictive models use many default values that have been derived from crash data in HSM-related research. For example, the urban intersection predictive model in Chapter 12 uses pedestrian factors that are based

**Commented [BP9]:** This section deleted because a) crash type/severity SPFs from 17-62 are now available and b) Default proportions are not provided for other types and severities, assuming that a jurisdiction will have sufficient crashes for local estimation for types of interest.

on the proportion of pedestrian crashes compared to total crashes. Replacing these default values with locally derived values will improve the reliability of the Part C predictive models. Table A-3 identifies the specific tables in Part C that may be replaced with locally derived values. In addition to these tables, there is one equation—Equation 10-18—which uses constant values given in the accompanying text in Chapter 10. These constant values may be replaced with locally derived values.

Providing locally derived values for the data elements identified in Table A-3 is optional. Satisfactory results can be obtained with the Part C predictive models, as they stand, when the predictive model for each facility type is calibrated with the procedure given in Appendix A.1.1. But, more reliable results may be obtained by updating the data elements listed in Table A-3. It is acceptable to replace some, but not all of these data elements, if data to replace all of them are not available. Each element that is updated with locally derived values should provide a small improvement in the reliability of that specific predictive model. To preserve the integrity of the Part C predictive method, the quantitative values in the predictive models, (other than those listed in Table A-3 and those discussed in Appendices A.1.1 and A.2.2), should not be modified. Any replacement values derived with the procedures presented in this section should be incorporated in the predictive models before the calibration described in Appendix A.1.1 is performed.

**Table A-3.** Default Crash Distributions Used in Part C Predictive Models Which May Be Calibrated by Users to Local Conditions

Chapter	Table or Equation Number	Type of Roadway Element		Data Element or Distribution That May Be Calibrated to Local Conditions
		Roadway Segments	Intersections	
10—Rural Two-Lane, Two-Way Roads	Table 10-3	X		Crash severity by facility type for roadway segments
	Table 10-4	X		Collision type by facility type for roadway segments
	Table 10-5		X	Crash severity by facility type for intersections
	Table 10-6		X	Collision type by facility type for intersections
	Equation 10-18	X		Driveway-related crashes as a proportion of total crashes ( $p_{dw}$ )
	Table 10-12	X		Nighttime crashes as a proportion of total crashes by severity level
	Table 10-15		X	Nighttime crashes as a proportion of total crashes by severity level and by intersection type
11—Rural Multilane Highways	Table 11-4	X		Crash severity and collision type for undivided segments
	Table 11-6	X		Crash severity and collision type for divided segments
	Table 11-9		X	Crash severity and collision type by intersection type
	Table 11-15	X		Nighttime crashes as a proportion of total crashes by severity level and by roadway segment type for undivided roadway segments
	Table 11-19	X		Nighttime crashes as a proportion of total crashes by severity level and by roadway segment type for divided roadway segments
	Table 11-24		X	Nighttime crashes as a proportion of total crashes by severity level and by intersection type
12—Urban and Suburban Arterials	Table 12-4	X		Crash severity and collision type for multiple-vehicle nondriveway collisions by roadway segment type
	Table 12-6	X		Crash severity and collision type for single-vehicle crashes by roadway segment type
	Table 12-7	X		Crash severity for driveway-related collisions by roadway segment type*
	Table 12-8	X		Pedestrian crash adjustment factor by roadway segment type
	Table 12-9	X		Bicycle crash adjustment factor by roadway segment type

Table 12-14	X	Crash severity and collision type for multiple-vehicle collisions by intersection type
Table 12-15	X	Crash severity and collision type for single-vehicle crashes by intersection type
Table 12-16	X	Pedestrian crash adjustment factor by intersection type for stop-controlled intersections
Table 12-17	X	Bicycle crash adjustment factor by intersection type
Table 12-23	X	Nighttime crashes as a proportion of total crashes by severity level and by roadway segment type
Table 12-27	X	Nighttime crashes as a proportion of total crashes by severity level and by intersection type

\*The only portion of Table 12-7 that should be modified by the user are the crash severity proportions.

Note: No quantitative values in the Part C predictive models, other than those listed here and those discussed in Appendices A.1.1 and A.1.2, should be modified by HSM users.

Procedures for developing replacement values for each data element identified in Table A-3 are presented below. Most of the data elements to be replaced are proportions of crash severity levels and/or crash types that are part of a specific distribution. Each replacement value for a given facility type should be derived from data for a set of sites that, as a group, includes at least 100 crashes and preferably more. The duration of the study period for a given set of sites may be as long as necessary to include at least 100 crashes. In the following discussion, the term “sufficient data” refers to a data set including a sufficient number of sites to meet this criterion for total crashes. In a few cases, explicitly identified below, the definition of sufficient data will be expressed in terms of a crash category other than total crashes. In assembling data for developing replacements for default values, crashes are to be assigned to specific roadway segments or intersections following the definitions explained in Appendix A.2.3 and illustrated in Figure A-1.

#### A.1.3.1. Replacement of Default Values for Rural Two-Lane, Two-Way Roads

Five specific sets of default values for rural two-lane, two-way roads may be updated with locally derived replacement values by HSM users. Procedures to develop each of these replacement values are presented below.

