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Evaluation of the Intelligent Cruise Control System
Volume II – Appendices

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13. ABSTRACT (Maximum 200 words)

The Intelligent Cruise Control (ICC) system evaluation was sponsored by the National Highway Traffic Safety Administration (NHTSA) and based on an ICC Field Operational Test (FOT) conducted under a cooperative agreement between the NHTSA and the University of Michigan Transportation Research Institute (UMTRI). The FOT was performed in Michigan and involved one hundred-eight volunteers recruited to drive ten ICC-equipped Chrysler Concordes. Testing was initiated in July 1996 and completed in September 1997. The ICC system tested automatically maintains a set time-headway between an ICC-equipped vehicle and a preceding vehicle through throttle modulation and down-shifting (but not braking).
The Volpe National Transportation Systems Center (Volpe Center), with support from Science Applications International Corporation (SAIC), conducted the independent evaluation of the ICC for NHTSA. The overall goals were to evaluate: (1) Safety Effects of the ICC System, (2) ICC System and Vehicle Performance, (3) User Acceptance of the ICC System, and (4) System Deployment Issues.
The FOT provided three primary sources of data used in the evaluation: (1) digital data on ICC system and vehicle performance (e.g., velocity, time-headway, range) collected in deci-second intervals by an on-board data acquisition system, (2) video data from a forward-looking camera mounted on the vehicle, and (3) participant questionnaires and focus groups. The data was collected by UMTRI and was forwarded to the Volpe Center and SAIC on CD-ROM disks. A special database was established to support the evaluation. In addition, a number of data processing and analysis tools were also developed. This evaluation report describes the approaches used to address each evaluation goal, discusses detailed results and findings, and makes recommendations in each area. Volume I provides the study results and Volume II provides the supporting appendices.
With respect to the primary evaluation goal (safety), it was concluded that use of the ICC system was associated with safer driving compared to manual control and, to a lesser extent, conventional cruise control, and is projected to result in net safety benefits if widely deployed. The evaluation also uncovered some areas of safety concern associated with ICC driving. In spite of these concerns, however, there are several ameliorating factors that suggest the concerns do not represent an overall safety problem for the ICC system.

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Preface

The conduct of the evaluation study necessitated the development and application of various tools, model methodologies, algorithms, protocols, calculations, definitions, and supporting analyses. These are contained in the appendices to make the body of the report more readable. Special recognition is given here to the main individual contributors to each appendix.

Appendix A *Snow Trip Examination* – Andy Lam, Volpe Center

Appendix B *Calculation of Minimum Retro-reflectivity for Target Detection* – Charles Goodspeed, SAIC

Appendix C *Driving State Identification Tool* – Mark Carter and Mark Robinson, SAIC

Appendix D *Lane Change Algorithm* – Mark Carter and Mark Baker, SAIC

Appendix E *Fuel Emission Algorithm* – Michael Penic, SAIC

Appendix F *GIS/GPS Map Matching Model* – Mark Carter, SAIC

Appendix G *Congestion Model* – Mark Baker, SAIC, and Michel Van Aerde, Virginia Polytechnic University

Appendix H *Video/Digital Data Integration Tool* – Mark Robinson, SAIC

Appendix I *Video Classification Training Manual* – Mark Robinson, SAIC

Appendix J *State Space Boundary Definitions* – Andy Lam, Volpe Center

Appendix K *State Space Boundary Crossing Analyses* – Joe Koziol and Andy Lam, Volpe Center

Appendix L *Video Analysis of Critical Pre-Crash Scenarios* – Sam Park, Andy Lam and Joe Koziol, Volpe Center

Appendix M *Intelligent Cruise Control Systems and Traffic Flow Behavior* – Darbha Swaroop and Shaival Gupta, Texas A&M University

Appendix N *Cost Model Inflation Factors* – Andrew Dixson, SAIC

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

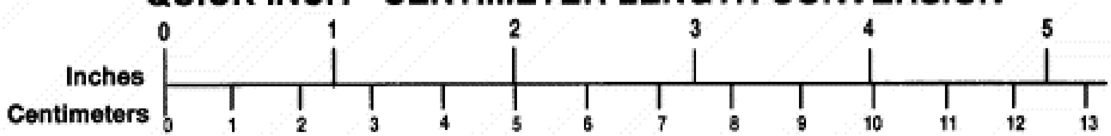
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Appendix A

Snow Trip Examination

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The ICC field operational test was suspended during the winter months of testing because of known problems of snow build-up in front of the sensors mounted on the grille of the test vehicles. Tests by the participants confirmed that snow build-up could be interpreted by the system as a lead vehicle traveling within a meter in front of the ICC host vehicle. The purpose of this examination was to identify any drivers that experienced snow problems before the tests were suspended and that might have been inadvertently included in the data.

As a first step in this examination process, UMTRI provide the Volpe Center with a list of suspect drivers and their trips based on weather-related information that was available. To examine these cases, Volpe utilized the Video Analyzer that was developed under the evaluation project. (See Appendix H for a full description of the Video Analyzer.) The Video Analyzer was developed to integrate both the video data and key digital data for purposes of determining measures of effectiveness from the test. With the Video Analyzer, Volpe was thus readily able to determine if there were snow problems with the sensor during portions of these trips.

With the initial list of three drivers and six trips, snow problems were found with two of the drivers and four trips. Since this indicated potential snow problems with the existing data at that time, a more comprehensive approach was undertaken to scan all the data taken before the test was suspended. First, UMTRI developed an algorithm that queried the database for data inconsistencies. Second, the evaluation team queried the Video Analyzer database (catalog files) that had been previously processed and that had provisions for entering weather conditions. In this manner a total of 125 trips and 165 separate videos involving 16 drivers were identified as potential snow problem trips. A thorough examination of all these videos was conducted with the video analyzer. The results are shown in Table A-1.

In total, 10 trips and 24 separate videos were found to have snow problems. Of the 24 videos, 18 had snow present as well as a lead vehicle present, and there was tracking but zero range was indicated. This is evidence of the problem mentioned above where the ICC system was interpreting this condition as a lead vehicle traveling within a meter in front of the ICC host vehicle. The snow build-up was apparently reflecting the beam directly back to the sensor. Since the system disengages the ICC when the range is short (less than two meters), the driver might consider this situation a nuisance. However there is a potential hazard that that the driver would need to be aware of if he/she were using ICC. With disengagement, the vehicle would begin to coast. If the system were functioning properly, the control authority would include downshifting. This discrepancy is what makes the snow problem a potential hazard. However, none of the videos showed a dangerous situation. Either the ICC was not engaged, the driver took control, or no hazardous closing situation with a lead vehicle developed.

With the remaining 6 videos, snow was present, a lead vehicle was present, but there was no tracking, and there was no range indicated. This is evident of another type of snow problem where the ICC system was interpreting this condition as no lead vehicle present. The snow build-up in this case may have been diffusing the IR beam thus not resulting in any reflection back to the sensor. Clearly this false negative is a potentially dangerous situation. If the driver had ICC engaged and a closing situation with a lead vehicle developed, the driver would have to recognize that the system was malfunctioning and take control of the vehicle. Fortunately, there was no hazard in the 6 videos examined.

In addition to the 24 videos mentioned above there were 30 videos where there was clearly no vehicle present, yet tracking was indicated at zero range. This is also evidence of the same problem mentioned above where the ICC system was interpreting this condition as a lead vehicle traveling within a meter in front of the ICC host vehicle. In these cases, no lead vehicle was present and therefore no hazard would have developed. However, if the driver were using the ICC, then system disengagement would be viewed as a nuisance.

There were also 8 cases where there was clearly no vehicle present, tracking was indicated and a range was indicated. Although indicative of a false alarm, even if ICC were engaged, there may be no indication to the driver of malfunctioning, if the system does not respond or disengage because the signal being tracked does not warrant a response or disengagement.

For purposes of the ICC evaluation it was decided to drop all the snow problem trips including the trips with tracking problems from the analysis. The overriding consideration in this matter is that the ICC system is a prototype, not a pre-production or production system. The problems uncovered with the system in the field operational test are only a concern to the extent that they may affect the outcome of the evaluation. The evaluation focuses on the functional outcomes of the problems, not on the nature of the problem itself. Hence dropping all known snow problems from the evaluation was felt to have no bearing on the remainder of the evaluation. Overall the exclusion amounted to 21 trips for 8 drivers. The exclusion applied to both the scenario analyses as well as the statistical analyses. Compared to a total of over 10,000 trips for the 108 drivers that were amassed during the evaluation, the impact of their inclusion or exclusion for any statistical analysis would either way be miniscule.

As a further check of the data quality/consistency, the following data were analyzed from the database for all 108 drivers. The results are shown in Table A-2.

- Range — 0 = false, > 0 = true
- Tracking — boolean value, 1 = true, 0 = false
- Valid Target — boolean value, 1 = true, 0 = false

The dominant cases are:

(0,0,0) - no valid target present
(1,1,1) - valid target present
(1,1,0) – tracking but not valid target

The remaining cases may be considered data inconsistencies. Together they amount to about 0.1% of all the data in the primary SQL database used in this analysis. The evaluation team has also decided to eliminate these data points (0,0,1 0,1,0 0,1,1 1,0,0 and 1,0,1) from the analyses. They should eliminate many of the problems with the data such as the snow problems mentioned above. However, this method does not directly eliminate all the false negatives or false positives. As mentioned above, there were some cases where a vehicle was present, yet “Range” and “Tracking” were indicated as “0”. Conversely, there were a few cases where a vehicle was not present, yet “Range” and “Tracking” were indicated as “1”. Only with the use of a forward-looking video for all of the test data could there be assurance of eliminating these types of signal problems.

Table A-1 Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
26	19	0	yes	yes	yes	no	**	*	
26	19	1	yes	yes	yes	no	**	*	
26	19	2	yes	no	yes	no		*	
26	19	3	yes	no	yes	no		*	
26	19	4	yes	yes	yes	no	**	*	
26	19	5	yes	yes	yes	no	**	*	
26	19	6	yes	no	yes	no		*	
26	22	0	yes	yes	yes	no	**	*	
26	22	1	yes	yes	yes	no	**	*	
26	69	0	yes	yes	yes	yes			
26	69	2	yes	no	yes	no		*	
26	69	3	yes	no	yes	no		*	
26	69	4	yes	no	yes	no		*	
26	69	5	yes	yes	yes	no	**	*	
26	69	7	no	no	yes	no		*	
26	69	9	yes	no	yes	no		*	
26	69	10	yes	no	yes	no		*	
30	20	0	yes	no	yes	yes		*	
30	20	1	yes	no	yes	yes		*	
30	20	2	yes	no	yes	yes		*	
30	20	3	yes	no	yes	yes		*	
30	20	13	yes	no	yes	yes		*	
30	20	15	yes	no	yes	yes		*	
33	95	0	yes	yes	no	no	**	*	
33	95	1	yes	yes	no	no	**	*	
33	96	0	yes	no	yes	no		*	
33	96	1	yes	no	yes	no		*	
33	96	2	yes	no	yes	no		*	
33	96	3	yes	no	yes	no		*	
33	96	4	yes	no	yes	no		*	
33	96	5	yes	yes	yes	no	**	*	
33	96	6	yes	yes	yes	no	**	*	
33	96	7	yes	yes	yes	no	**	*	
33	96	8	yes	yes	yes	no	**	*	
37	21	N/A							
37	25	N/A							
37	26	N/A							
37	30	N/A							
37	37	N/A							
37	42	N/A							
37	71	0	no	no	no	no			Road is wet

Table A-1 (Cont'd) Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
37	77	N/A							
37	85	N/A							
37	88	0	no	no	no	no			Weather is raining
37	89	0	no	no	no	no			
38	2	N/A							
38	23	N/A							
38	24	N/A							
38	26	N/A							
38	29	N/A							
38	49	N/A							
38	54	N/A							
38	60	N/A							
38	61	0	no	no	no	no			
38	65	N/A							
38	69	0	no	yes	yes	yes			
39	8	0	yes	no	yes	no		*	60% tracking
39	18	0	yes	yes	yes	no	**	*	
39	18	1	yes	yes	yes	no	**	*	
39	19	0	yes	no	yes	no		*	Heavy snow
39	19	1	yes	no	yes	no		*	Heavy snow
39	19	2	yes	no	yes	no		*	Heavy snow
39	32	0	yes	no	yes	no		*	No snowing
39	32	1	yes	no	yes	no		*	No snowing
39	32	2	yes	no	yes	no		*	No snowing
39	32	3	yes	no	yes	no		*	No snowing
39	32	4	yes	no	yes	no		*	
39	32	5	yes	no	yes	no		*	
39	32	6	yes	yes	yes	no	**	*	
39	32	7	yes	yes	yes	no	**	*	
39	32	8	yes	yes	yes	no	**	*	
39	32	9	yes	yes	yes	no	**	*	
39	33	0	yes	yes	yes	yes			
39	33	1	yes	yes	yes	yes			
39	33	2	yes	yes	yes	yes			
39	33	3	yes	no	yes	no		*	
39	35	0	?	?	yes	no		*	night time, unsure
39	35	1	?	?	yes	no		*	night time, unsure
39	36	0	yes	no	yes	no		*	55% tracking
39	36	1	yes	no	yes	no		*	5% tracking
39	36	2	yes	no	yes	no		*	10% tracking
39	37	0	yes	yes	yes	yes			20% tracking
39	37	1	yes	no	yes	no		*	
39	55	0	yes	yes	yes	yes			

Shaded area – initial list provided by UMTRI

Table A-1 (Cont'd) Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
39	61	0	yes	no	no	no			
39	61	1	yes	yes	yes	yes			
39	64	1	?	?	yes	yes			
39	64	2	?	?	yes	yes			
40	8	N/A							
40	22	N/A							
40	23	N/A							
40	33	N/A							
40	45	0	no	yes	yes	yes			
40	50	N/A							
40	54	0	no	yes	yes	yes			
40	54	1	no	yes	yes	yes			
40	54	2	no	no	no	no			
40	54	3	no	yes	yes	yes			
40	61	N/A							
40	79	N/A							
40	98	0	no	no	no	no			
40	100	N/A							
40	103	N/A							
40	110	N/A							
40	112	N/A							
40	136	0	no	yes	yes	yes			tracks vehicle next lane
41	27	N/A							
41	35	N/A							
41	38	N/A							
41	53	N/A							
42	12	N/A							
42	14	0	yes	no	yes	no		*	
42	36	N/A							
43	2	0	no	no	no	no			
43	2	1	no	no	no	no			
43	7	N/A							
43	10	0	no	yes	yes	yes			
43	14	0	no	?	no	no			night time
43	15	0	no	yes	yes	yes			
43	16	0	no	yes	yes	yes			
43	16	1	no	yes	yes	yes			
43	17	0	no	yes	yes	yes			
43	25	N/A							
43	27	0	yes	yes	yes	yes			
43	27	1	yes	yes	yes	yes			

Shaded area – initial list provided by UMTRI

Table A-1 (Cont'd) Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
43	27	2	yes	?	no	no			
43	27	3	yes	yes	no	no	**	*	
43	28	0	yes	yes	yes	yes			
43	29	N/A							
43	30	0	no	yes	yes	yes			
43	30	1	no	yes	yes	yes			
43	31	0	no	yes	yes	yes			
43	31	1	no	yes	yes	yes			
43	34	0	no	no	no	no			
43	34	1	no	no	no	no			
43	35	0	no	?	no	no			night time
43	39	0	no	yes	yes	yes			
43	40	0	no	?	no	no			night time
43	41	0	yes	yes	yes	yes			
43	41	1	no	yes	yes	yes			
43	42	0	no	no	no	no			
43	42	1	no	no	no	no			
43	42	2	no	no	no	no			
43	48	N/A							
43	52	0	yes	?	yes	yes			? - night time
43	52	1	yes	yes	yes	yes			
43	53	0	no	yes	yes	yes			
43	62	0	no	yes	yes	yes			
43	64	N/A							
43	65	0	no	yes	yes	yes			
43	66	0	no	?	yes	no		*	night time, 90% tracking
43	72	0	no	yes	yes	yes			
43	72	1	no	yes	yes	yes			
44	100	N/A							
44	128	N/A							
44	148	0	no	yes	yes	yes			
44	148	1	no	no	no	no			
44	148	2	no	yes	yes	yes			
44	148	3	no	no	no	no			
44	152	0	no	yes	yes	yes			
45	13	N/A							
45	26	N/A							
45	34	0	no	no	no	no			
45	34	1	no	no	no	no			
46	2	N/A							
46	3	N/A							
46	9	N/A							

Shaded area – initial list provided by UMTRI

Table A-1 (Cont'd) Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
46	19	N/A							
46	40	N/A							
46	50	N/A							
46	53	N/A							
46	58	N/A							
46	61	N/A							
46	66	N/A							
46	83	0	no	yes	yes	yes			35% tracking
46	83	1	no	no	no	no			
47	14	0	no	no	no	no			
47	14	1	no	no	no	no			
47	18	0	no	no	no	no			
47	18	1	no	no	no	no			
47	18	2	no	no	no	no			
47	18	3	no	no	no	no			
47	20	0	no	no	no	no			
47	20	1	no	no	no	no			
47	20	2	no	no	no	no			
47	28	0	no	no	no	no			
47	28	1	no	no	no	no			
47	32	0	no	yes	yes	yes			
47	45	0	yes	no	no	no			
47	45	1	yes	no	no	no			
47	46	0	yes	no	no	no			
47	46	1	yes	no	no	no			
47	47	0	yes	yes	yes	yes			
47	47	1	yes	yes	yes	no	**	*	5% tracking
47	47	2	yes	no	no	no			
47	51	N/A							
47	53	0	yes	no	no	no			
47	53	1	yes	yes	yes	yes			
47	56	0	yes	no	yes	yes		*	5% tracking
47	56	1	yes	yes	yes	yes			
47	58	0	yes	yes	yes	yes			
47	58	1	yes	no	no	no			
47	58	2	yes	no	no	no			
47	58	3	yes	no	no	no			
47	58	4	yes	no	no	no			
47	58	5	yes	no	yes	yes		*	5% tracking
47	58	6	yes	no	no	no			
47	58	7	yes	no	no	no			
48	25	N/A							

Table A-1 (Cont'd) Snow Trip Examination

Driver ID	Trip ID	Video No.	Snow Present	Vehicle Present	Tracking Indicated	Range Indicated	Snow Problem	Tracking Problem	Comment
49	8	0	no	no	no	no			
49	8	1	no	no	no	no			
49	20	0	yes	no	no	no			
49	20	1	yes	yes	no	no	**	*	
49	20	2	yes	yes	no	no	**	*	
49	20	3	yes	yes	no	no	**	*	
49	25	0	yes	no	no	no			
49	38	0	no	no	no	no			
49	38	1	no	no	no	no			
49	73	0	no	no	no	no			
49	73	1	no	no	no	no			

Total:		Results:
16 Drivers	*55 trips - NO video*	*** 10 trips (24 video) - snow problems*
125 Trips	*67 video - NO snow present*	** 21 trips (65 video) - tracking problems*
165 Video	*94 video - Snow present*	
	4 video - Unsure if snow present	

Snow Problems:

6 video - snow & vehicle present but no tracking and zero range indicated
18 video - snow & vehicle present, tracking but zero range indicated

Tracking Problems:

30 video - no vehicle present, tracking but zero range indicated
18 video - vehicle present, tracking but zero range indicated
6 video - vehicle present but no tracking & zero range indicated
8 video - no vehicle present but tracking & range indicated
3 video - unsure vehicle present, tracking but zero range indicated

Shaded area – initial list provided by UMTRI

Table A-2 Data Quality/ Consistency Check

Range	Tracking	Valid	Cases	% of Total
0	0	0	5, 444,513	48.8
0	0	1	0	0.0
0	1	0	6,462	< 0.1
0	1	1	5,104	< 0.1
1	0	0	0	0.0
1	0	1	0	0.0
1	1	0	2,254,641	20.2
1	1	1	3,441,513	30.8
Total			11,152,233	100.0

Appendix B

Calculation of Minimum Retro-Reflectivity

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Retro-Reflectivity

A 3.8 cm by 5 cm plaque with the calibrated reflectance of 70 cd/lux/m^2 was mounted on a non-reflecting matte black stand such that the plaque was elevated 0.6 m above the ground. The plaque was moved toward the sensor, from directly in front of the vehicle, until it was detected, and then away from the sensor until it was no longer detected. This procedure was repeated five times.

Detection of the plaque occurred at 11 meters. The amount of reflected infrared energy required for target detection was calculated as follows:

> It was assumed that the intensity, denoted by **I,** of the IR sensor was constant. The reflectance of plaque is denoted by **D**.
>
> The energy from the IR Sensor to the reflectance plaque is represented by:
>
> $$\mathbf{E_{from\ ACC} = I/d^2}$$
>
> Where $\mathbf{E_{from\ ACC}}$ is the illuminance coming from the IR sensor, and **d** is distance from IR sensor to the plaque, and represents the energy striking the reflectance plaque.
>
> The energy reflected from the plaque back towards the IR sensor is represented by:
>
> $$\mathbf{E_{from\ plaque} = L * A/d^2}$$
>
> Where $\mathbf{E_{from\ plaque}}$ represents the illuminance or reflected energy from the plaque returning to the IR sensor, **A** represents the area of the reflectance plaque, and **L** represents luminance, or the amount of energy coming from the plaque towards the IR sensor per solid angle. **L** is approximated by:
>
> $$\mathbf{L = D * E_{from\ ACC}}$$
>
> Substituting the approximation for L yields:
>
> $$\mathbf{E_{from\ plaque} = D * E_{from\ ACC}/d^2}$$
>
> Substituting for $E_{from\ ACC}$ in the above equation yields:
>
> $$\mathbf{E_{from\ plaque} = D * I * A/d^2}$$

Substituting in 70 cd/lux/m^2 for Δ, 0.0019 m^2 for A, and 11 meters for d, yields 3×10^{-6} of original intensity of IR sensor output as the amount of reflected energy required for target detection.

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Appendix C

Driving State Identification Tool

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C-1 Introduction

This appendix introduces a set of driving states and transitions used in the evaluation of the Intelligent Cruise Control (ICC) System. This set of driving states and transitions is intended to aid in the analysis of the vast amounts of data being collected in the FOT by allowing classification of any driving situation that the ICC vehicle encounters into a standard format, thus providing a continuous description of the driving experience of each FOT subject. Specifically, the driving states and transitions will be utilized in two ways. First, they will permit data analysis to be performed at a level lower than the trip level. Second, they will be used as direct measure of driving experience through the consideration of their frequency of occurrence.

The defined driving states and transitions are identified with a computer driven set of algorithms based on the values of the numerical data recorded continuously by the ICC vehicle. This appendix provides a general definition of driving states and transitions, and describes the development and validation of the numerical based classification tool.

C-2 Definitions

In order to allow the classification of any driving situation encountered by the ICC vehicle into a standard format, the evaluation team defined a set of driving states and transitions. The following paragraphs provide definitions of both.

C-2.1 Driving States

In order to be consistent and effective for use in data analysis, each defined driving state needed to be mutually exclusive, and the set of defined driving states needed to be collectively exhaustive. If the states were not mutually exclusive, data could fit into more than one state, which could complicate interpretation of the results. If the set of states were not collectively exhaustive, some data would not be classifiable and would be left out of the analysis.

The evaluation team decided to define the driving states in terms of the vehicle's position and rate of closure relative to another vehicle lying directly in it's path. Specifically, the evaluation team identified four main categories of driving state:

1) Driving with no preceding target vehicle within sensor range (cruising).
2) Driving behind a preceding vehicle with a similar velocity (following) and within sensor range.
3) Driving behind a preceding vehicle with a lower velocity (closing) and within sensor range.
4) Driving behind a preceding vehicle with a higher velocity (separating) and within sensor range.

A further category, invalid target, allows the evaluation team to separate data for which the ICC vehicle was tracking an invalid target such as a stopped vehicle. Table C-1 describes the main driving state categories in terms of the variables range (distance to the target vehicle) and range rate (rate of change in distance to the target vehicle). The cells of Table C-1 are labeled to describe the driving state that the cell represents.

Table C-1: High Level Driving States

	Range	
dR/dt	Valid Target	No Target (R=0)
-ve	Closing (3)	Cruising (1)
0	Following (2)	Cruising (1)
+ve	Separating (4).	Cruising (1)

While the set of driving states in Table C-1 meets the requirements of being both mutually exclusive and collectively exhaustive, they are very broad states, including many different driving situations. In order to allow a more in-depth analysis of the driving states the evaluation team decided to further divide the Valid Target column and the positive and negative range rate rows. The first division was the sub-classification of the valid target states (closing, following, and separating) by time headway. Specifically, the bin was divided into close, middle and far time headways. These headway category thresholds were selected based on the operational limitations of the sensor and with consideration to their impacts on safety. The second sub-classification involved the division of the closing state (negative range rate) into closing moderately closing rapidly. Similarly, the separating state (positive range rate) was divided into separating moderately and separating rapidly. The evaluation team performed these divisions, as they believe each bin represents a different condition in terms of safety, yet there are not so many bins as to make analysis impractical. Table C-2 describes the driving states with the further bin divisions in place. Each cell is labeled as s_{ij}, where "i" is the row (range rate) and "j" is the column (headway). For example, the s_{11} cell represents closing rapidly at a close time headway. All of the cells in the No Target category have been labeled as cruising, as range rate does not apply when there is no valid target.

C-2.2 Transitions

In addition to driving states, the evaluation team defined a set of special events or transitions that are of interest from a safety perspective. These transitions are events that result in a change in the vehicle being tracked by the ICC vehicle and may or may not accompany a change in driving state. Transitions differ from driving states primarily in that they are discrete rather than continuous events. In order to allow classification of these transitions into a standard format, the evaluation team defined the following set of high-level transition categories:

1) Target Acquisition (acquisition of a preceding vehicle where none was previously present)
2) Target Drop (Loss of preceding vehicle - not replaced by another vehicle)
3) Target Switch (Switching from one preceding vehicle to another vehicle)

In order to capture whether the transition was a result of a lane movement by the ICC vehicle, or a lane movement by another vehicle, the evaluation team further categorized the transition descriptions into active and passive. An active transition is one that results from a lane movement by the ICC vehicle, while a passive transition is one that results from a lane movement by another vehicle.

Table C-2: Refined Driving States

	Headway			
	Valid Target			No Target
dR/dt	Close	Middle	Far	0
closing rapidly	s_{11}	s_{12}	s_{13}	cruising
closing moderately	s_{21}	s_{22}	s_{23}	cruising
0	s_{31}	s_{32}	s_{33}	cruising
separating moderately	s_{41}	s_{42}	s_{43}	cruising
separating rapidly	s_{51}	s_{52}	s_{53}	cruising

C-2.3 Illustration of Driving States and Transitions

The driving states and transitions can be illustrated in the range-versus-range-rate state space as well. First, the states are shown in Figure C-1 and are distinguished by the two vertical and one horizontal lines. The cruising state is defined as the region in the state space beyond the reliable in-lane sensor range. This was determined in pilot tests for different velocities to be equivalent to a time headway of 2.4 s. The criteria of 1.5 m/s distinguishes the *closing*, *following*, and *separating* states. This criteria was also used by the Field Operational Test Partners and provided a practical region for distinguishing between *following*, and *closing/separating*.

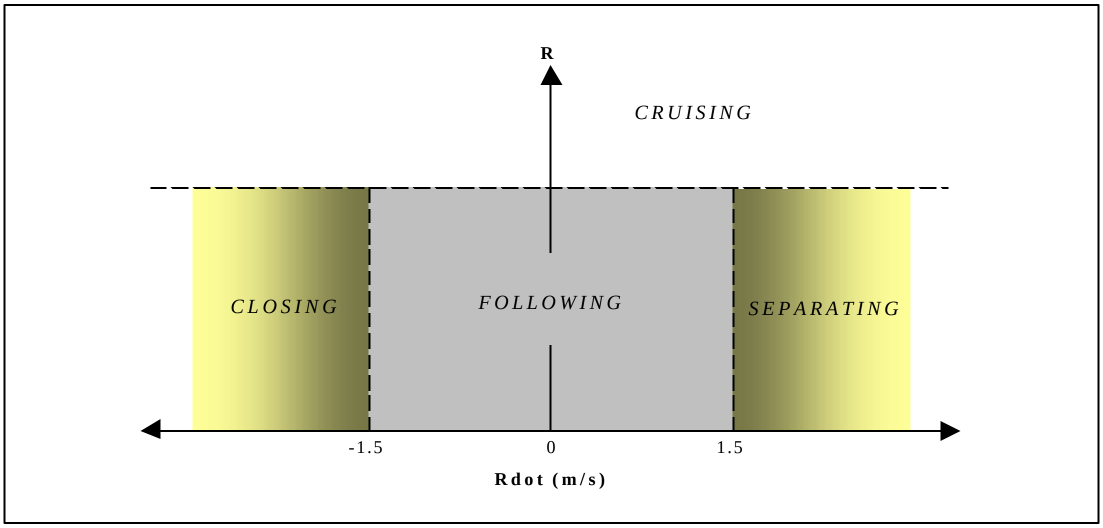

Figure C-1 Illustration of Driving States in the Range-Versus-Range Rate Space

Transitions are illustrated in Figure C-2. The numerical codes are explained in Table C-3. The 37 possible transitions are shown. The illustrations include active and passive movements, as well as transitions due to accelerations. It should be noted that representative time tracks are shown before a "drop", after an "acquire", and during an "a". For "switch", the choice is arbitrary – some show a "before" and others an "after" time track.

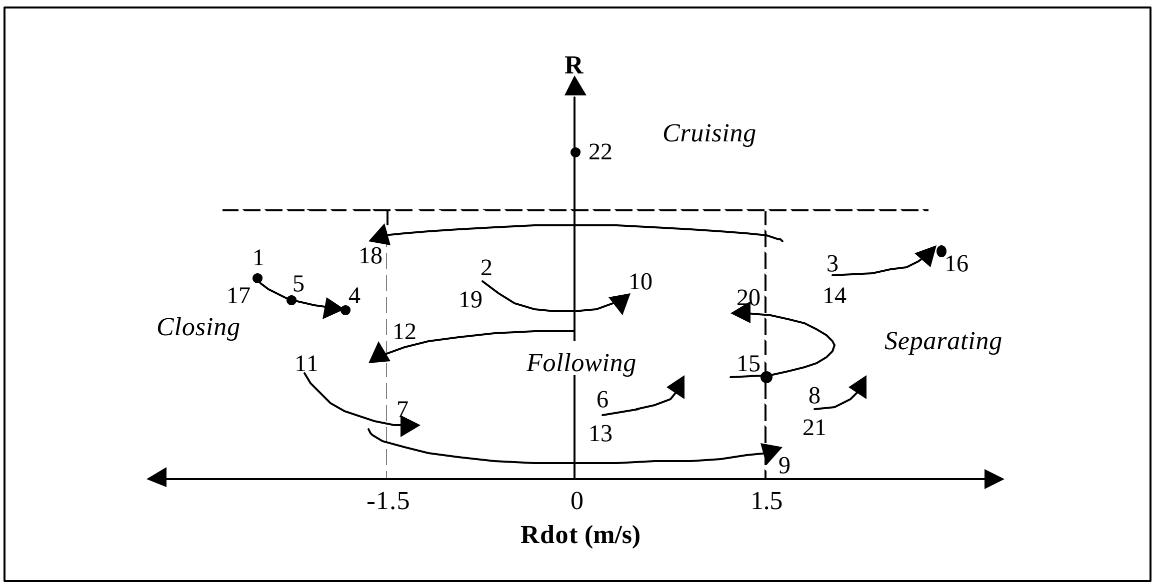

Figure C-2 Illustration of Transitions in the Range-Versus-Range-Rate Space

Table C-3 Numerical Codes Illustrating the Transitions

Numerical Code	Type	Numerical Code	Type
1. Cruising to Closing – acquire, active	1	19. Following to Closing – switch, active	11
2. Cruising to Closing – acquire, passive	1	20. Following to Closing – switch, passive	11
3. Cruising to Following – acquire, active	2	21. Following to Closing – a	12
4. Cruising to Following – acquire, passive	2	22. Following to Following – switch, active	13
5. Cruising to Separating – acquire, active	3	23. Following to Following – switch, passive	13
6. Cruising to Separating – acquire, passive	3	24. Following to Separating – switch, active	14
7. Closing to Cruising – drop, active	4	25. Following to Separating – switch, passive	14
8. Closing to Cruising – drop, passive	4	26. Following to Separating – a	15
9. Closing to Closing – switch, active	5	27. Separating to Cruising – drop, active	16
10. Closing to Closing – switch, passive	5	28. Separating to Cruising – drop, passive	16
11. Closing to Following – switch, active	6	29. Separating to Closing – switch, active	17
12. Closing to Following – switch, passive	6	30. Separating to Closing – switch, passive	17
13. Closing to Following – a	*7*	31. Separating to Closing – a	18
14. Closing to Separating – switch, active	8	32. Separating to Following – switch, active	19
15. Closing to Separating – switch, passive	8	33. Separating to Following – switch, passive	19
16. Closing to Separating – a	9	34. Separating to Following – a	20
17. Following to Cruising – drop, active	10	35. Separating to Separating – switch, active	21
18. Following to Cruising – drop, passive	10	36. Separating to Separating – switch, passive	21
		37. Cruising to Cruising	22

C-3 Means of Identifying Driving States and Transitions

Driving States and Transitions are identified in the deci-second numerical data using rule based computer algorithms. The driving state identification tool consists of three computer driven rule-based algorithms. The first identifies the specific driving state. The second identifies the occurrence of the high level transitions. The third identifies whether a given transition was active or passive. Driving states are identified using the recorded variables of range, rate of change in range and valid target. Transitions are identified using the same variables as driving states, with the addition of preceding vehicle velocity to help aid in the identification of certain target switches. Transition sub-type (active vs. passive) identification is performed by a custom rule-based methodology that employs a moving analysis window to examine the degree of curvature information recorded by the ICC vehicle. These algorithms identify the driving state for every deci-second of recorded numerical data, and the transitions (including sub-type) at the point that they occur.

The following sections describe the development of the first two of these algorithms. The performance of the third element, active/passive classification, is described separately in Appendix D *Development of a Lane Movement Algorithm*.

C-3.1 Driving State Identification Algorithm

The basic calculation of driving states depends solely on four variables reported by the ICC vehicle:

- Tracking (indicates the presence of a physical object, valid or otherwise in the sensor area);
- Valid Target (indicates the tracking of a valid target, one that the ICC vehicle will respond to if ICC engaged);
- Range (distance to preceding target); and
- Range Rate (rate of change of range).

The simplest class of driving state occurs when there is no target (valid or otherwise) in the sensor area. This state is classified as cruising and is calculated as follows:

If Tracking = 0 then State = Cruising

A similar state involves tracking an invalid target. In this case, the state is referred to simply as invalid.

If Tracking = 1 and Valid Target = 0 then State = Invalid

The remaining states deal with situations in which a valid target is tracked. These states are defined in terms of range and range rate. The first value examined is range. Three range categories - close, middle and far - are defined by the category boundaries.

If Range (seconds) >= 0.8 seconds then Range = Close

or

If 0.8 < Range <= 1.6 seconds then Range = Middle

or

If Range > 1.6 seconds then Range = Far

The next stage in classifying the various forms of following states, is an examination of the rate of change of range between the ICC and preceding vehicle. For this classification, the following criteria are used:

If Rdot =< -6.0 m/s fps then Range Rate = Closing Rapidly

or

If -6.0 m/s < Rdot <= -1.5 m/s then Range Rate = Closing Moderately or

If -1.5 m/s < Rdot < 1.5 m/s then Range Rate = Following Same Speed

or

If 1.5 m/s <= Rdot < 6.0 m/s then Range Rate = Separating Moderately

or

If Rdot >= 6.0 m/s then Range Rate = Separating Rapidly

C-3.2 Transition Identification Algorithm

As with driving states, transitions are also identified through the application of a clearly defined set of rules, as described below.