##### *Crash Severity by Facility Type*

Tables 10-3 and 10-5 present the distribution of crashes by five crash severity levels for roadway segments and intersections, respectively, on rural two-lane, two-way roads. If sufficient data, including these five severity levels (fatal, incapacitating injury, nonincapacitating injury, possible injury, and property damage only), are available for a given facility type, the values in Tables 10-3 and 10-5 for that facility type may be updated. If sufficient data are available only for the three standard crash severity levels (fatal, injury, and property damage only), the existing values in Tables 10-3 and 10-5 may be used to allocate the injury crashes to specific injury severity levels (incapacitating injury, nonincapacitating injury, and possible injury).

##### *Collision Type by Facility Type*

Table 10-4 presents the distribution of crashes by collision type for seven specific types of single-vehicle crashes and six specific types of multiple-vehicle crashes for roadway segments, and Table 10-6 presents the distribution of crashes by collision type for three intersection types on rural two-lane, two-way roads. If sufficient data are available for a given facility type, the values in Tables 10-4 and 10-6 for that facility type may be updated.

##### *Driveway-Related Crashes as a Proportion of Total Crashes for Roadway Segments*

Equation 10-18 includes a factor,  $p_{\text{driv}}$ , which represents the proportion of total crashes represented by driveway-related crashes. A value for  $p_{\text{driv}}$  based on research is presented in the accompanying text. This value may be replaced with a locally derived value, if data are available for a set of sites that, as a group, have experienced at least 100 driveway-related crashes.

##### *Nighttime Crashes as a Proportion of Total Crashes for Roadway Segments*

Table 10-12 presents the proportions of total nighttime crashes by severity level and the proportion of total crashes that occur at night for roadway segments on rural two-lane, two-way roads. These values may be replaced with

locally-derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

#### *Nighttime Crashes as a Proportion of Total Crashes for Intersections*

Table 10-15 presents the proportion of total crashes that occur at night for intersections on rural two-lane, two-way roads. These values may be replaced with locally-derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

#### **A.1.3.2.—Replacement of Default Values for Rural Multilane Highways**

Five specific sets of default values for rural multilane highways may be updated with locally-derived replacement values by HSM users. Procedures to develop each of these replacement values are presented below.

##### *Crash Severity and Collision Type for Undivided Roadway Segments*

Table 11-4 presents the combined distribution of crashes for four crash severity levels and six collision types. If sufficient data are available for undivided roadway segments, the values in Table 11-4 for this facility type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available.

##### *Crash Severity and Collision Type for Divided Roadway Segments*

Table 11-6 presents the combined distribution of crashes for four crash severity levels and six collision types. If sufficient data are available for divided roadway segments, the values in Table 11-6 for this facility type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires sites that have experienced at least 200 crashes in the time period for which data are available.

##### *Crash Severity and Collision Type by Intersection Type*

Table 11-9 presents the combined distribution of crashes at intersections for four crash severity levels and six collision types. If sufficient data are available for a given intersection type, the values in Table 11-9 for that intersection type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available.

##### *Nighttime Crashes as a Proportion of Total Crashes for Roadway Segments*

Tables 11-15 and 11-19 present the proportions of total nighttime crashes by severity level and the proportion of total crashes that occur at night for undivided and divided roadway segments, respectively, on rural multilane highways. These values may be replaced with locally-derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

##### *Nighttime Crashes as a Proportion of Total Crashes for Intersections*

Table 11-24 presents the proportion of total crashes that occur at night for intersections on rural multilane highways. These values may be replaced with locally-derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

#### **A.1.3.3.—Replacement of Default Values for Urban and Suburban Arterials**

Eleven specific sets of default values for urban and suburban arterial highways may be updated with locally-derived replacement values by HSM users. Procedures to develop each of these replacement values are presented below.

##### *Crash Severity and Collision Type for Multiple-Vehicle Nondriveway Crashes by Roadway Segment Type*

Table 12-4 presents the combined distribution of crashes for two crash severity levels and six collision types. If sufficient data are available for a given facility type, the values in Table 12-4 for that facility type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available.

##### *Crash Severity and Collision Type for Single-Vehicle Crashes by Roadway Segment Type*

Table 12-6 presents the combined distribution of crashes for two crash severity levels and six collision types. If sufficient data are available for a given facility type, the values in Table 12-6 for that facility type may be updated.



Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available.

***Crash Severity for Driveway-Related Collision by Roadway Segment Type***

Table 12-7 includes data on the proportions of driveway-related crashes for two crash severity levels (fatal and injury and property damage only crashes) by facility type for roadway segments. If sufficient data are available for a given facility type, these specific severity-related values in Table 12-7 for that facility type may be updated. The rest of Table 12-7, other than the last two rows of data which are related to crash severity, should not be modified.