C-3.2.1 Target Acquisition

The first transition considered is a target acquisition. As defined previously, an acquisition is assumed to have occurred whenever there is change from cruising to any of the valid target states (closing, following or separating).

If {Tracking (t-1)=0 and Valid Target (t-1)=0} and {Tracking (t)=1 and Valid Target (t)=1}

then Target Acquisition

Where t = current time slice, t-1 = previous time slice

C-3.2.2 Target Drop

A target drop is just the opposite of an acquisition and is assumed to have occurred whenever there is a change from any of the valid target states to cruising. It may be defined as follows:

If {Tracking (t-1)=1 and Valid Target (t-1)=1} and {Tracking (t)=0 and Valid Target (t)=0}

then Target Drop

Where t = current time slice, t-1 = previous time slice

C-3.2.3 Target Switch

A target switch involves switching from following one preceding vehicle to following another. Such a switch is currently calculated by monitoring changes in range and the velocity of the preceding vehicle. Whenever, a change occurs which cannot be explained by the potential actions of a single preceding vehicle, a target switch is assumed to occur. For example, if the range to the preceding vehicle switches from 60 to 90 meters between t-1 and t (0.1 seconds) then a switch is assumed since no vehicle can accelerate that rapidly.

For a switch detected by a rapid change in range:

RangeChange = R (t) - R (t-1)

If {RangeChange >= 1.5 or RangeChange <= -1.5} and {Valid (t-1)=1 and Valid (t)=1} then Target Switch

Where t = current time, t-1 = current time - 0.1 seconds

For a target switch detected by a change in Velocity

VelChange = (Vp (t) - Vp (t-1)) / 0.1

If {VelChange >= 7.6 m/s or VelChange <= -7.6 m/s} and {Valid (t-1)=1 and Valid (t)=1}

then Target Switch

Where t = current time, t-1 = current time - 0.1 seconds

Thus, if the range changes by more than 1.5 meters in one deci-second, or the velocity of the preceding vehicle changes by more than 7.6 m/s (effectively equivalent to about 0.8 g) than a target switch is assumed. Target switches between two preceding vehicles with similar velocities, located a similar distance from the subject vehicle will not be detected.

C-3.2.4 Preceding Vehicle Deceleration

The preceding vehicle deceleration transition is identified whenever the preceding vehicle exhibits a deceleration greater than 0.05 g's. This is the same threshold value used for ICC vehicle braking in the triggering of video episodes.

If VpDot < -0.05 g's then Preceding vehicle Decelerating

C-3.3 Transitions Sub-Classification Algorithm

As mentioned previously the methods for sub-classifying transitions as being either active or passive are described in Appendix D *Development of a Lane Movement Algorithm*.

C-4 Sensor Output Vs Observed Reality

In analyzing the results of the pilot testing and in performing initial validation, a disparity was uncovered between the image of the driving environment created by the sensor output, and the image perceived by an observer. Specifically, situations arose in which the two images or "realities" did not agree. For example, the sensor periodically picked up brief, false targets, often while cruising with no real vehicles in front. To someone relying on sensor data the transitions for this situation would be classed a series of brief cut-ins and cutouts. In addition, the calculated driving would have fluctuated between cruising and following. This contrasts sharply with the fact that an independent human observer would classify the entire sequence as simply cruising. There were also other similar situations to this, such as targets being acquired in adjacent lanes while maneuvering around sharp bends.

After some debate, it was decided to attempt to log and calculate the driving states and transitions for both situations, namely sensor and observed "reality." "Sensor reality" is captured by applying the basic rules defining transitions and driving states to the raw unfiltered sensor data. "Observed reality" is obtained by running a series of correcting filters on the raw sensor data. These filters were designed to automatically classify driving states and transitions as a human observer (such as the video analysts) would. Both sets of data are thus available. This provides for a unique opportunity to perform system characterization checks based on a comparison of the two "realities."

The following section examines each of these filters. Specifically it examines the obstacles that each filter was designed to address and explores the actual structure of the resultant filter.

C-4.1 Distance Concerns

One of the earliest concerns noted with sensor data was the variability of target acquisitions and losses at the leading edge of the sensor beam. It was found that the distance at which the sensor classified a target as valid tended to be somewhat variable. In addition, a problem was posed by preceding vehicles passing backwards and forwards through the sensor range periodically as slight shifts in relative velocity occurred. Both of these situations caused a series of target acquisitions and drops to be recorded, while the associated driving state switched between cruising and following. In addition, the cone of the sensor tends to bleed out of the ICC vehicle's lane as the maximum sensor range is approached. This results in targets being recorded from adjacent lanes. Both of these occurrences are aggravated on curves.

To address this problem, a series of sensitivity analyses were performed to determine the maximum range at which the sensor could reliably be expected to detect another vehicle in the lane in front of the ICC vehicle, and not in other lanes. The maximum range value obtained in this exercise was then converted to a time headway of 2.4 seconds.

For driving states, the 2.4-second value was instituted as a boundary on the far headway bin. Targets at headways greater than this value were not considered valid.

For transitions, the value was similarly utilized, thus treating all targets beyond 2.4 seconds as invalid. Furthermore, it was decided that a vehicle 'transitioning' from just beyond sensor range to within sensor range did not adequately fit the description of target acquisition. Likewise, a vehicle moderately moving beyond the maximum headway, was not felt to represent a true target drop. As a result all target drops and acquisitions have the requirement that the range at which the target is first acquired must be at least 1.5 meters less than the range associated with a headway of 2.4 seconds for the current velocity.

> If Target Acquisition / Drop and if Range > ((2.4 * Velocity) – 1.5 meters)
>
> Then
>
> No Target Acquisition / Drop

C-4.2 Additional Curvature Concerns

It was previously mentioned that some concerns exist with the combination of curvature and targets near the maximum sensor range. While the addition of a 2.4 second maximum range value does tend to reduce most of these concerns, problems continue to persist for extreme cases such as ramps and other high curvature roadway sections which exceed the capabilities of the ICC sensor. During preliminary validation, the evaluators found instances in which the impacts of just a single on-ramp caused twice as many ‘false’ transitions to be recorded in a trip as ‘real’ transitions recorded by a video analyst (on continuous video).

Some improvements were realized with the use of a maximum range filter, and by the use of brief loss/acquisition filters to be described in the next sections. However, it is recognized that some problems continue to exist with regards to ramps, and therefore ramp data is currently separated from freeway and arterial data for analysis.

C-4.3 False Targets

False targets, are targets that the sensor picks up that do not exist. In this way, they are different from erroneous targets in other lanes, or at the edge of the sensor beam. They may include such sources as rain, snow, traffic signs, and even trees and bushes. Often, they occur well within the sensor's maximum operating range, and can occur on either straight or curved sections of roadway. Fortunately, they are typically characterized by a very short duration and tend to occur mainly when no valid targets are present. As a result, filters have been added to both the transition and driving states rule sets to effectively ignore series of target acquisitions and drops (or cruising - following -cruising) which last less than 1.5 seconds.

For Transitions:

> If Target Drop (t) and If Target Acquisition (t-15) then No Transition
>
> where t = current time, t-15 = 1.5 seconds previous

For Driving States:

> If (Cruising (t) and Following (t-1)) and If Cruising (t-15) then Cruising for t through t - 15

C-4.4 Target Drop Outs

In addition to reporting false targets, the ICC sensor also periodically misses, or loses, actual valid targets. These situations may occur independently of sensor range and roadway curvature and may be attributed to effects such as hardware problems and environmental factors such as snow. Fortunately, as with false targets, target drop out periods are typically characterized by short durations. Consequently, a filter has been applied which effectively ignores series of target drop, target acquisition (or following - cruising - following) of less than 1.5 seconds duration.

For Transitions:

> If Target Acquisition (t) and If Target Drop (t-15) then No Transition

For Driving States:

> If (Following (t) and Cruising (t-1)) and If Following (t-15) then Following for t through t -15

C-4.5 Target Switches

An additional difficulty that has been encountered corresponds to the occurrence of target switches. Often such transitions are accompanied by brief periods of target loss as the sensor beam moves from one vehicle, to a gap between the two vehicles and then on to the new target vehicle. While the target losses themselves are fairly short, there may be several of them strung together within a single target switch. Consequently, a filter has been added that disallows cruising or target loss/acquisitions for one second preceding and for one second following the switch.

If Transition = Target Switch then

For a=1 to 10

Transition (t-a) = 99, Transition (t+a) = 99

State (t-a) = 99, State (t+a) = 99

Next a

Where: t = time of switch, a = counter variable, and 99 = state associated with target switch

C-4.6 Velocity

The final filter restricts the analysis to values with an associated velocity greater than or equal to the minimum operating speed of the ICC system, 40.3 km/h.

If Velocity < 40.3 km/h Then (Transition = Below Speed and Driving State = Below Speed)

C-5 Model Validation

Validation of the driving state classification model was conducted using a thirty-minute portion of pilot test data. This pilot test trip was conducted over a variety of roadway types, including ramps, arterials and freeways and during moderate to heavy traffic conditions. During this test, a continuous record of the various driving states was collected by a video camera focused on the area in front of the ICC vehicle. In comparing the results from this video record to those predicted by the filtered driving state classification tool, a 97.5% agreement was noted. As expected, the small disagreements that did arise, typically occurred while the ICC vehicle was negotiating an area with pronounced roadway curvature. Overall, the results were encouraging enough to lead to the use of the driving state classification model.

In a similar manner, a validation of the transition component was performed. For this validation the evaluation team used a twenty-minute period of a pilot test trip in which a series of planned transitions were staged using two or more test vehicles. All of the major transitions discussed were performed, as well as a number of variations such as a cut-in of a faster versus a slower moving vehicle. The wide sample of scenarios that were considered here were aimed at ensuring a more robust validation of the model.

For this test, the outputs from the high-level (no active/passive sub-class) transition identification model were compared against the continuous video log recorded for this trip. In doing so, it was found that of the 43 observed transitions, 39 (or 91%) were correctly identified (both occurrence and type) by the model. The model missed, four observed transitions and reported six transitions where none actually occurred (false alarms). Because the model was run on every deci-second of the trip, these results translate into 15,630 of 15,636 non-transitions being correctly rejected. These results are summarized in Table C-4.

Table C-4: Validation of the Transition Classification Model

	Count	Out of
Correctly Identified	39	43
Correctly Rejected	15,630	15,636
Missed	4	43
False Alarms	6	15,636

Appendix D

Development of a Lane Movement Algorithm

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D-1 Introduction

There are a number of issues related to driver decisions within the traffic stream that are being considered directly by the evaluation of the ICC system. Primarily, the ICC evaluation of the impacts on safety and traffic flow will consider how fast a driver will desire to travel within a given lane as a function of the presence of vehicles ahead of it. A second decision relates to how vehicles may perform lane movements in order to increase travel freedom or gain access to a specific facility.

Lane movements may be performed by vehicles equipped with the ICC system and also by those vehicles not equipped with the system. The extent to which these lane movements occur, both in terms of frequency and severity, is an informative measure by which the ICC system will be evaluated. For those vehicles equipped with ICC, lane movements were enumerated by processing raw degree of curvature data logged by the vehicle to infer a defined pattern. However, since the behavior of the surrounding vehicles is impossible to monitor directly and continually, capturing the lane movement behavior of these vehicles required an alternative approach. It is these issues, regarding identifying vehicle lane movements within the traffic stream, that are the focus of this document.

D-2 Background

The ability to identify vehicle lane movements within the traffic stream became desirable during the development stages of the driving state model. The driving state model was capable of categorizing the instantaneous state of the ICC vehicle in terms of following behavior, and as such, any change in state would suggest a transition has occurred. The next logical step involved determining if the identified transition was active, in that the ICC vehicle performed a maneuver, or passive, in that the target vehicle performed a maneuver. Classifying these transitions, as either passive or active, required pursuing an algorithm that was capable of identifying lane movements performed by the ICC vehicle. An active transition was triggered by the presence of a lane movement by the ICC vehicle, and a passive transition was triggered by the absence of a lane movement by the ICC vehicle.

The degree of curvature variable logged by the ICC vehicle provided the most appropriate measure of estimating lane movements. Some preliminary analysis of the raw data indicated that a time series of degree of curvature readings forming a sinusoidal like wave pattern was indicative of a lane movement. Lane movements to the left and right could also be distinguished by the orientation of the wave, as illustrated in Figure D-1. Discerning between a lane movement as opposed to traveling in the same lane around a curve, or capturing a lane movement while on a curve, proved to be more taxing since these scenarios exhibited similar trends in the degree of curvature data.

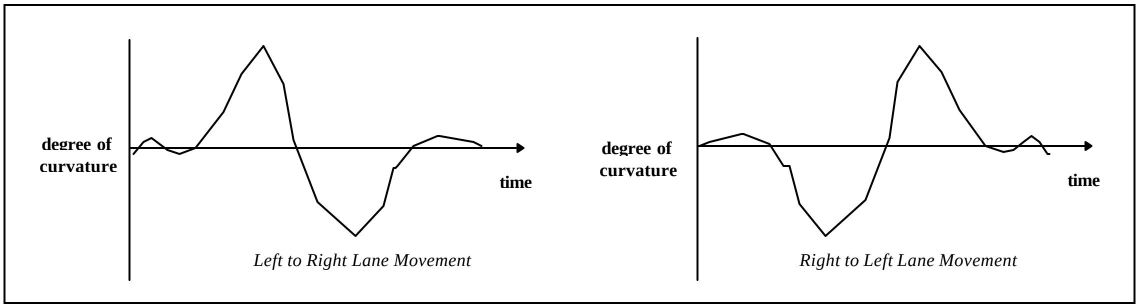

Figure D-1: Schematic Representation of Lane Movements on a Section of Straight Road

A series of known lane movements were quantified in terms if a number of parameters (*a* through *e*) in an effort to better define the nature of any candidate lane movement. The parameters, as depicted in Figure D-2, provide a means by which a candidate lane movement could be quantified. Although certain scenarios, such as lane deviations or curved roads, may produce similar patterns to a pure lane movement, it was anticipated that by defining a range of acceptable parameters that characterize a lane movement, many of the false lane movements may be identified as such. Point *a* refers to an inflection of the curve, points b_{max} and b_{min} refer to the maximum and minimum values of the recorded degree of curvature, duration *c* represents the length of time between the occurrence of the two previous values, and duration *e* represents the duration of the complete lane movement activity. Point *d* was not utilized.

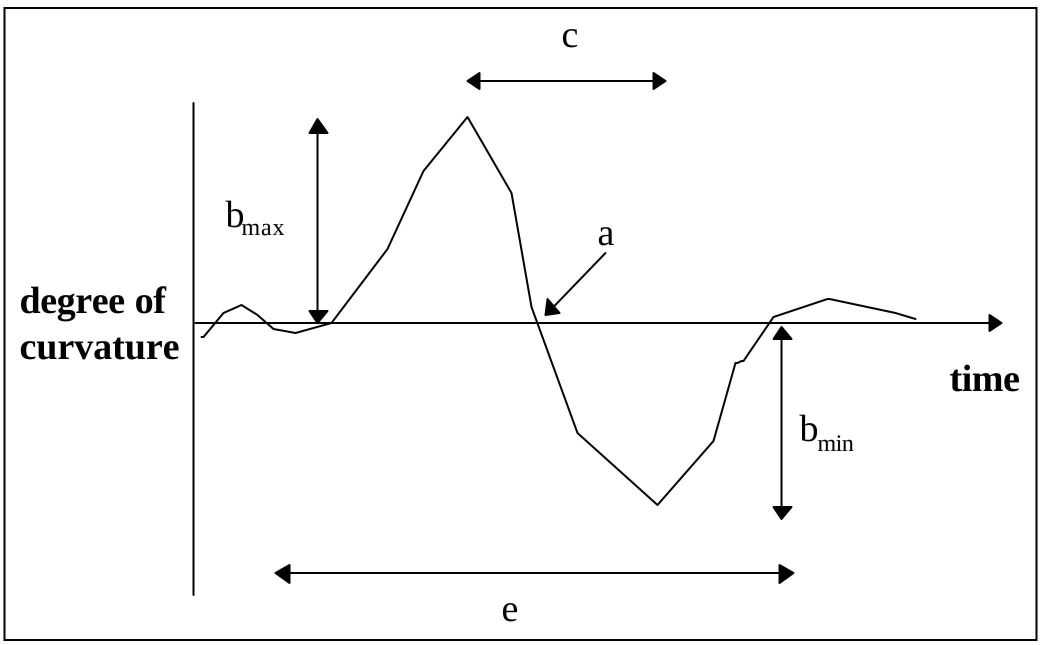

Figure D-2: Lane Movement Characterization Parameters

D-3 Model Development

The development of the lane movement model involved characterizing each candidate lane movement in terms of the parameters discussed earlier and determining if the computed parameters were indicative of a lane movement. Sample lane movement data is also presented in this section.

D-3.1 Characterizing the Lane Movement

The first step in characterizing the data stream was to select a time frame over which the analysis should be completed. A time frame that was too short may not enable the characteristic shape of the pattern to emerge, and a time frame that was too long may mask more gradual lane movements. A preliminary analysis indicated that a window of approximately 8 seconds was suitable for identifying lane movements within the deci-second degree of curvature data stream.

Figure D-3 illustrates the four step process conducted. At each point x within the data stream (Step I), the subsequent 8 seconds of data was normalized in an effort to eliminate the impact of any potential curvature in the road and to compute the point of inflection. This process was accomplished by simply computing the slope of the line joining the first and last data point (Step II), and transforming each point based on this new frame of reference (Step III). If integrating this relationship (Step IV) yielded an inflection point near the middle of the time frame, then a lane movement may have occurred, and parameters a through e were computed to further characterize the potential lane movement. If an inflection point was not present, then the current window would be discarded and the next 8 second window, starting 1 second later, would be evaluated. It was determined that a step size of 1 second would be more efficient than a 1 deci-second.

If present, an inflection point will occur at either a maximum or minimum value of the integrated data stream, computed simply as the sum of all degree of curvature values within the 8 second data window. A positive sum would indicate a lane movement from the left lane to the right lane, while a negative sum would suggest a lane movement from the right lane to the left lane. The time at which the inflection point occurred within the data stream may be interpreted as the approximate time at which the lane movement took place.

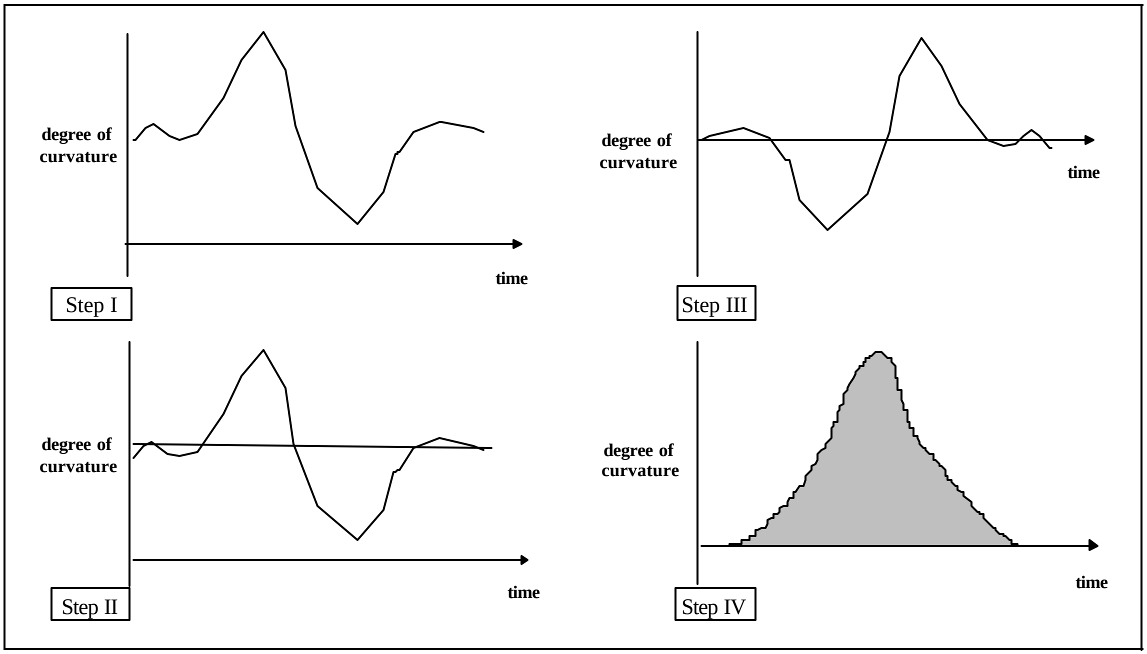

Figure D-3 Four Step Lane Movement Analysis Process

The next step, in characterizing the lane movement, involved computing the series of defining parameters. The value of the integral, or area under the curve, was determined as described previously. The maximum and minimum values (b_{max} and b_{min}), or the amplitude of the curve, were then identified, and the time interval (*c*) computed. Finally, the duration of the complete lane movement (*e*) was determined by computing the difference between the time the sinusoidal pattern commenced and the time the pattern terminated. These two values were determined by initiating a step-wise search from each peak value, and progressing in the appropriate direction of time until the degree of curvature value was within 80 percent of the peak.

These defining parameters were selected such that both abrupt and more gradual lane movements could be potentially captured. One would expect a severe lane movement to have a greater amplitude, but a shorter duration, while a gradual lane movement would be characterized by a smaller amplitude and longer duration. Furthermore, it was anticipated that by placing boundaries on the acceptable range of these parameters, scenarios such as lane deviations and following a bending road geometry may be identified as phenomenon other than a standard lane movement.

After qualitatively describing the parameters considered in characterizing potential lane movements, quantitative boundaries were placed on these parameters in an effort to definitively classify the data as indicative of a lane movement. Initially, these boundaries were based on a preliminary analysis of a small sample of known lane movement data, and were modified as the analysis/validation process evolved. Table D-1 provides a listing of the parameters utilized in the subsequent validation of field data. Note that there were no constraints placed on the maximum time interval between peaks or the duration of the lane movement.

Table D-1: Lane Movement Characterization Parameters

Parameter	Description	Minimum Value	Maximum Value
f	area under curve	16	200
a	inflection point	0.1 sec	5.0 sec
|b|	amplitude	0.6	5.0
c	time interval between peaks	1.5 sec	n/a
e	duration of lane movement	n/a	n/a

D-3.2 Sample Lane Movement Data

The following figures represent sample degree of curvature versus time relationships utilized in the development of the lane movement algorithm. The two simplest scenarios, namely lane movements from right to left and left to right on straight sections of roadway, are illustrated in Figure D-4 and Figure D-5, respectively. The additional complexity associated with completing a lane movement while negotiating a curve in the roadway is presented next. Figure D-6 represents a right to left lane movement while on section of road curving right, while Figure D-7 represents the same right to left maneuver but while on a section of road curving left.

The last two examples represent more sophisticated scenarios. Figure D-8 illustrates the impact of completing two consecutive right to left lane movement across multiple lanes, and Figure D-9 illustrates the data stream recorded as a result of completing a right to left lane movement after departing from a ramp that curved to the left. It is these later two scenarios that may elude detection from the lane movement algorithm described above.

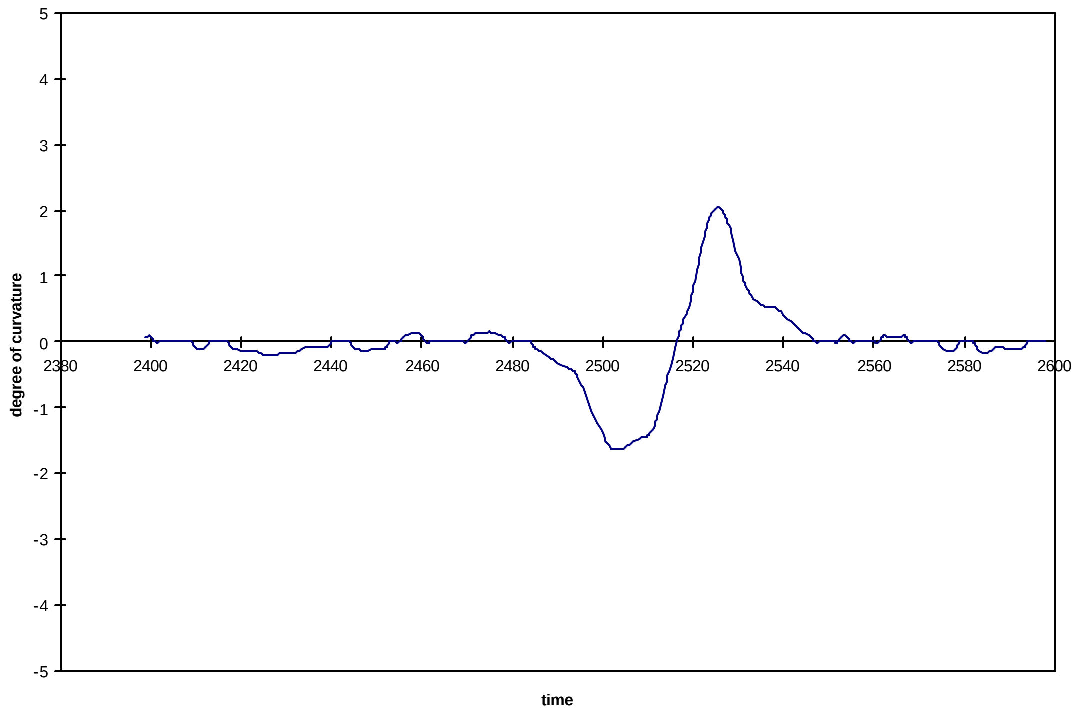

Figure D-4 Right to left lane movement on a straight section of roadway

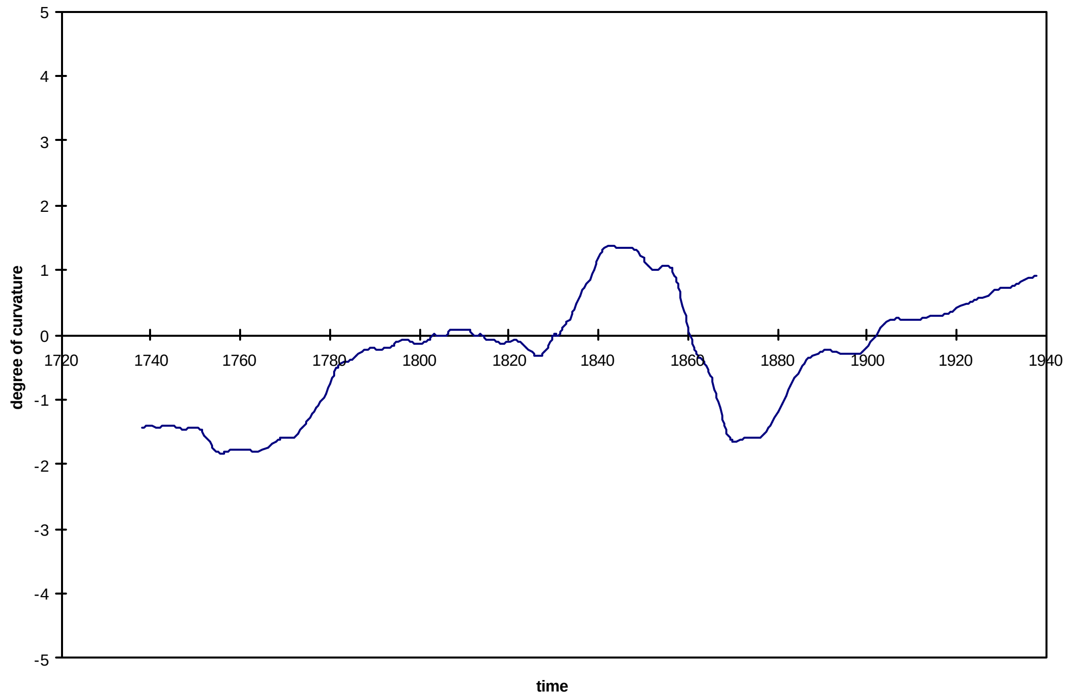

Figure D-5 Left to right lane movement on a straight section of roadway

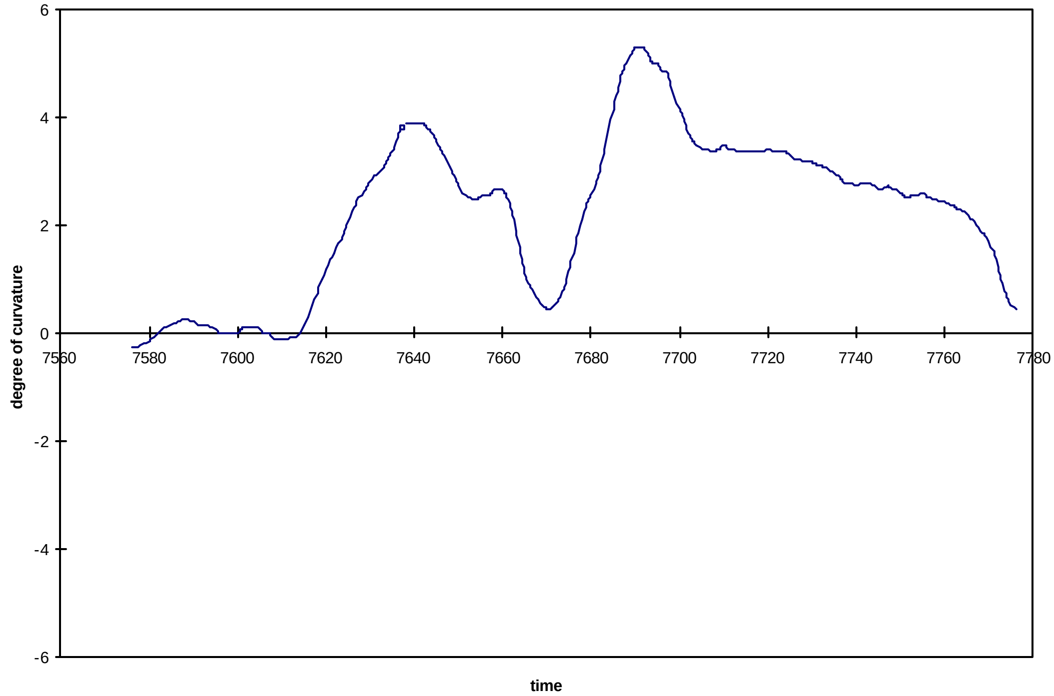

Figure D-6 Right to left lane movement on a section of roadway curving right

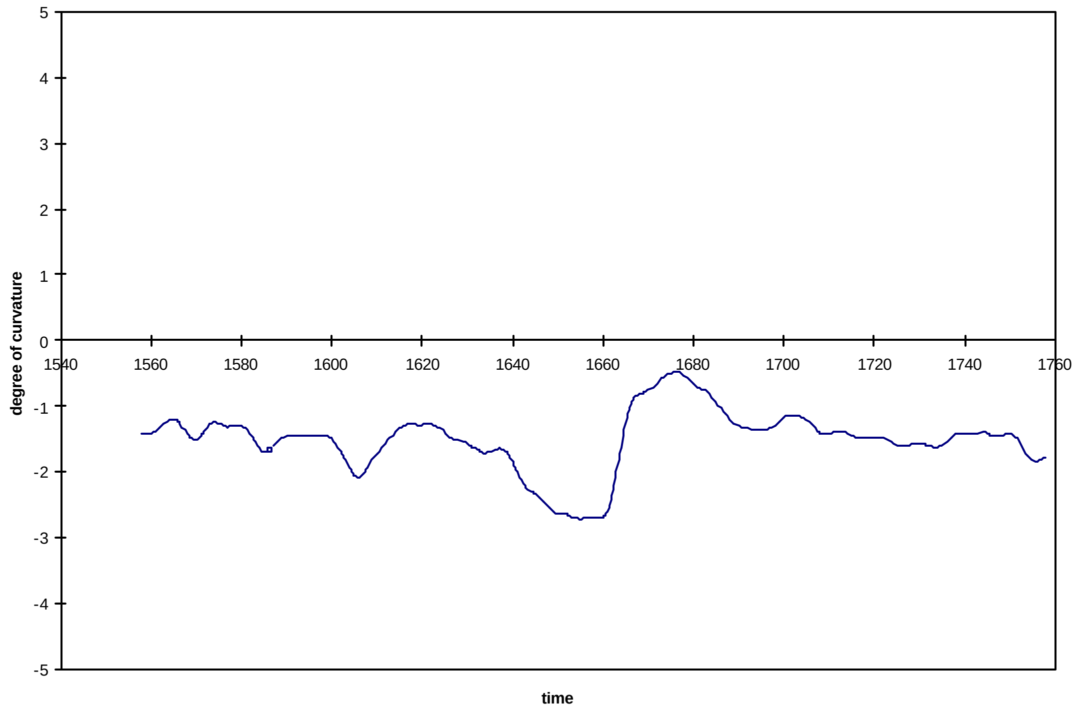

Figure D-7 Right to left lane movement on a section of roadway curving left

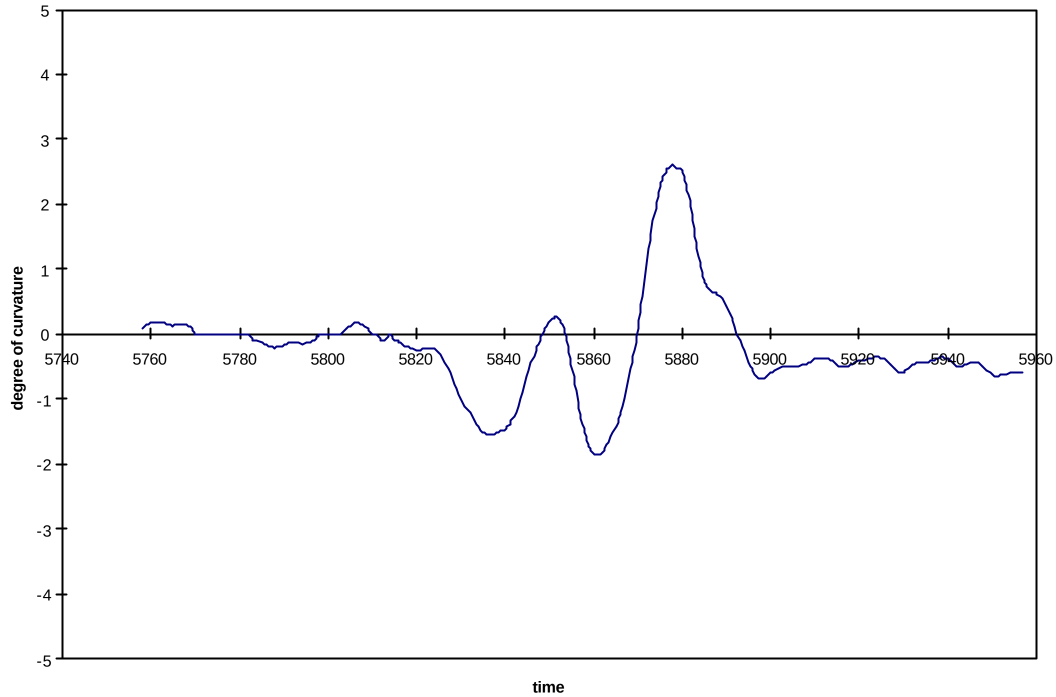

Figure D-8 Two consecutive right to left lane movements on a straight section of roadway