***Pedestrian Crash Adjustment Factor by Roadway Segment Type***

Table 12-8 presents a pedestrian crash adjustment factor for specific roadway segment facility types and for two speed categories: low speed (traffic speeds or posted speed limits of 30 mph or less) and intermediate or high speed (traffic speeds or posted speed limits greater than 30 mph). For a given facility type and speed category, the pedestrian crash adjustment factor is computed as:

$$f_{pedr} = \frac{K_{ped}}{K_{non}} \quad (A-2)$$

Where:

$f_{pedr}$  = pedestrian crash adjustment factor;

$K_{ped}$  = observed vehicle-pedestrian crash frequency; and

$K_{non}$  = observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crash.

The pedestrian crash adjustment factor for a given facility type should be determined with a set of sites of that speed type that, as a group, includes at least 20 vehicle-pedestrian collisions.

***Bicycle Crash Adjustment Factor by Roadway Segment Type***

Table 12-9 presents a bicycle crash adjustment factor for specific roadway segment facility types and for two speed categories: low speed (traffic speeds or posted speed limits of 30 mph or less) and intermediate or high speed (traffic speeds or posted speed limits greater than 30 mph). For a given facility type and speed category, the bicycle crash adjustment factor is computed as:

$$f_{biker} = \frac{K_{bike}}{K_{non}} \quad (A-3)$$

Where:

$f_{biker}$  = bicycle crash adjustment factor;

$K_{bike}$  = observed vehicle-bicycle crash frequency; and

$K_{non}$  = observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes.

The bicycle crash adjustment factor for a given facility type should be determined with a set of sites of that speed type that, as a group, includes at least 20 vehicle-bicycle collisions.

***Crash Severity and Collision Type for Multiple-Vehicle Crashes by Intersection Type***

Table 12-11 presents the combined distribution of crashes for two crash severity levels and six collision types. If sufficient data are available for a given facility type, the values in Table 12-11 for that facility type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available.

***Crash Severity and Collision Type for Single-Vehicle Crashes by Intersection Type***

Table 12-13 presents the combined distribution of crashes for two crash severity levels and six collision types. If sufficient data are available for a given facility type, the values in Table 12-13 for that facility type may be updated. Given that this is a joint distribution of two variables, sufficient data for this application requires a set of sites of a given type that, as a group, have experienced at least 200 crashes in the time period for which data are available. The default values for  $f_{ijm}$  in Equation 12-27 should be replaced with locally available data.

#### ***Pedestrian Crash Adjustment Factor by Intersection Type***

Table 12-16 presents a pedestrian crash adjustment factor for two specific types of intersections with stop control on the minor road. For a given facility type and speed category, the pedestrian crash adjustment factor is computed using Equation A-2. The pedestrian crash adjustment factor for a given facility type is determined with a set of sites that, as a group, have experienced at least 20 vehicle pedestrian collisions.

#### ***Bicycle Crash Adjustment Factor by Intersection Type***

Table 12-17 presents a bicycle crash adjustment factor for four specific intersection facility types. For a given facility type, the bicycle crash adjustment factor is computed using Equation A-3. The bicycle crash adjustment factor for a given facility type is determined with a set of sites that, as a group, have experienced at least 20 vehicle-bicycle collisions.

#### ***Nighttime Crashes as a Proportion of Total Crashes for Roadway Segments***

Table 12-22 presents the proportions of total nighttime crashes by severity level for specific facility types for roadway segments and the proportion of total crashes that occur at night. These values may be replaced with locally derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

#### ***Nighttime Crashes as a Proportion of Total Crashes for Intersections***

Table 12-27 presents the proportions of total nighttime crashes by severity level for specific facility types for intersections and the proportion of total crashes that occur at night. These values may be replaced with locally derived values for a given facility type, if data are available for a set of sites that, as a group, have experienced at least 100 nighttime crashes.

## **A.2. USE OF THE EMPIRICAL BAYES METHOD TO COMBINE PREDICTED AVERAGE CRASH FREQUENCY AND OBSERVED CRASH FREQUENCY**

Application of the EB Method provides a method to combine the estimate using a Part C predictive model and observed crash frequencies to obtain a more reliable estimate of expected average crash frequency. The EB Method is a key tool to compensate for the potential bias due to regression-to-the-mean. Crash frequencies vary naturally from one time period to the next. When a site has a higher than average frequency for a particular time period, the site is likely to have lower crash frequency in subsequent time periods. Statistical methods can help to assure that this natural decrease in crash frequency following a high observed value is not mistaken for the effect of a project or for a true shift in the long-term expected crash frequency.

There are several statistical methods that can be employed to compensate for regression-to-the-mean. The EB Method is used in the HSM because it is best suited to the context of the HSM. The Part C predictive models include negative binomial regression models that were developed before the publication of the HSM by researchers who had no data on the specific sites to which HSM users would later apply those predictive models. The HSM users are generally engineers and planners, without formal statistical training, who would not generally be capable of developing custom models for each set of the sites they wish to apply the HSM to and, even if there were, would have no wish to spend the time and effort needed for model development each time they apply the HSM. The EB Method provides the most suitable tool for compensating for regression-to-the-mean that works in this context.