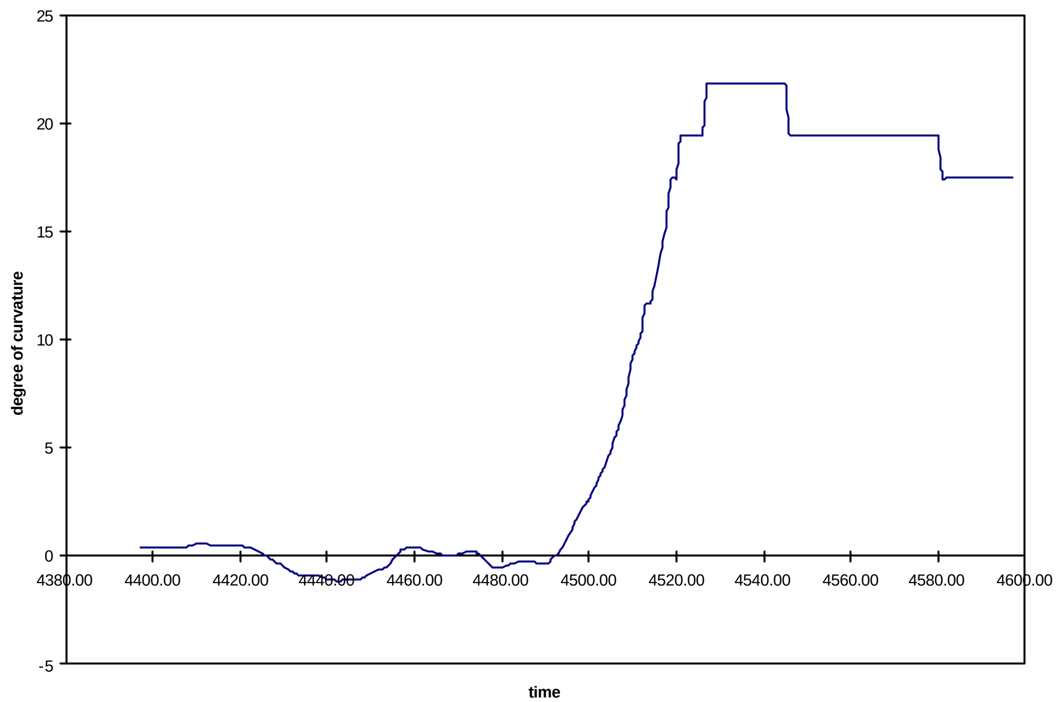

Figure D-9 Left to right lane movement following a sharp curvature to the left

D-4 Model Validation

Validation of the candidate lane movement model was conducted using a thirty minute portion of pilot testing data. During this test, 46 lane movements were manufactured by the test driver and recorded on video. The driver made a conscious effort to perform a complete range of lane movement maneuvers, including lane movements entering/exiting curves and lane movements across multiple lanes. These unusual scenarios should ensure that a more robust model is developed, but given their complexity, they may also give rise to validation statistics that are below expectation.

The first step in the validation procedure involved reviewing the video coverage of the 30 minute drive. Each observed lane movement was described in terms of the approximate time the lane movement was initiated, the geometry of the roadway at the time the lane movement occurred, the direction of the lane movement, and the number of lanes over which the lane movement occurred. The video record of the lane movements was reviewed a second time, this time to demarcate changes in the geometry of the road. Transitions from arterials, ramps, and freeways were noted, in addition to any obvious changes in road curvature. In this way, any subsequent false or missed lane movement classifications could be investigated more closely.

The next step involved processing the sample FOT data logged by the ICC system during this particular drive. Approximately 30 minutes of deci-second interval data were considered. Of the 46 actual lane movements that occurred during the drive, the algorithm correctly identified 36, yielding a hit rate of 78 percent. The algorithm did predict 3 additional lane movements that did not occur in the field, and the algorithm was unable to predict 10 of the observed lane movements. These statistics provide an overall success rate for the algorithm of 73 percent. Assuming the 1 second step size of the window within the 30 minute duration of the data, the algorithm provided 1800 responses. Of these responses, 1754 were correctly rejected, which provides a false alarm rate of 0.2 percent. These results are summarized in Table D-2.

Table D-2: Lane Movement Model Responses

Responses			
true	false	miss	total
36	3	10	49

A closer investigation was conducted into the nature of the false alarms and missed lane movements. The three false alarms appear to have occurred on, in the vicinity of, curves in the road geometry. Two of the missed lane movements involved consecutive lane movements, and the majority of the remaining missed lane movements occurred either proceeding or following a sharp curve such as an off/on ramp. These conditions are indicative of merge or diverge environments, which are integral component of freeway operations.

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Appendix E

Fuel Consumption and Emissions Estimation

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E-1 Introduction

This appendix summarizes the approach to constructing queries and computational algorithms to test several hypotheses that relate to quantifying fuel consumption and pollutant emissions benefits of Intelligent Cruise Control (ICC) versus conventional cruise control (CCC) or manual driving.

E-2 Source of Fuel Consumption and Emissions Data

The consumption and emissions rates used in the query were developed by Oak Ridge National Laboratories (ORNL) in 1997. These rates are expressed as a function of both velocity and acceleration, and are suitable for use in microsimulation models, or for empirical driving studies that produce detailed drive mode profiles such as the ICC field operational test. The ORNL data was originally developed as a series of look-up tables as a function of velocity and acceleration rate for eight different vehicle types representative of different engine sizes and technologies. These look-up tables were later fitted to curves by the Center for Transportation Research at the Virginia Polytechnic Institute and State University (VPI). The consumption and emissions curves are a family of third-order polynomials.

VPI also prepared a family of linear equations which define the upper limits of acceleration and velocity that can be achieved by each of the vehicles tested. In the event that instantaneous acceleration rates exceed this boundary, the rate for the highest point on the boundary for that speed should be used, because the equation forms do not provide reliable estimates of extrapolated rates beyond these acceleration boundaries.

The ORNL data did not extend to deceleration rates below -5 ft/sec/sec. Below this level, consumption and emissions rates are approximately constant with respect to acceleration, and the -5 ft/sec/sec rates can be used as a reasonable approximation for deceleration rates below -5 ft/sec/sec.

The test vehicle for the ICC was a 1996 Chrysler Concorde, which was equipped with a 161-horsepower, 3.3-liter, six-cylinder engine. Of the eight vehicles represented in the ORNL test fleet, the 1994 Oldsmobile 88 (Olds 88) is most similar to the Chrysler Concorde. The Olds 88 was equipped with a 170-horsepower 3.8-liter, six-cylinder engine. Therefore, equations for the Olds 88 are used for evaluating the fuel and emissions impact of ICC.

E-3 Maximum Acceleration Threshold

The maximum rate of acceleration that can be sustained by the test vehicle is a function of the instantaneous velocity. For the Olds 88, the maximum acceleration rate A_{max} is predicted from the following equation:

$A_{max} = -0.10953*(V) + 15.10751$

where A_{max} = Maximum acceleration in ft/sec/sec

V = Current velocity in ft/sec

Based on this equation, the maximum rate of acceleration for an Olds 88 is 15.1 ft/sec/sec at zero velocity, and the maximum speed where no further positive acceleration is possible is about 138 miles per hour. This relationship was developed by VPI through regression analysis.

E-4 Fuel and Emissions Equations

VPI developed equations for fuel and emissions as a function of velocity and acceleration. Several models were tested as part of the ITS Metropolitan Model Deployment Initiative (MMDI) study. The best fit was obtained using a third-order polynomial model calibrated against transformed data using the natural log function. The equation requires sixteen parameters. The form of the equation was the same for fuel consumption and all three air pollutants:

$$\ln(F)=a+bA+cA^2+dA^3+eS+fS^2+gS^3+hAS+iAS^2+jAS^3+kA^2S+lA^2S^2+mA^2S^3+nA^3S+oA^3S^2+pA^3S^3$$

where F: fuel consumption or emission rates (liters/second or milligrams/second)

a: intercept

b,c,…,p: coefficients

A : acceleration (ft/s^2)

S : speed (ft/s)

ln : natural log, base "e" (e = 2.718281828 ...)

The coefficients of these equations for the Olds 88 are summarized below:

Parameters	Fuel Consumption	Hydro Carbon Emissions	Carbon Monoxide Emissions	Nitrogen Oxide Emissions
a	-7.54740E+00	-9.21346E-01	9.94428E-01	-3.64531E+00
b	1.87319E-01	5.00794E-02	1.80196E-01	4.12205E-01
c	3.16184E-02	3.25467E-02	3.70812E-02	8.93588E-02
d	-2.58691E-03	-9.23518E-04	-1.76909E-03	-8.34337E-03
e	2.46331E-02	1.46511E-02	4.57495E-02	1.16663E-01
f	-2.67300E-04	-2.34790E-04	-7.07983E-04	-1.33770E-03
g	2.02936E-06	4.42470E-06	7.29962E-06	8.11745E-06
h	3.78675E-03	1.49929E-02	1.52469E-02	1.78212E-02
i	3.20880E-05	-1.63829E-04	-2.06107E-04	1.63313E-05
j	-2.55155E-07	6.01643E-07	1.03077E-06	-1.07571E-06
k	-1.15209E-03	-1.31724E-03	-1.46257E-03	-2.50631E-03
l	3.08215E-05	7.35484E-05	8.62032E-05	5.67589E-05
m	-2.29074E-07	-5.01100E-07	-6.23591E-07	-5.37688E-07
n	3.91402E-05	-1.52223E-04	-1.63821E-04	2.82700E-04
o	-1.36172E-06	1.10401E-06	2.24143E-06	-1.19278E-05
p	-8.68747E-09	7.06001E-09	-9.96398E-09	2.80363E-08

The equations for each vehicle are not valid when the rate of acceleration exceeds the threshold value at the current velocity. The previous section defines the upper threshold relationship for the Olds 88. The equations were not calibrated against speeds greater than 110 ft/sec (75 mph) and acceleration rates less than -5 ft/sec/sec. Consumption and emissions rates for acceleration are approximately constant below -5 ft/sec/sec. Therefore, for acceleration rates below -5 ft/sec/sec, consumption and emissions rates for -5 ft/sec/sec are used from the equations.

E-5 ICC Data Fields

The ICC field studies produced a series of linked databases describing second-by-second drive mode parameters and different categories of events. Fields from the database which contains second-by-second drive mode data are needed to perform the fuel and emissions calculations. The first three fields are key fields which serve as linkages to other databases that identify driver and trip characteristics:

- DRIVERID - Unique identification number assigned to each driver.
- TRIPID - Unique trip number for given driver.
- SEC_COUNT - Cumulative time in seconds since the start of current trip

The fields that are needed for computing fuel consumption and emissions include:

- VELOCITY - Speed of vehicle during the current second of travel in feet per second.
- VDOT - Acceleration of vehicle during the current second of travel in fractions of the gravitational acceleration (g = 32.1740 ft/sec/sec).

Since many queries of fuel and emissions impacts will be performed based on different combinations of state variables, new fields are needed to store new second-by-second consumption and emissions values for subsequent queries. There are already four fields in the database that contain fuel consumption and emissions of CO, HC and NOx using a less-detailed modeling process. However, these fields are not used in this study. The new fields include:

- OVERMAXACCEL - TRUE when current acceleration exceeds maximum acceleration for current vehicle and speed
- UNDERMINACCEL - TRUE when current deceleration is below -5 ft/sec/sec
- NEWFUEL - Fuel Consumption for current second (liters/second)
- NEWHC - Hydro Carbon Emissions for current second (milligrams/second)
- NEWCO - Carbon Monoxide Emissions for current second (milligrams/second)
- NEWNOX - Nitrogen Oxide Emissions for current second (milligrams/second)

The first two new fields, which are conditional flags, will be used to establish how often the second-by-second speed and acceleration rates of the test vehicle exceeded the acceleration threshold for the Olds 88, or how often the deceleration rates were below the lower range of rates in which the equations apply.

E-6 Computing Fuel and Emissions Rates

This section describes the process that was used to compute fuel consumption and emissions for all trip sets that were used in the study. Before performing calculations, the six new fields mentioned previously were added to the database. ACCEL and SPEED are temporary variables used for intermediate calculations.

For each trip

For each second-by-second record

1. Compute new variable ACCEL by converting VDOT from g's to ft/sec/sec (g = 32.1740 ft/sec/sec)
2. If acceleration is greater than zero, compare acceleration rate to maximum allowed at the current speed (VELOCITY) using VPI equation for the subject vehicle class. If ACCEL exceeds maximum, set OVERMAXACCEL to TRUE and set ACCEL equal to the maximum acceleration rate for that speed, otherwise set OVERMAXACCEL to FALSE.
3. If acceleration is less than -5 ft/sec/sec, set ACCEL to -5 ft/sec/sec, and set UNDERMINACCEL to TRUE, otherwise set it to FALSE
4. Compute new variable SPEED by converting VELOCITY to km/hr (km/hr = ft/sec * 3600 sec/hr / 3280.84 ft/km)
5. Convert ACCEL to km/hr/sec (km/hr/sec = ft/sec/sec * 3600 sec/hr / 3280.84 ft/km)
6. Use VPI equations to compute fuel consumption and emissions rates based on SPEED and ACCEL and store as new fields NEWFUEL, NEWCO, NEWHC, and NEWNOX.

Next second

Next Trip

E-7 Identifying State Variables

It is necessary to use various state variables as filters when defining queries for analysis of fuel consumption and pollutant emissions effects. It is also necessary to look at other state variables while testing other hypotheses. The times when state variables changed are stored in a separate event database which is tied to the trip database by the DRIVERID and TRIPID fields.

Driving Mode - time in which ICC was on, time in which CCC was on, and time in which no cruise control was used by the driver.

Roadway Class - time in which the test vehicle traveled on freeways, state highways, arterials, ramps, light-duty streets (collectors and locals) or unclassified roadways.

Level of Service - time in which the test vehicle traveled on a roadway under similar traffic flow conditions.

Snow Trips - trips in which there was evidence of snow, or other precipitation on the pavement made evident by video log data.

E-8 Frequency Distributions

The purpose of extracting acceleration-velocity frequency distributions from trip records is to determine how often the vehicle traveled in different drive modes during each trip. This will help indicate whether ICC smooths vehicular drive mode profiles relative to CCC or manual control. However, under high flows, external factors may play a part in limiting speed variability.

- Matrix of acceleration rates and velocities - Accumulate number of records using velocity ranges from zero to 120 ft/sec in 10 ft/sec intervals and acceleration from -13 to +13 ft/sec/sec in 2 ft/sec/sec intervals.

E-9 Descriptive Statistics

The mean and variance of acceleration rates are computed for each mode for like trips.

This provides an indication of whether ICC smooths the flow of traffic over manual control conditions, and whether speed change behavior becomes notably more or less erratic under ICC versus CCC or manual control. However, under moderate-to-high flows, speed variations may be restricted by the influence of surrounding vehicles.

E-10 Cumulative Statistics

For each like trip, the following cumulative statistics are accumulated for reporting and comparison purposes. These statistics are stored in a database using DRIVERID and TRIPID as identifying variables.

1. Trip Length - Total distance traveled on this trip in miles
2. Total Time - Total amount of time in trip records
3. Travel Time - Time from first record of motion to last record of motion (excludes stopped time at the beginning and end of the trip) in minutes
4. Average Travel Speed - Trip Length divided by Travel Time converted to miles/hour
5. Time in Acceleration Mode - Time while vehicle is accelerating greater than 0.05 g's (1.6 ft/sec/sec)
6. Time in Deceleration Mode - Time while vehicle is decelerating less that 0.05 g's (-1.6 ft/sec/sec)
7. Time at Constant Speed - Time while vehicle has non-zero velocity and acceleration between +/- 0.05 g's (+/- 1.6 ft/sec/sec)
8. Stopped Delay Time - Time in which acceleration and velocity are zero, excluding time before start and after end of trip.
9. Moving Time - Sum of time at constant speed, acceleration and deceleration.
10. Valid Tracking Time - Time while vehicle is tracking a valid target.
11. Total Fuel Consumption
12. Total CO Emissions
13. Total HC Emissions
14. Total NOx Emissions
15. Time when vehicle acceleration/velocity rates exceed acceptable upper limit for that vehicle.
16. Time when vehicle acceleration/velocity rates were less than minimum of -5 ft/sec/sec represented by consumption and emissions data.

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Appendix F

Development of the GIS/GPS Map Matching Tool

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F-1 Introduction

This Appendix characterizes the operation of the GIS/GPS Map Matching tool that was developed for the analysis of the Intelligent Cruise Control (ICC) Field Operational Test (FOT). The purpose of the tool, its development and application to the evaluation are discussed.

F-2 Purpose

During the course of the ICC FOT subject drivers were given free rein to travel wherever and whenever they want. As a result, their driving experience include an eclectic mix of different road types. Despite the wealth of in-car data that was collected, little information was available that allowed this experience to be measured directly. For example, while video clips are provided at regular intervals of 5 or 10 minutes, depending on the number of weeks of driver participation, this spacing was felt to be too lengthy and the clips too short to provide a complete and adequate picture of the road class use. Similarly, the collected GPS data was also of limited use. Without a means of tying these points to a corresponding road network they served little purpose other than indicating commonly used starting and end points. The purpose of this GIS/GPS Map Matching tool then was to identify continuously the road type as drivers drove during the FOT. With road type available as an independent variable, both usage and safety effects could be more meaningful determined.

F-3 Model Development

There were a number of steps involved in the development of this tool. They began before any subjects saw the vehicles and have now reached a state of completion. They include:

- Characterization of the raw GPS points,
- Selection of an appropriate map database,
- Selection of a map-matching algorithm,
- Inclusion of level of land use,
- Development of a smoothing algorithm and,
- Validation.

These various stages are described in the following paragraphs.

F-3.1 Characterization of the Raw GPS Points

The first step in developing a roadway classification scheme was to benchmark the available input data; namely the raw GPS points. This characterization served two purposes. Firstly, it aided the evaluation in team in evaluating the feasibility of even proceeding with the map matching development. Secondly, once the decision to proceed was made it provided valuable insights into the best approach to take.

Raw GPS data points have historically been plagued by a number of limitations. One of the primary sources of error is introduced deliberately by the U.S. military. It is called selective availability and was designed to prevent the signals from GPS satellites from being used for illegal activities. Essentially, a small variable error is entered into every point that is received. This may cause not only absolute error but also relative error as points taken from the same location may drift substantially over time. Some systems can correct for this error automatically, and are referred to as differential GPS units or, DGPS. The system selected by UMTRI does not contain this costly ability. Another potential source of error associated with raw GPS points may be caused by the deflection or blocking of the signal by trees and tall buildings. These occurrences may lead to erroneous position estimates. Finally, the reliability of a GPS system may be affected by limitations and or damage to the GPS receivers themselves. This had the potential to introduce errors in consistency of data points between the various vehicles in the ICC fleet. In order to examine the impacts of all of these potential errors a series of pilot tests were established.

F.3.2 Consistency over Time

The first characterization test examined the consistency of the GPS signals over time. As Figure F-1 illustrates a single ICC equipped vehicle was driven over a pre-determined route on three different days over the course of the initial two-week pilot testing period. The circuit began close to the UMTRI facility (origin 0.0, 0.0) in Ann Arbor, Michigan, then proceed south on US Highway 23 for approximately 9 km, then east on I-94 for nearly 20 km, then north on I-275 for 18 km, and finally southwest back towards the UMTRI facility. Figure F-2 demonstrates an enlarged portion of the data at the I-94 and I-275 interchange. As both figures suggest, the discrepancy in the logged GPS system over time was found to be very minor.

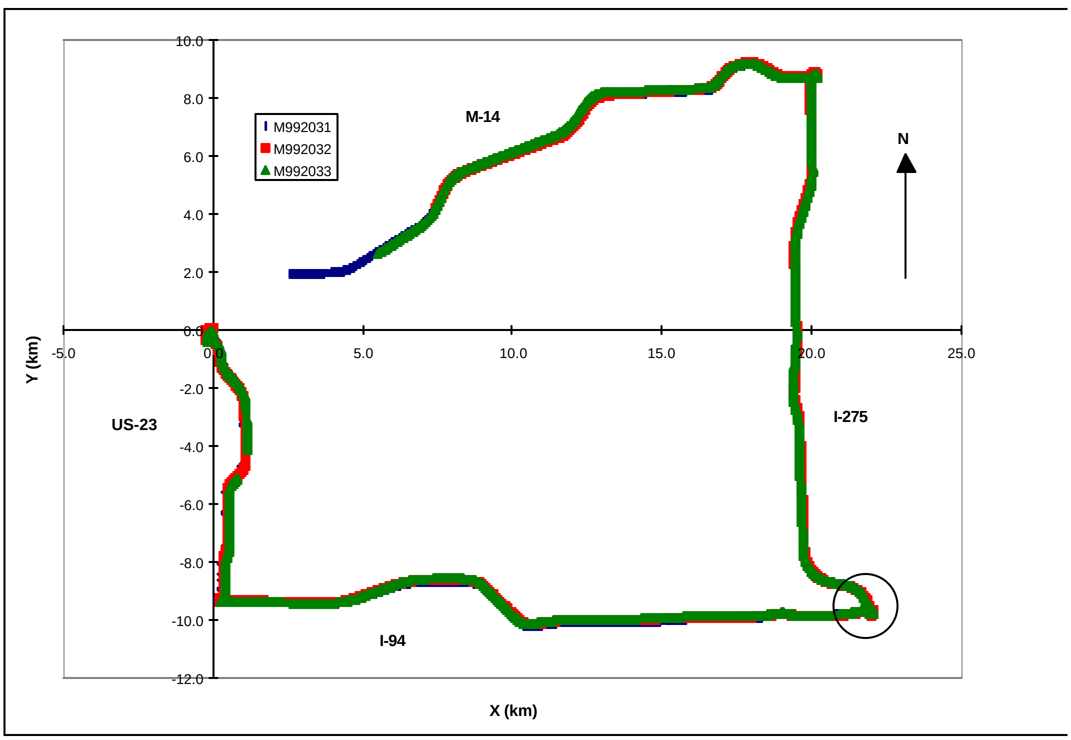

Figure F-1 Consistency of GPS Data over Time for a Typical Freeway Route

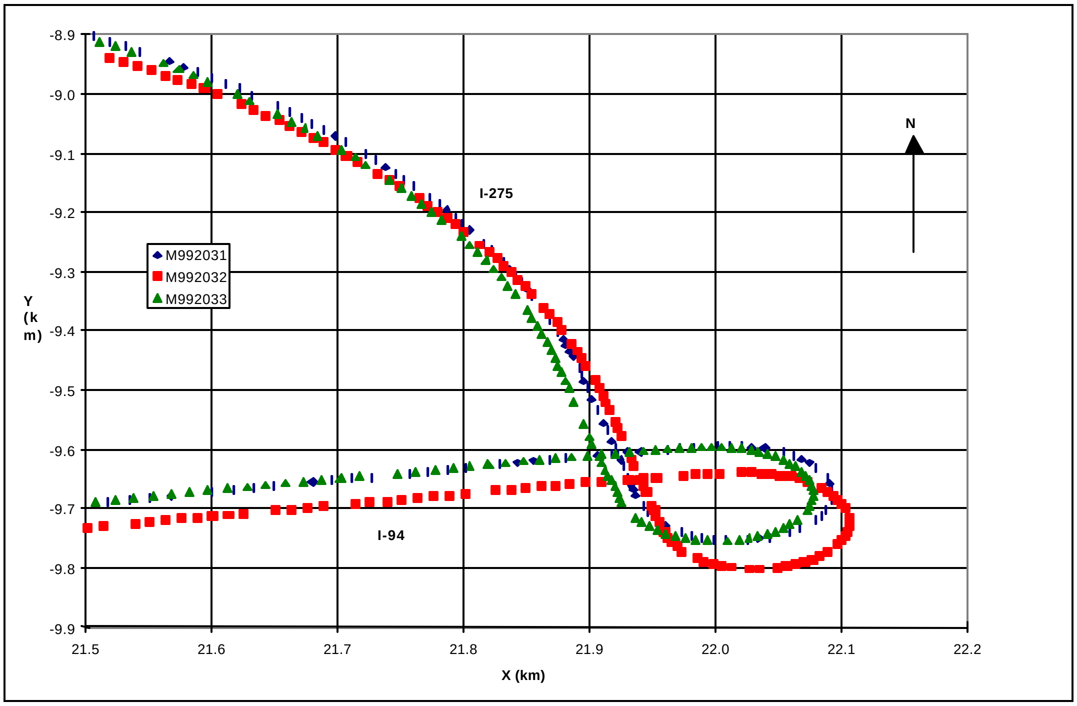

Figure F-2 Consistency of GPS Data over Time for a Typical Freeway Route (enlarged)

F-3.3 Consistency between Vehicles

The second characterization test analyzed the consistency of the logged GPS points between units. It was conducted on the same circuit as described previously and involved two ICC vehicles being driven one directly behind the other, effectively eliminating any potential time discrepancies. As Figure F-3 illustrates both the latitude and longitude values showed very little difference between the two units. However, when an examination was conducted of the altitude records from the two vehicles some disturbing inconstancies were discovered. As Figure F-4 illustrates, for this particular recording period the two estimates of vehicle altitude differ by as much as 60 meters for a substantial period of time. Fortunately, however the measurement of altitude is not a critical requirement in the determination of road class. As such, it was determined that the map matching procedure would not be hindered by inconstancies between hardware units.

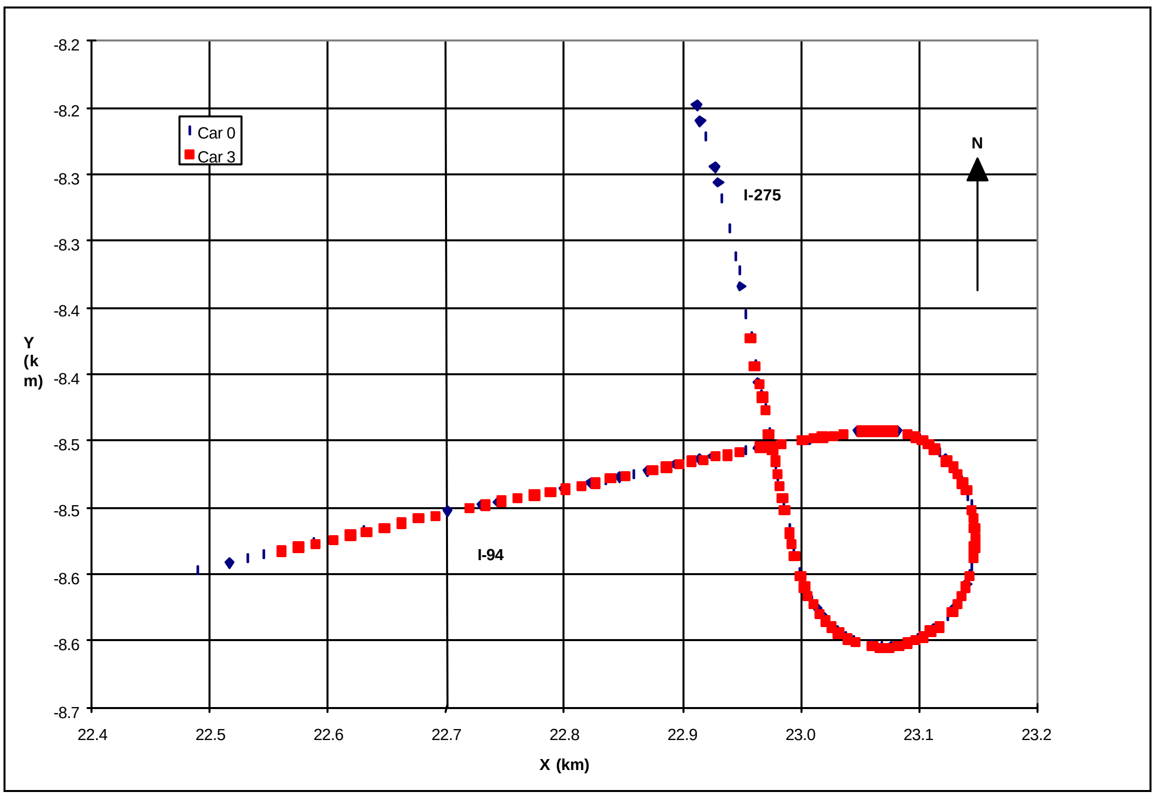

Figure F-3 Consistency of GPS Data between Units (enlarged)

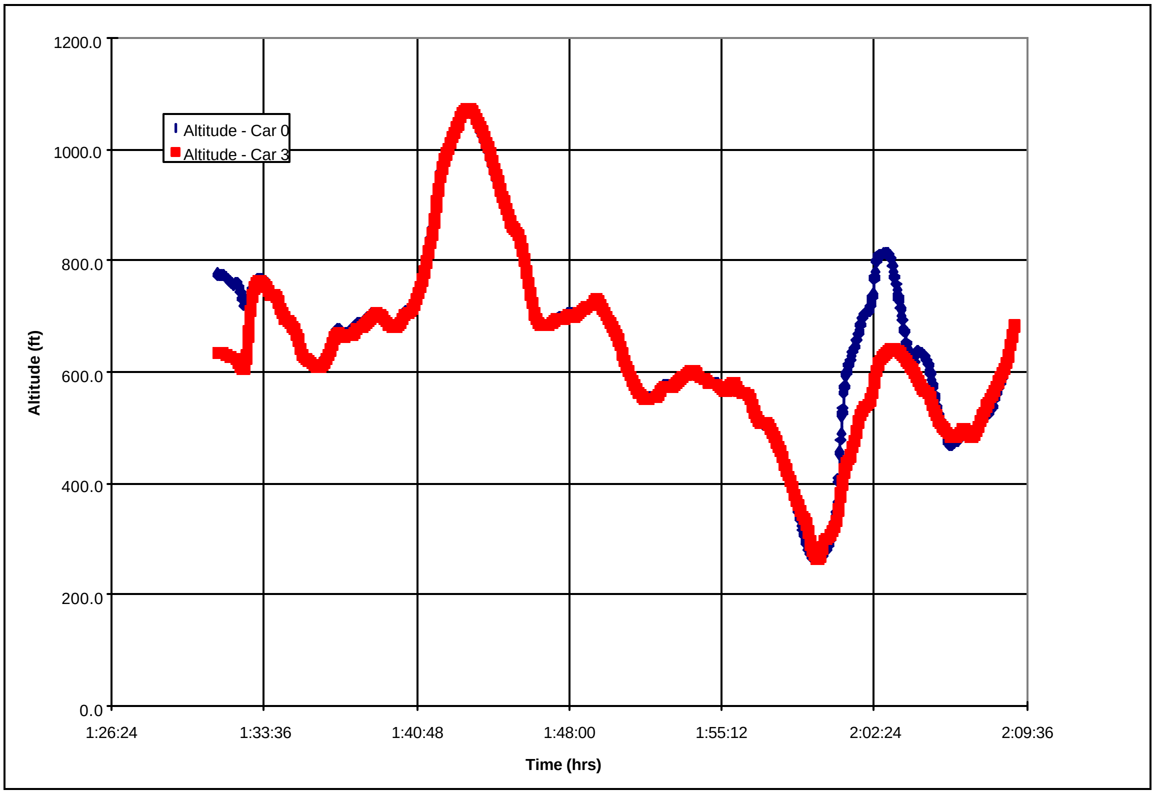

Figure F-4 Consistency of GPS Altitude Data between Units

F-3.4 Lost Points

The final set of characterization tests examined the occurrence of lost or missed data points. Ideally, the GPS data within the ICC system are to be recorded at a frequency of 2 Hz (0.5 sec). However, as was mentioned previously trees, hills and tall buildings may impede these regular transmissions. Of these, the most commonly occurring is the blocking of the signal by buildings. Areas where this impedance occurs are referred to as urban canyons. Figure F-5 illustrates the sample reporting frequency of the GPS unit during a drive through one such urban canyon in the central business district of the City of Detroit, Michigan. As can be seen, the majority of the counts did occur at the prescribed 0.5-second rate. However, a number of counts also fell into the 1.0-second bin and higher, indicating the presence of some signal loss. However, for this particular worse case trip, the overall reception rate was found to be an acceptable 82 percent. In addition, the distribution of the 12 percent of data elements that were lost was very favorable, with few gaps longer than 2.0 seconds. This excellent reception rate was considered to strongly favor the proposed process of map matching.

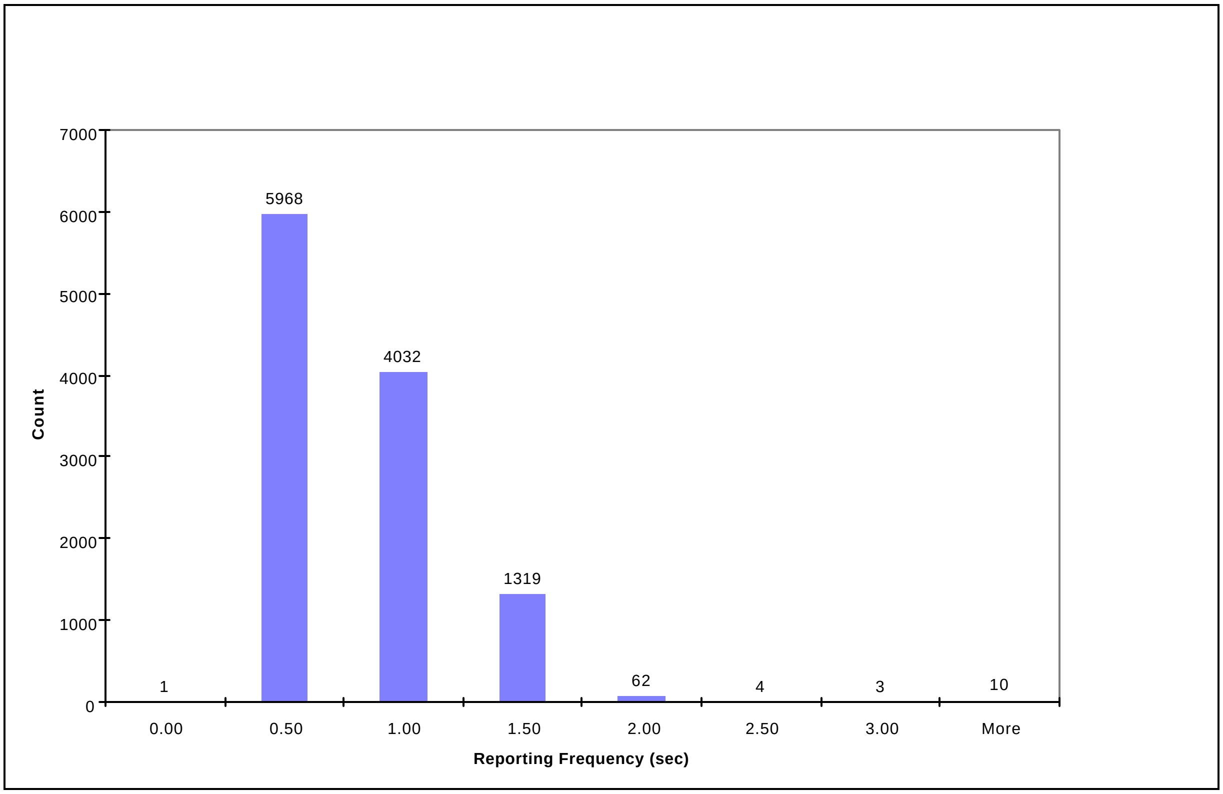

Figure F-5 Reporting Frequency of GPS Unit

In general the GPS units used in the ICC vehicles were found to provide excellent results for all measures considered including consistency over time, consistency between units, and reception rate. Faced with these results and the stated benefits of developing a road classification scheme a decision was made by the evaluation team to proceed with the development of such a model.