Each of the Part C chapters presents a four-step process for applying the EB Method. The EB Method assumes that the appropriate Part C predictive model (see [Section 10.3.1](#) for rural two-lane, two-way roads, [Section 11.3.1](#) for rural multilane highways, or [Section 12.3.1](#) for urban and suburban arterials) has been applied to determine the predicted crash frequency for the sites that make up a particular project or facility for a particular past time period of interest. The steps in applying the EB Method are:

- Determine whether the EB Method is applicable, as explained in [Appendix A.2.1](#).
- Determine whether observed crash frequency data are available for the project or facility for the time period for which the predictive model was applied and, if so, obtain those crash frequency data, as explained in [Appendix A.2.2](#). Assign each crash instance to individual roadway segments and intersections, as explained in [Appendix A.2.3](#).
- Apply the EB Method to estimate the expected crash frequency by combining the predicted and observed crash frequencies for the time period of interest. The site-specific EB Method, applicable when observed crash frequency data are available for the individual roadway segments and intersections that make up a project or facility, is presented in [Appendix A.2.4](#). The project-level EB Method, applicable when observed crash frequency data are available only for the project or facility as a whole, is presented in [Appendix A.2.5](#).
- Adjust the estimated value of expected crash frequency to a future time period, if appropriate, as explained in [Appendix A.2.6](#).

Consideration of observed crash history data in the Part C predictive method increases the reliability of the estimate of the expected crash frequencies. When at least two years of observed crash history data are available for the facility or project being evaluated, and when the facility or project meets certain criteria discussed below, the observed crash data should be used. When considering observed crash history data, the procedure must consider both the existing geometric design and traffic control for the facility or project (i.e., the conditions that existed during the before period while the observed crash history was accumulated) and the proposed geometric design and traffic control for the project (i.e., the conditions that will exist during the after period, the period for which crash predictions are being made). In estimating the expected crash frequency for an existing arterial facility in a future time period where no improvement project is planned, only the traffic volumes should differ between the before and after periods. For an arterial on which an improvement project is planned, traffic volumes, geometric design features, and traffic control features may all change between the before and after periods. The EB Method presented below provides a method to combine predicted and observed crash frequencies.

#### **A.2.1. Determine whether the EB Method is Applicable**

The applicability of the EB Method to a particular project or facility depends on the type of analysis being performed and the type of future project work that is anticipated. If the analysis is being performed to assess the expected average crash frequency of a specific highway facility, but is not part of the analysis of a planned future project, then the EB Method should be applied. If a future project is being planned, then the nature of that future project should be considered in deciding whether to apply the EB Method.

The EB Method should be applied for the analyses involving the following future project types:

- Sites at which the roadway geometrics and traffic control are not being changed (e.g., the “do-nothing” alternative);
- Projects in which the roadway cross section is modified but the basic number of through lanes remains the same (This would include, for example, projects for which lanes or shoulders were widened or the roadside was improved, but the roadway remained a rural two-lane highway);
- Projects in which minor changes in alignment are made, such as flattening individual horizontal curves while leaving most of the alignment intact;
- Projects in which a passing lane or a short four-lane section is added to a rural two-lane, two-way road to increase passing opportunities; and
- Any combination of the above improvements.

The EB Method is not applicable to the following types of improvements:

- Projects in which a new alignment is developed for a substantial proportion of the project length; and
- Intersections at which the basic number of intersection legs or type of traffic control is changed as part of a project.

The reason that the EB Method is not used for these project types is that the observed crash data for a previous time period is not necessarily indicative of the crash experience that is likely to occur in the future after such a major geometric improvement. Since, for these project types, the observed crash frequency for the existing design is not relevant to estimation of the future crash frequencies for the site, the EB Method is not needed and should not be applied. If the EB Method is applied to individual roadway segments and intersections, and some roadway segments and intersections within the project limits will not be affected by the major geometric improvement, it is acceptable to apply the EB Method to those unaffected segments and intersections.

If the EB Method is not applicable, do not proceed to the remaining steps. Instead, follow the procedure described in the [Applications section of the applicable Part C chapter](#).

#### **A.2.2. Determine whether Observed Crash Frequency Data are Available for the Project or Facility and, if so, Obtain those Data**

If the EB Method is applicable, it should be determined whether observed crash frequency data are available for the project or facility of interest directly from the jurisdiction's crash record system or indirectly from another source. At least two years of observed crash frequency data are desirable to apply the EB Method. The best results in applying the EB Method will be obtained if observed crash frequency data are available for each individual roadway segment and intersection that makes up the project of interest. The EB Method applicable to this situation is presented in [Appendix A.2.4](#). Criteria for assigning crashes to individual roadway segments and intersections are presented in [Appendix A.2.3](#). If observed crash frequency data are not available for individual roadway segments and intersections, the EB Method can still be applied if observed crash frequency data are available for the project or facility as a whole. The EB Method applicable to this situation is presented in [Appendix A.2.5](#).