F-3.5 Selection of a Road Database

Having verified that the GPS points were of sufficient quality to support a map matching process the next step was to select an appropriate digital database. A digital database is essentially a computerized map. It may contain such information as political boundaries, road locations, names and classifications, and even points of interest and zip codes. In order to support this study a cost-effective platform was required, which contained accurate, detailed information on both road classifications and locations. In addition, this database had to cover as much of the area in which drivers were expected to operate as was financially feasible.

Based on these criteria a number of different road database packages were considered. Amongst these were the government supplied TIGER files and the commercially maintained Navtech databases. While the TIGER files were found to be very cost effective, concern was raised as to their limited accuracy and failure to depict true roadway curvature. The Navtech database was recognized as a much more accurate system, but reservations were forwarded over the costs associated with securing an appropriate coverage area. As a result a third group of files were examined and ultimately selected: the ETAK database.

ETAK maps are off-the-shelf digital road maps with superior accuracy and competitive costs. They are capable of capturing roadway curvature, including low speed, sharp radius ramps and are digitized to six decimal places or one millionth of a degree. In addition the ETAK maps provided a consistent, easy to use road classification scheme. The various levels of this classification are outlined in Table F-1.

Table F-1 ETAK Database Road Classes

Road Class	**Description**
Class 0 ***HighSpeedRamp***	An entrance or exit ramp from a freeway that has large radius curves and does not require a driver to slow down.
Class 1 ***Interstate***	Interstate highways, other limited access roads and primary thoroughfares. These roads are accessed through interchanges. They generally have no traffic lights or stop signs. A primary thoroughfare may have cross traffic but is nevertheless a principal route in the area.
Class 2 ***StateHighway***	Semi-limited access roads. Includes state highways. These are typically multiple lane roads, and are usually divided. They occasionally have traffic lights and generally have a high speed limit (50-55 mph).
Class 3 ***Arterial***	Arterials. These roads feed traffic to and from limited access roads. In urban areas these are medium to high volume roads. They may be divided multi-lane roads. They generally have lights at their intersections and usually do not have stop signs. The speed limit on these roads is normally around 40 mph.
Class 4 ***Collector***	Collector. A through road in a residential or high-density area.
Class 5 ***LightDuty***	Light Duty. In urban areas these are generally local streets. In rural areas these are minor roads.
Class 6 ***AlleyorUnpaved***	Navigable alleys or unpaved roads. In rural areas these are generally dirt roads and jeep trails.
Class 8 ***Unknown***	Roadways that either have an unknown class or represent an error.
Class 9 ***LowSpeedRamp***	An entrance or exit ramp from a freeway that requires a driver to slow down. A typical example is a cloverleaf ramp.

Once the map supplier was identified it was necessary to decide on an appropriate coverage area. This was accomplished by performing a trade-off between financial constraints and estimates of the range over which the test was expected to cover. After considering this trade-off two ETAK databases were selected which offered coverage of eleven counties in Southeast Michigan. This area which is outlined in Figure F-6 covers the entire range of locations from which drivers were recruited and included a substantial buffer zone for non home-based trips taken by these drivers. Obviously, a certain number of trips were expected to occur outside of the coverage area, especially by drivers who used the vehicles to go on vacation.

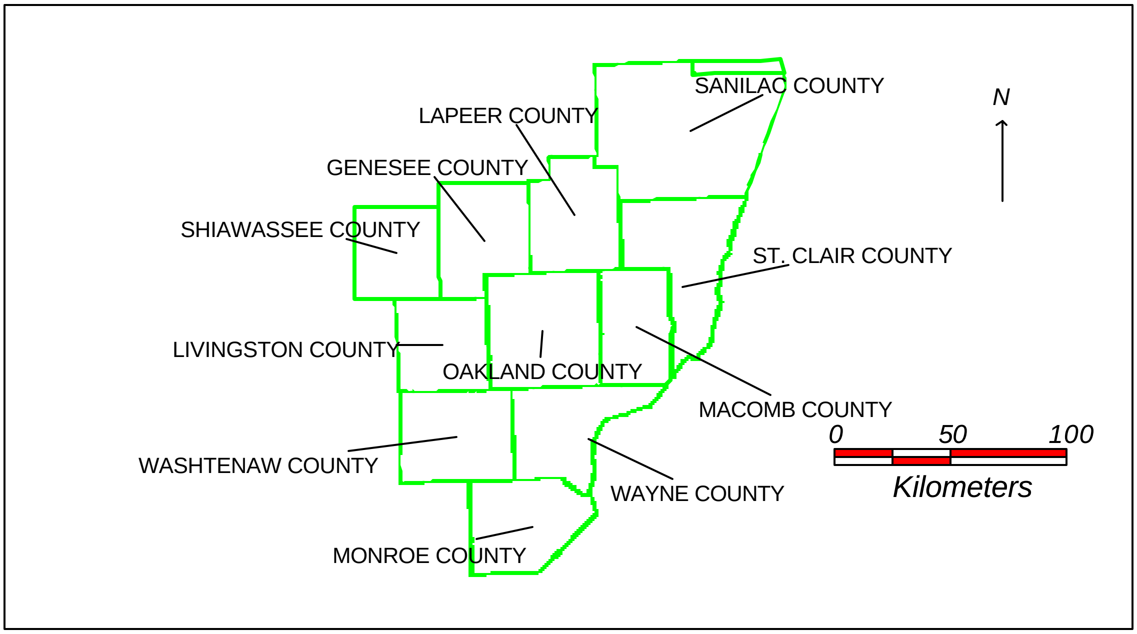

Figure F-6 ETAK Road Database Coverage Area

F-3.6 Selection of a Map-Matching Algorithm

The next stage in the development of the GIS model was the selection of an appropriate map-matching algorithm. Such an algorithm is necessary to serve as bridge between the raw GPS points and the ETAK database. Unfortunately, it is not a simple straightforward process to correlate the latitude and longitude outputs from the ICC vehicle with the road link coordinates from the map database. Furthermore, there is currently no off-the-shelf software available for performing this task. As such a custom program had to be developed.

Owing to the complexity of the task, a decision was made to purchase this custom programming from an external source. After some searching, the work was tasked to Mapping Solutions operating out of East Lansing, Michigan. Mapping Solutions was chosen for a number of reasons. Firstly, they had experience in similar tasks and were familiar with the ETAK database. Secondly, they were certified resellers for the Map-INFO GIS mapping software package. This package was well suited for the task we were performing and was compatible with MS-ACCESS that was the format for all of our data.

The final program that was developed combines the input GPS files from the various MS-

ACCESS databases with the road data from the ETAK database, and customized Map-INFO user interface. This interface allowed the operator to specify which FOT trips to analyze, and which road classes to match. The program was run to match all road classes (Class 1, Interstate become Freeways in our evaluation).

F-3.7 Smoothing Algorithm

After performing a number of initial validation runs with the custom map-matching algorithm one consistent source of error was identified. Specifically, the program struggled with separated grade crossings of freeways and arterials. In these and other such areas where two separate classes of roadway are physically very close to one another, the program has difficulty deciding on the appropriate classification. While the program does place some bias on the last roadway section identified, it only carries this bias for 16 points, or 8 seconds at a 2Hz-collection frequency. In areas where two competing roadway sections are sufficiently close to one another for greater than these 16 points the program will automatically default to select the highest class of roadway of the two available choices. Consequently situations may arise where classifications may transition from arterial to freeway and back to arterial in a short period of time if the ICC vehicle happened to be on an arterial crossing a freeway.

This concern has been addressed by creating and applying a customized filter to the map-matched data. Specifically, the program is designed to identify situations where the road name (and thus class) change from one value to another and then back to the original value in less than 60 seconds. In situations where this occurs an error is assumed and the short, intermediate road name and class is changed to the beginning/end name and class.

F-3.8 Inclusion of Land Use

After initiating the development of the map-matching algorithm, interest was raised in supplementing road class information with estimations of level of land use. This land use data would aid in differentiating amongst various levels of population density, and presumably driving experiences. For example it was felt that a driver in the City of Detroit might have a much different exposure rate to traffic conflicts than a driver on the same road class, at the same time of day in a remote rural area.

In order to facilitate the inclusion of this data the existing geopolitical boundaries in the ETAK database were modified by the evaluators to include population data from the 1992 census. In this manner, 4 different levels of land use were established:

- Rural – no political boundaries,
- Small urban – population 0 to 5,000,
- Medium urban – population 5,000 to 50,000 and,
- Large urban – population greater than 50,000.

Using these parameters the level of land use for every GPS point within the coverage area can be determined.

F-3.9 Validation

Owing to the important role that roadway classification is expected to play in the analysis of the ICC system, a thorough program of validation was deemed necessary. Specifically, analyses were conducted that compared the map/matching algorithm against recorded notes and visual inspection, against continuos video from pilot tests and against the classifications made by the video analyst.

For the first of these analyses, the evaluators conducted a series of runs during pilot testing of the ICC vehicle. These runs took place over a series of pre-determined routes and were designed to cover a broad range of roadway types and to explore potential problems such as urban canyons and closely spaced roadways. For this level of analysis, validation was performed by comparing the plotted output from the map/matching process against a combination of the underlying map of actual roadway names and classes and records taken during the pilot test runs. Furthermore, the analysis was expanded to consider the accuracy of the resultant data for both the basic application (with the absence of the smoothing algorithm discussed previously) and for an application including smoothing. Finally, it should be noted from Table F-2 that three measures of effectiveness were considered. The first, "classification" indicates the number of GPS points that were matched (accurately or otherwise) to some point in the roadway database. The second, "Error – Original", indicates the percentage of these classified points that were classified accurately in the absence of a smoothing algorithm. The third, "Error – Smoothed" refers to points that were accurately classified after application of smoothing.

The first set of runs considered a rural arterial. As the perfect results from the table indicate, this is perhaps the easiest test for the approach given the lack of trees, tall buildings or nearby roadways.

A slightly more challenging test was encountered when the test was moved to an inner-city urban arterial in the northern part of Detroit. As the results indicate, the classification rate remained high, while the error rate increased slightly to just over 3%.

A similar trend was noted in considering the set of runs on the urban freeway. Here the classification rate remained high (99%) while the error from the original application was non-trivial, but low (3%). The real difference between the urban freeway and arterial runs can be found in considering the error rate reduction introduced by the smoothing algorithm. For the arterial the algorithm had no effect, however, for the freeway it reduced the error to less than 1%. The reason for this discrepancy may be explained by the fact that the arterial examined did not cross any freeway segments, while the freeway crossed a number of arterials.

The second last set of runs included a mixture of freeway and arterial in both low and high-density environments. For this test the results were similarly promising, with a continued high level of classification and a relatively low error rate, reduced even further with the smoothing algorithm.

The final run provided a worst case scenario, with the pilot vehicle being driven on both an urban freeway and its corresponding parallel service road. For this situation the classification rate remained high (which is not surprising considering the test was conducted in a tightly packed urban area), however the error rate exceeded 20% for both the original and smoothed algorithm. Taken in isolation these results may be disturbing, however, it should be noted that the pattern of driving exhibited in this particular run is considered highly irregular and unlikely to appear in actual field operations. This run was selected simply to show the absolute worse case bounds of the technology.

Table F-2 Map-Matching Validation Runs

Trip	Type	Classified	Error – Original	Error - Smoothed
900163	Rural Arterial	100%	0%	0%
900171	Rural Arterial	100%	0%	0%
Average		100%	0%	0%
903034	Urban Arterial	100%	4.16%	4.16%
903035	Urban Arterial	99.5%	6.35%	6.35%
903036	Urban Arterial	100%	0%	0%
903037	Urban Arterial	100%	0%	0%
903038	Urban Arterial	98.7%	6.43%	6.43%
Average		99.4%	3.38%	3.38%
903057	Urban Freeway	97.7%	1.3%	0%
903058	Urban Freeway	100%	7.6%	0%
903060	Urban Freeway	100%	3.9%	3.6%
903061	Urban Freeway	100%	0.3%	0.3%
Average		99.4%	2.6%	0.98%
992045	Mixed – Including High Density	99.2%	5.15%	3.08%
900152	Freeway and Parallel Arterial	100%	22.78%	20.6%

F-3.10 Ramp Filtering Algorithm

Upon completion of the various validation runs a final limitation of the map-matching approach was identified and addressed. Specifically, the level of accuracy with which the procedure identified freeway/arterial ramps was improved.

Owing to the fact that ramps, by definition, must lie very close to the freeway and arterial road segments that they connect, they suffer from a similar problem that made the smoothing algorithm discussed previously necessary. Specifically, because both ramp points and arterial or freeway points are often within the same search buffer of the matching algorithm and since the algorithm defaults to the higher class of roadway in these situations, ramps are often overlooked either in part or in entirely. Furthermore, the previous smoothing algorithm cannot be employed in these situations since the transition is not from one roadway to a 'false roadway' and quickly back to the original roadway. Rather, the transition is from one roadway (freeway or arterial), to a third roadway (arterial or freeway). Often this occurs with no notice of the intermediary ramp at all, or if the ramp is classed only a small portion of it is accurately identified. The net result of this process is that many ramp points became incorrectly classified as the higher class of freeway points.

In order to correct this situation a second algorithm was developed which automatically detects and reclassifies suspected ramp points that were previously mislabeled. This is accomplished by identifying two types of points in the data stream; one, where the road class transitions either from a freeway to an arterial or from a freeway to a ramp, and two, where the road class either transitions from an arterial or a ramp to a freeway. In the first situation (freeway to ramp/arterial) all road segments from the transition point and back 400m are re-classed as suspected ramp points. In the second situation all road segments from the transition point and forward 400m are similarly classed. The suspected ramp points are always removed from the predicted freeway segments as this is the highest class of roadway and thus most likely to have been classed erroneously.

As Table F-3 indicates, the employment of this ramp filter for a set of sample pilot data results in a dramatic improvement in the accurate classification of ramp segments, with only a slight decrease in the apparent accuracy of freeway classification. Furthermore, investigation has shown that these small number of freeway points that were 'erroneously' identified as ramp were often within the ramp influence area, typically occurring in acceleration/deceleration lanes that, while physically part of the freeway, are operationally quite different from mainline freeway segments. As a result of these findings the ramp identification algorithm was adopted as an integral component of the map-matching process.

Table F-3 Results of Applying Ramp Filter

	Freeway	Ramp	Overall
Base Case	98.7%	32%	86.1%
With Ramp Filter	96.6%	76%	91.8%

F-3.11 Data Storage

The final step in the map-matching process is to output the results to an appropriate results table. Table F-4 indicates the format for this output in the post-processed GPS table, while Table F-5 indicates the format for the added entries to the modified transition table.

Table F-4 GPS File/Table Fields

Name	Units	Type	Source	Description
Cnty		text(5)	map-matching	The county in which the current record lies. If the record occurred outside of the ETAK database coverage area then the field is blank.
ETAKClass		text(1)	map-matching & smoothing	Value determined from the ETAK database after map-matching and smoothing indicating the road class of the current road segment. 1 = Interstate highway, 2 = Semi-Limited access roads, 3 = Arterials, 4= Collector, 5 = Light Duty, 6 = Alley or Unpaved, 8 = Unknown type, 9 = Low Speed ramp and 0 = High-speed ramp. For further description see description in this appendix.
GPSTime	days	double	GPS	Days since Dec 30 1899 + fraction of day
Mapinfo_ID		long integer	map - matching	Used to plot map-matched points, may be ignored in analysis
Name		text(50)	map - matching & smoothing	Road name as determined after map matching and smoothing. May be some error due to signal drift and buffer size, particularly with ramp-freeway interchanges and
Taken	logical	long integer	map - matching	True if the point was classified successfully.
Urban		long integer	map - matching	A measure of the level of development. O = not within a political boundary, 1= urban area, population < 5,000, 2= urban area, 5,000 < pop < 50,000, 3 = urban area, 50,000 < pop. Note: For areas outside of the coverage area this field will be blank.
Latitude	deg	single	GPS	Latitude, + for North
Longitude	deg	single	GPS	Longitude, + for East
Altitude	ft	single	GPS	Altitude
Grade		single		UpVelocity/sqrt(NorthVelocity**2+East Velocity**2)
Heading	deg	single		Calculated from Lat and Long
OldName		text(50)	map - matching	Name of road segment before smoothing process. May be eliminated
OldClass		integer	map - matching	Road class before smoothing, may be eliminated.

Table F-5 Table/File Format

Name	Type	Units	Description
Time	double	days	Days since Dec 30 1899 + Fraction of a day
ChannelID	long integer		Unique event type descriptor 200's - ICC operation 300's - Video episodes 400's - Road class 500's - Level of development
Duration	single	g's for video events, sec's for all others	Magnitude of video event for 300's, duration in seconds for all 200,400 and 500's

Appendix G

Development of a Congestion Model

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G-1 Introduction

It is hypothesized that the performance of the ICC system may be influenced by the level of congestion in which the equipped vehicle is being driven. However, in order to test such a hypothesis, there must exist a capability to characterize the nature of the surrounding traffic congestion, based on the data available to the evaluation team. The ability to quantify the level of congestion, from the continuous data stream and video exposure clips provided by the vehicle, is an intriguing problem. Firstly, there is considerable debate as to how traffic congestion should be quantified (speed, volume, density, or other measures), and secondly, the data stream provided by the ICC vehicle is pertinent only to that vehicle and not necessarily to that of the surrounding traffic.