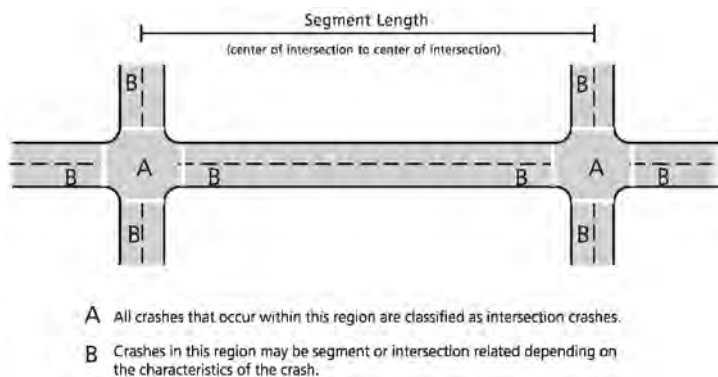
If appropriate crash frequency data are not available, do not proceed to the remaining steps. Instead, follow the procedure described in the Applications section of the applicable Part C chapter.

#### **A.2.3. Assign Crashes to Individual Roadway Segments and Intersections for Use in the EB Method**

The Part C predictive method has been developed to estimate crash frequencies separately for intersections and roadway segments. In the site-specific EB Method presented in [Appendix A.2.4](#), observed crashes are combined with the predictive model estimate of crash frequency to provide a more reliable estimate of the expected average crash frequency of a particular site. In Step 6 of the predictive method, if the site-specific EB Method is applicable, observed crashes are assigned to each individual site identified within the facility of interest. Because the predictive models estimate crashes separately for intersections and roadway segments, which may physically overlap in some cases, observed crashes are differentiated and assigned as either intersection related crashes or roadway segment related crashes.

Intersection crashes include crashes that occur at an intersection (i.e., within the curb limits) and crashes that occur on the intersection legs and are intersection-related. All crashes that are not classified as intersection or intersection-related crashes are considered to be roadway segment crashes. Figure A-1 illustrates the method used to assign crashes to roadway segments or intersections. As shown:

- All crashes that occur within the curblane limits of an intersection (Region A in the figure) are assigned to that intersection.
- Crashes that occur outside the curblane limits of an intersection (Region B in the figure) are assigned to either the roadway segment on which they occur or an intersection, depending on their characteristics. Crashes that are classified on the crash report as intersection-related or have characteristics consistent with an intersection-related crash are assigned to the intersection to which they are related; such crashes would include rear-end collisions related to queues on an intersection approach. Crashes that occur between intersections and are not related to an intersection, such as collisions related to turning maneuvers at driveways, are assigned to the roadway segment on which they occur.



**Figure A-1.** Definition of Roadway Segments and Intersections

In some jurisdictions, crash reports include a field that allows the reporting officer to designate the crash as intersection-related. When this field is available on the crash reports, crashes should be assigned to the intersection or the segment based on the way the officer marked the field on the report. In jurisdictions where there is not a field on the crash report that allows the officer to designate crashes as intersection-related, the characteristics of the crash may be considered to make a judgment as to whether the crash should be assigned to the intersection or the segment. Other fields on the report, such as collision type, number of vehicles involved, contributing circumstances, weather condition, pavement condition, traffic control malfunction, and sequence of events can provide helpful information in making this determination.

If the officer's narrative and crash diagram are available to the user, they can also assist in making the determination. The following crash characteristics may indicate that the crash was related to the intersection:

- Rear-end collision in which both vehicles were going straight approaching an intersection or in which one vehicle was going straight and struck a stopped vehicle
- Collision in which the report indicates a signal malfunction or improper traffic control at the intersection

The following crash characteristics may indicate that the crash was not related to the intersection and should be assigned to the segment on which it occurred:

- Collision related to a driveway or involving a turning movement not at an intersection
- Single-vehicle run-off-the-road or fixed object collision in which pavement surface condition was marked as wet or icy and identified as a contributing factor

These examples are provided as guidance when an "intersection-related" field is not available on the crash report; they are not strict rules for assigning crashes. Information on the crash report should be considered to help make the determination, which will rely on judgment. The information needed for classifying crashes is whether each crash is, or is not, related to an intersection. The consideration of crash type data is presented here only as an example of one approach to making this determination.

Using these guidelines, the roadway segment predictive models estimate the average frequency of crashes that would occur on the roadway if no intersection were present. The intersection predictive models estimate the average frequency of additional crashes that occur because of the presence of an intersection.

#### **A.2.4. Apply the Site-Specific EB Method**

Equations A-4 and A-5 are used directly to estimate the expected crash frequency for a specific site by combining the predictive model estimate with observed crash frequency. The value of  $N_{\text{expected}}$  from Equation A-4 represents the

expected crash frequency for the same time period represented by the predicted and observed crash frequencies.  $N_{\text{predicted}}$ ,  $N_{\text{observed}}$ , and  $N_{\text{expected}}$  all represent either total crashes or a specific severity level or collision type of interest. The expected average crash frequency considering both the predictive model estimate and observed crash frequencies for an individual roadway segment or intersection is computed as:

$$N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}} \quad (\text{A-4})$$

$$w = \frac{1}{1 + k \times \left( \sum_{\text{all study years}} N_{\text{predicted}} \right)} \quad (\text{A-5})$$

Where:

- $N_{\text{expected}}$  = estimate of expected average crashes frequency for the study period;
- $N_{\text{predicted}}$  = predictive model estimate of average crash frequency predicted for the study period under the given conditions;
- $N_{\text{observed}}$  = observed crash frequency at the site over the study period;
- $w$  = weighted adjustment to be placed on the predictive model estimate; and
- $k$  = overdispersion parameter of the associated SPF used to estimate  $N_{\text{predicted}}$ .

When observed crash data by severity level is not available, the estimate of expected average crash frequency for fatal-and-injury and property-damage-only crashes is calculated by applying the proportion of predicted average crash frequency by severity level ( $N_{\text{predicted}(FI)} / N_{\text{predicted}(\text{total})}$  and  $N_{\text{predicted}(PDO)} / N_{\text{predicted}(\text{total})}$ ) to the total expected average crash frequency from Equation A-4.

Equation A-5 shows an inverse relationship between the overdispersion parameter,  $k$ , and the weight,  $w$ . This implies that when a model with little overdispersion is available; more reliance will be placed on the predictive model estimate,  $N_{\text{predicted}}$ , and less reliance on the observed crash frequency,  $N_{\text{observed}}$ . The opposite is also the case; when a model with substantial overdispersion is available, less reliance will be placed on the predictive model estimate,  $N_{\text{predicted}}$ , and more reliance on the observed crash frequency,  $N_{\text{observed}}$ .

It is important to note in Equation A-5 that, as  $N_{\text{predicted}}$  increases, there is less weight placed on  $N_{\text{predicted}}$  and more on  $N_{\text{observed}}$ . This might seem counterintuitive at first. However, this implies that for longer sites and for longer study periods, there are more opportunities for crashes to occur. Thus, the observed crash history is likely to be more meaningful and the model prediction less important. So, as  $N_{\text{predicted}}$  increases, the EB Method places more weight on the number of crashes that actually occur,  $N_{\text{observed}}$ . When few crashes are predicted, the observed crash frequency,  $N_{\text{observed}}$ , is not likely to be meaningful, in statistical terms, so greater reliance is placed on the predicted crash frequency,  $N_{\text{predicted}}$ .

The values of the overdispersion parameters,  $k$ , for the safety performance functions used in the predictive models are presented with each SPF in Sections 10.6, 11.6, and 12.6.

Since application of the EB Method requires use of an overdispersion parameter, it cannot be applied to portions of the prediction method where no overdispersion parameter is available. For example, vehicle-pedestrian and vehicle-bicycle collisions are estimated in portions of Chapter 12 from adjustment factors rather than from models and should, therefore, be excluded from the computations with the EB Method. Chapter 12 uses multiple models with different overdispersion parameters in safety predictions for any specific roadway segment or intersection. Where observed crash data are aggregated so that the corresponding value of predicted crash frequency is determined as the sum of the results from multiple predictive models with differing overdispersion parameters, the project-level EB Method presented in Appendix A.2.5 should be applied rather than the site-specific method presented here.

Chapters 10, 11, and 12 each present worksheets that can be used to apply the site-specific EB Method as presented in this section.

Appendix A.2.6 explains how to update  $N_{\text{expected}}$  to a future time period, such as the time period when a proposed future project will be implemented. This procedure is only applicable if the conditions of the proposed project will not be substantially different from the roadway conditions during which the observed crash data was collected.

### A.2.5. Apply the Project-Level EB Method

HSM users may not always have location specific information for observed crash data for the individual roadway segments and intersections that make up a facility or project of interest. Alternative procedures are available where observed crash frequency data are aggregated across several sites (e.g., for an entire facility or project). This requires a more complex EB Method for two reasons. First, the overdispersion parameter,  $k$ , in the denominator of Equation A-5 is not uniquely defined, because estimate of crash frequency from two or more predictive models with different overdispersion parameters are combined. Second, it cannot be assumed, as is normally done, that the expected average crash frequency for different site types are statistically correlated with one another. Rather, an estimate of expected average crash frequency should be computed based on the assumption that the various roadway segments and intersections are statistically independent ( $r = 0$ ) and on the alternative assumption that they are perfectly correlated ( $r = 1$ ). The expected average crash frequency is then estimated as the average of the estimates for  $r = 0$  and  $r = 1$ .

The following equations implement this approach, summing the first three terms, which represent the three roadway-segment-related crash types, over the five types of roadway segments considered in the (2U, 3T, 4U, 4D, 5T) and the last two terms, which represent the two intersection-related crash types, over the four types of intersections (3ST, 3SG, 4ST, 4SG):

$$N_{\text{predicted (total)}} = \sum_{j=1}^5 N_{\text{predicted } rmj} + \sum_{j=1}^5 N_{\text{predicted } rsj} + \sum_{j=1}^5 N_{\text{predicted } rdj} + \sum_{j=1}^4 N_{\text{predicted } imj} + \sum_{j=1}^4 N_{\text{predicted } isj} \quad (\text{A-6})$$

$$N_{\text{observed (total)}} = \sum_{j=1}^5 N_{\text{observed } rmj} + \sum_{j=1}^5 N_{\text{observed } rsj} + \sum_{j=1}^5 N_{\text{observed } rdj} + \sum_{j=1}^4 N_{\text{observed } imj} + \sum_{j=1}^4 N_{\text{observed } isj} \quad (\text{A-7})$$

$$N_{\text{predicted } w0} = \sum_{j=1}^5 k_{rmj} N_{rmj}^2 + \sum_{j=1}^5 k_{rsj} N_{rsj}^2 + \sum_{j=1}^5 k_{rdj} N_{rdj}^2 + \sum_{j=1}^4 k_{imj} N_{imj}^2 + \sum_{j=1}^4 k_{isj} N_{isj}^2 \quad (\text{A-8})$$

$$N_{\text{predicted, w1}} = \left[ \frac{\sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}^2} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}^2}}{\sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}^2} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}^2} + \sum_{j=1}^4 \sqrt{k_{imj} N_{imj}^2} + \sum_{j=1}^4 \sqrt{k_{isj} N_{isj}^2}} \right]^2 \quad (\text{A-9})$$

$$w_0 = \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} \quad (\text{A-10})$$

$$N_0 = w_0 N_{\text{predicted (total)}} + (1 - w_0) N_{\text{observed (total)}} \quad (\text{A-11})$$

$$w_1 = \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}} \quad (\text{A-12})$$

$$N_1 = w_1 N_{\text{predicted (total)}} + (1 - w_1) N_{\text{observed (total)}} \quad (\text{A-13})$$

$$N_{\text{expected/comb}} = \frac{N_0 + N_1}{2} \quad (\text{A-14})$$

Where:

$N_{\text{predicted (total)}}$  = predicted number of total crashes for the facility or project of interest during the same period for which crashes were observed;

$N_{\text{predicted } rmj}$  = Predicted number of multiple-vehicle nondriveway collisions for roadway segments of type  $j$ ,  $j = 1, \dots, 5$ , during the same period for which crashes were observed;

$N_{\text{predicted } rsj}$  = Predicted number of single-vehicle collisions for roadway segments of type  $j$ , during the same period for which crashes were observed;

$N_{\text{predicted } rdj}$  = Predicted number of multiple-vehicle driveway-related collisions for roadway segments of type  $j$ , during the same period for which crashes were observed;

$N_{\text{predicted } imj}$  = Predicted number of multiple-vehicle collisions for intersections of type  $j$ ,  $j = 1, \dots, 4$ , during the same period for which crashes were observed;

$N_{\text{predicted } isj}$  = Predicted number of single-vehicle collisions for intersections of type  $j$ , during the same period for which crashes were observed;

$N_{\text{observed (total)}}$  = Observed number of total crashes for the facility or project of interest;

$N_{\text{observed } rmj}$  = Observed number of multiple-vehicle nondriveway collisions for roadway segments of type  $j$ ;

$N_{\text{observed } rsj}$  = Observed number of single-vehicle collisions for roadway segments of type  $j$ ;

$N_{\text{observed } rdj}$  = Observed number of driveway-related collisions for roadway segments of type  $j$ ;

$N_{\text{observed } imj}$  = Observed number of multiple-vehicle collisions for intersections of type  $j$ ;

$N_{\text{observed } isj}$  = Observed number of single-vehicle collisions for intersections of type  $j$ ;

$N_{\text{predicted } w0}$  = Predicted number of total crashes during the same period for which crashes were observed under the assumption that crash frequencies for different roadway elements are statistically independent ( $\rho = 0$ );

$k_{rmj}$  = Overdispersion parameter for multiple-vehicle nondriveway collisions for roadway segments of type  $j$ ;

$k_{rsj}$  = Overdispersion parameter for single-vehicle collisions for roadway segments of type  $j$ ;

$k_{rdj}$  = Overdispersion parameter for driveway-related collisions for roadway segments of type  $j$ ;

$k_{imj}$  = Overdispersion parameter for multiple-vehicle collisions for intersections of type  $j$ ;

$k_{isj}$  = Overdispersion parameter for single-vehicle collisions for intersections of type  $j$ ;



$N_{\text{predicted } w1}$	=	Predicted number of total crashes under the assumption that crash frequencies for different roadway elements are perfectly correlated ( $\rho = 1$ );
$w_0$	=	weight placed on predicted crash frequency under the assumption that crash frequencies for different roadway elements are statistically independent ( $r = 0$ );
$w_1$	=	weight placed on predicted crash frequency under the assumption that crash frequencies for different roadway elements are perfectly correlated ( $r = 1$ );
$N_0$	=	expected crash frequency based on the assumption that different roadway elements are statistically independent ( $r = 0$ );
$N_1$	=	expected crash frequency based on the assumption that different roadway elements are perfectly correlated ( $r = 1$ ); and
$N_{\text{expected/comb}}$	=	expected average crash frequency of combined sites including two or more roadway segments or intersections.

All of the crash terms for roadway segments and intersections presented in Equations A-6 through A-9 are used for analysis of urban and suburban arterials (Chapter 12). The predictive models for rural two-lane, two-way roads and multilane highways (Chapters 10 and 11) are based on the site type and not on the collision type. Therefore, only one of the predicted crash terms for roadway segments ( $N_{\text{predicted } rmj}$ ,  $N_{\text{predicted } rsj}$ ,  $N_{\text{predicted } rdj}$ ), one of the predicted crash terms for intersections ( $N_{\text{predicted } imj}$ ,  $N_{\text{predicted } isj}$ ), one of the observed crash terms for roadway segments ( $N_{\text{observed } rmj}$ ,  $N_{\text{observed } rsj}$ ,  $N_{\text{observed } rdj}$ ), and one of the observed crash terms for intersections ( $N_{\text{observed } imj}$ ,  $N_{\text{observed } isj}$ ) is used. For rural two-lane, two-way roads and multilane highways, it is recommended that the multiple-vehicle collision terms (with subscripts  $rmj$  and  $imj$ ) be used to represent total crashes; the remaining unneeded terms can be set to zero.

Chapters 10, 11, and 12 each present worksheets that can be used to apply the project-level EB Method as presented in this section.

The value of  $N_{\text{expected/comb}}$  from Equation A-14 represents the expected average crash frequency for the same time period represented by the predicted and observed crash frequencies. The estimate of expected average crash frequency of combined sites for fatal-and-injury and property-damage-only crashes is calculated by multiplying the proportion of predicted average crash frequency by severity level ( $N_{\text{predicted}(FI)}/N_{\text{predicted}(total)}$ ) and  $N_{\text{predicted}(PDO)}/N_{\text{predicted}(total)}$  to the total expected average crash frequency of combined sites from Equation A-14. Appendix A.2.6 explains how to update  $N_{\text{expected/comb}}$  to a future time period, such as the time period when a proposed future project will be implemented.

#### A.2.6. Adjust the Estimated Value of Expected Average Crash frequency to a Future Time Period, If Appropriate

The value of the expected average crash frequency ( $N_{\text{expected}}$ ) from Equation A-4 or  $N_{\text{expected/comb}}$  from Equation A-14 represents the expected average crash frequency for a given roadway segment or intersection (or project, for  $N_{\text{expected/comb}}$ ) during the before period. To obtain an estimate of expected average crash frequency in a future period (the after period), the estimate is corrected for (1) any difference in the duration of the before and after periods; (2) any growth or decline in AADTs between the before and after periods; and (3) any changes in geometric design or traffic control features between the before and after periods that affect the values of the CMFs for the roadway segment or intersection. The expected average crash frequency for a roadway segment or intersection in the after period can be estimated as:

$$N_f = N_p \left( \frac{N_{bf}}{N_{bp}} \right) \left( \frac{CMF_{1f}}{CMF_{1p}} \right) \left( \frac{CMF_{2f}}{CMF_{2p}} \right) \dots \left( \frac{CMF_{nf}}{CMF_{np}} \right) \quad (A-15)$$

Where:

$N_f$	=	expected average crash frequency during the future time period for which crashes are being forecast for the segment or intersection in question (i.e., the after period);
$N_p$	=	expected average crash frequency for the past time period for which observed crash history data were available (i.e., the before period);
$N_{bf}$	=	number of crashes forecast by the SPF using the future AADT data, the specified nominal values for geometric parameters, and—in the case of a roadway segment—the actual length of the segment;
$N_{bp}$	=	number of crashes forecast by the SPF using the past AADT data, the specified nominal values for geometric parameters, and—in the case of a roadway segment—the actual length of the segment;
$CMF_{nf}$	=	value of the $n$ th CMF for the geometric conditions planned for the future (i.e., proposed) design; and
$CMF_{np}$	=	value of the $n$ th CMF for the geometric conditions for the past (i.e., existing) design.

Because of the form of the SPFs for roadway segments, if the length of the roadway segments are not changed, the ratio  $N_{bf}/N_{bp}$  is the same as the ratio of the traffic volumes,  $AADT_f/AADT_p$ . However, for intersections, the ratio  $N_{bf}/N_{bp}$  is evaluated explicitly with the SPFs because the intersection SPFs incorporate separate major- and minor-road AADT terms with differing coefficients. In applying Equation A-15, the values of  $N_{bp}$ ,  $N_{bf}$ ,  $CMF_{np}$ , and  $CMF_{nf}$  should be based on the average AADTs during the entire before or after period, respectively.

In projects that involve roadway realignment, if only a small portion of the roadway is realigned, the ratio  $N_{bf}/N_{bp}$  should be determined so that its value reflects the change in roadway length. In projects that involve extensive roadway realignment, the EB Method may not be applicable (see discussion in [Appendix A.2.1](#)).

Equation A-15 is applied to total average crash frequency. The expected future average crash frequencies by severity level should also be determined by multiplying the expected average crash frequency from the before period for each severity level by the ratio  $N_f/N_p$ .

In the case of minor changes in roadway alignment (i.e., flattening a horizontal curve), the length of an analysis segment may change from the past to the future time period, and this would be reflected in the values of  $N_{bp}$  and  $N_{bf}$ .

Equation A-15 can also be applied in cases for which only facility- or project-level data are available for observed crash frequencies. In this situation,  $N_{\text{expected}/\text{comb}}$  should be used instead of  $N_{\text{expected}}$  in the equation.