The most simplistic approach to identifying level of congestion would be on a time-of-day basis, as typically recurring congestion is most prevalent during the AM peak (i.e. 6 to 9 am) and PM peak (i.e. 3 to 6 pm) periods. However, the evaluators would still be responsible for estimating the magnitude and location of the congestion, and would have to accept the assumption that there is little variation within the congestion pattern from day-to-day. An alternative approach to estimating congesting would have the evaluators relying on the actual ICC vehicle data stream. The analyst could classify each video exposure clip (2 minute intervals) in terms of level of congestion, but would be expected to complete this arduous type of classification process for every FOT participant trip. Although this approach would be time consuming and tedious, near truth conditions could be expected, but only for those intervals in which the exposure clip was acquired. Ideally, a tool should be pursued in which the congestion level can be inferred automatically, on a continuous basis, based on the ICC data stream. The exposure clip approach may then be considered as a check for consistency if so desired.

Prior to developing an analytical technique for identifying traffic congestion level, there must first be a solid understanding of the fundamentals of traffic flow and driver behavior, and how traffic congestion may be quantified. These issues are addressed in Section 2. Section 3 describes the model development in terms of the data collection and analysis activities undertaken by the evaluation team, and the steps taken to derive a congestion model. Section 4 details the validation of the congestion model, while Section 5 provides a summary.

G-2 Background

The following section provides a background into the fundamentals of traffic flow theory, the industry standard for quantifying traffic congestion, and alternative methodologies for measuring the required traffic variables.

G-2.1 Fundamentals of Traffic Flow Theory

Figure G-1 illustrates the direct correspondence between the more familiar macroscopic steady state speed-flow and speed-density relationships, and the less familiar car-following relationship that is plotted in terms of speed-headway. It should be noted that density is equal to flow divided by speed, and distance headway is equal to the inverse of density. This correspondence is illustrated for three different traffic conditions, which are identified as points *a*, *b*, and *c*.

It can be noted from the speed-flow relationship that point *a* represents uncongested conditions, point *b* represents capacity flow, and that point *c* represents congested conditions. However, point *a* and point *c* can be noted as occurring at the same flow rate. The attributes of points *a*, *b*, and *c* are more difficult to discern from the speed-density and speed-headway relationships, which simply represent mathematical transformations of the same relationship. However, in this case speeds *a* and *c* have unique densities and headways associated with them. Qualitatively, it can be noted from the speed-headway relationship that vehicles will only attain their desired free-speeds when the headway in front of them is very large. Additional details regarding classical speed-flow-density relationships can be found in the literature (May, 1990 and Van Aerde/Rakha, 1996).

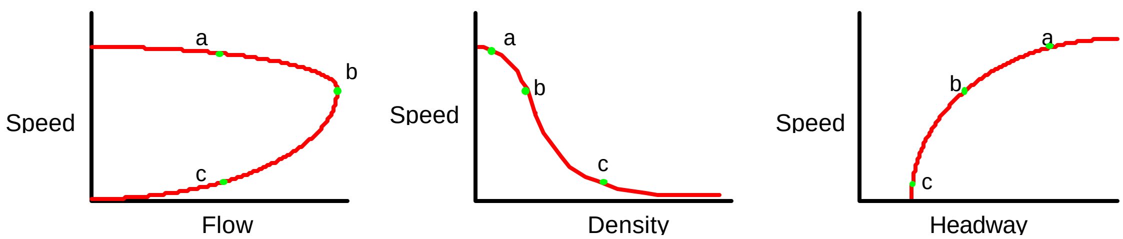


Figure G-1 Fundamental Steady State Traffic Flow Relationships

G-2.2 Quantifying Traffic Congestion

There is considerable debate as to how traffic congestion should be quantified. Currently, the Highway Capacity Manual (HCM) provides an approach based on density, for freeway and multi-lane highways, that is considered the industry standard. A speed based approach is recommended by the HCM for analyzing arterial sections.

G-2.2.1 Basic Freeway Sections

According to the HCM, modern freeway operating characteristics are such that speed is relatively constant over a wide range of flow rates and thus, speed is not an adequate measure of performance for level of service (LOS) determination. The freedom to maneuver within the traffic stream and the proximity to other vehicles, which are qualities relating to density, provide a more effective measure of service level. For a basic freeway section, the HCM considers six service levels, ranging from LOS A through LOS F. The maximum densities for the first four regimes (LOS A-D) are based on the collective professional judgment of the members of the appointed committee, and represent flow conditions during which speeds reduce only slightly. The maximum density values offered for LOS E represent the density at which capacity occurs for a specified free-flow speed and freeway width. Operations at this level are quite volatile since they are virtually no gaps in the traffic stream. A density at LOS F cannot be provided because of the variability in density during breakdown or congested traffic flow. Table G-1 provides a sample level of service criteria for a basic freeway section having a free-speed of 113 km/h (70 mph).

Table G-1 LOS Criteria for a Basic Freeway Section (free-speed 113 km/h)

LOS	Density (veh/km)	Speed (km/h)	Volume (veh/h)
A	6	113	700
B	10	113	1120
C	15	110	1644
D	20	101	2015
E	25	93	2300
F	var	var	var

G-2.2.2 Multilane Rural and Suburban Highways

A similar density based approach to LOS is defined by the HCM for multilane rural and suburban highways. Such highways generally have posted speed limits of between 65 km/h and 90 km/h, and have four to six lanes. Traffic signals may be found along these facilities, but at a sufficiently low density to avoid urban arterial conditions. Table G-2 provides a sample level of service criteria for a multilane highway section having a free-speed of 80 km/h (50 mph).

Table G-2 LOS Criteria for a Multilane Highway Section (free-speed 80 km/h)

LOS	Density (veh/km)	Speed (km/h)	Volume (veh/h)
A	7	80	600
B	12	80	1000
C	17	80	1400
D	21	78	1670
E	26	75	2000
F	var	var	var

G-2.2.3 Urban and Suburban Arterials

The HCM recommends a different approach to determine of level of service on urban arterials. Arterial LOS is based on average through-vehicle travel speed of all through vehicles on the arterial and as such, is strongly influenced by signal density and average intersection delay.

Table G-3 LOS Speed Criteria for an Urban Arterial Section (km/h)

LOS	Class I (free flow speed of 65 km/h)	Class II (free flow speed of 50 km/h)	Class III (free flow speed of 45 km/h)
A	>56	>48	>40
B	>45	>38	>30
C	>35	>29	>21
D	>27	>22	>14
E	>21	>16	>11
F	<21	<16	<11

G-2.3 Measuring Traffic Flow

Typically, induced loop detectors embedded in the road surface are utilized to estimate the speed, volume, and occupancy characteristics of the aggregate traffic stream. These aggregate measures, although suitable for quantifying traffic conditions during a defined time interval, are unable to trace the behavior of individual vehicles. This requirement of capturing individual vehicle behavior is essential in attempting to derive a predictive congestion model that is based on the independent variables provided by a series of single probe vehicles.

The data stream offered by the probe ICC vehicle is capable of providing one independent source of speed and headway measures for an individual vehicle, but other technologies do exist that track a stream of vehicles and thus are less dependent on individual driver behavior. Video imaging units, such as the Autoscope System™ employed by the evaluation team, are capable of producing individual vehicle estimates of various traffic flow measures. This process involves recording video footage of vehicles as they pass through an arbitrary section of roadway on which a series of virtual detectors have been defined. The Autoscope unit processes the behavior of each vehicle based on video imaging technology, and provides the user with a series of statistics, including individual vehicle headway.

However, there are fundamental differences between each of these sources in terms of their representation of headway in a distance versus time context, as described in Figure G-2. Initially, in Part I, a baseline series of typical vehicle trajectories are presented in which the distance each vehicle travels generally increases as time perpetuates. The first source of time headway data, the ICC probe vehicle (Part II), reports the time headway for one unique vehicle as it physically traverses across each time interval, considered to be each deci-second in this instance. The second source, the Autoscope unit (Part III), conversely, provides estimates of time headways for a series of individual vehicles based on video images acquired from a fixed camera location. Finally, the robustness of the INTEGRATION simulation model (Van Aerde *et al.*, 1996) is conceptually demonstrated in Part IV. Although not representative of recorded field measurements, the calibrated model can provide estimates of time headway both over time and at a fixed location.

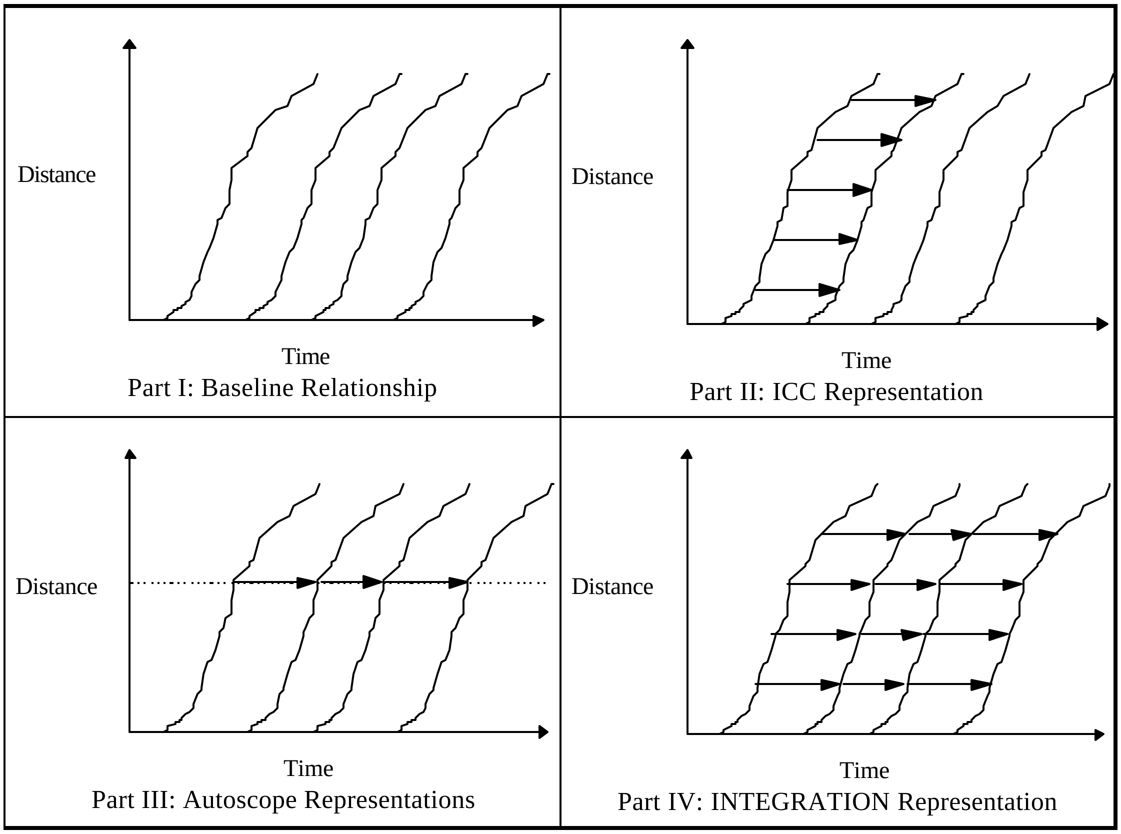


Figure G-2 Alternative Representations of the Time-Headway Relationship

G-3 Model Development

The following section provides a brief description of the data collection and analyses processes, and the statistical modeling activities in developing the congestion model.

G-3.1 Data Collection

Individual vehicle speed and headway data were considered critical in the development of the congestion model. The Autoscope System™ provided the evaluation team with this capability, and the flexibility to record data at a variety of appropriate locations. Video coverage of both freeway and urban arterial environments have been considered in this study. There was no opportunity to collect data on multilane rural or suburban highways.

G-3.1.1 Freeway Environment

Members of the evaluation team undertook an extensive effort to collect approximately 10 hours of video data at six different freeway sites in Southeastern Michigan. Each video collection site is described below in Table G-4. Of the six freeway sites considered, only three exhibited congestion during the peak period monitored. However, the site along I-75 northbound was considered the most promising in terms of the providing the data required for the development of the congestion model. All subsequent analyses and model development procedures for freeway environments were formulated based on this particular data set. A further discussion of the freeway data collection activities can be found in the document entitled *Pilot Test Data Collection and Characterization* (*Baker et al.*, 1997).

Table G-4 Video Collection Sites on Freeways

Camera Location	Hours	Congestion
I-94 WB	1.0	no
US-23 SB	2.5	no
I-696 WB	1.0	yes (snow)
I-75 NB	4.5	yes
I-696 EB	1.5	no
I-696 EB	1.0	yes

G-3.1.2 Arterial Environment

Preliminary video coverage of urban arterial traffic flow data was completed along a 2-lane section of roadway in Kingston, Ontario, as indicated in Table G-5. Project time and labor constraints did not permit extensive data collection activities for arterial facilities to be conducted in the Michigan area.

Table G-5 Video Collection Sites on Urban Arterials

Camera Location	Hours	Congestion
H-2 WB	5	yes

G-3.2 Data Analysis

The following section provides a description of the data analysis procedures considered in the development of candidate congestion models for both the freeway and arterial environment.

G-3.2.1 Freeway Environment

Figure G-3 represents sample speed and headway data, by lane, processed using the Autoscope System™ for a portion of I-75 near Madison Heights, Michigan. The corresponding speed and density data, for the median lane only, is shown in Figure G-4. These data clearly indicate the nature of the variability inherent in driver behavior, and subsequently, the need to consider the sensitivity of event data aggregation. This aggregation of data was completed by considering bins defined by specified vehicle counts, and alternatively, by considering bins defined by specified time intervals. Each approach is discussed next.

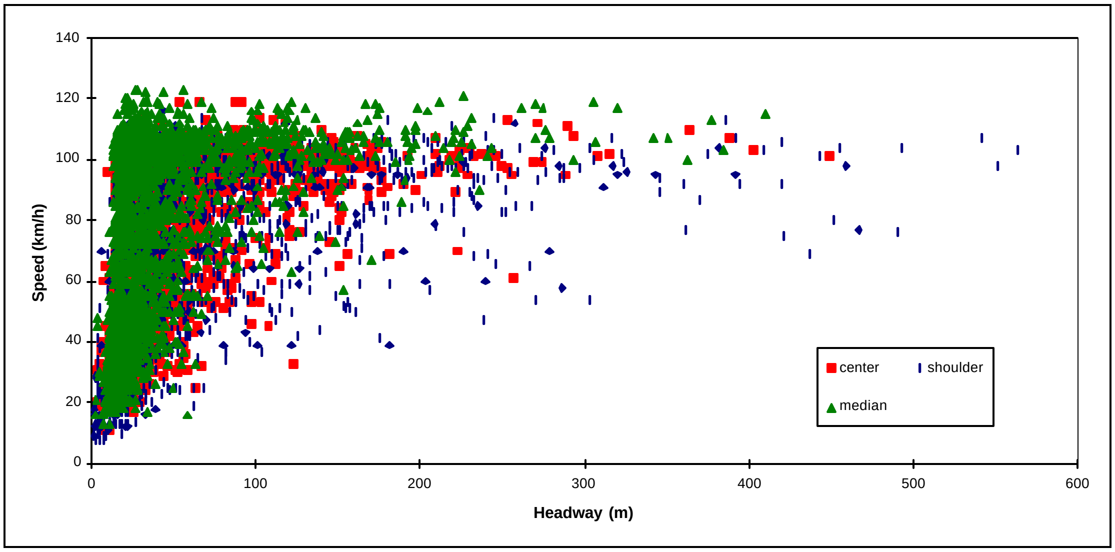


Figure G-3 Sample Speed-Headway Data Processed using Autoscope (I-75, Michigan)

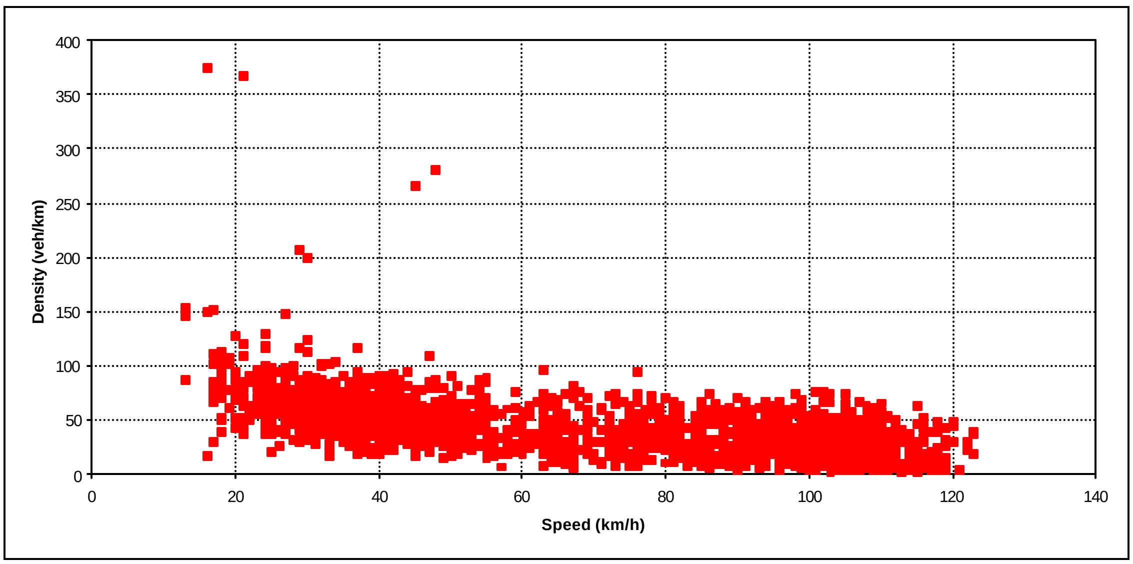


Figure G-4 Sample Event Speed - Event Density Data (median lane only I-75, Michigan)

G-3.2.1.1 Aggregation based on individual counts

An analysis was conducted in which both the estimated event speed and headway data was aggregated to represent a mean value about each individual observation/event. For each event within the data stream, the number of observations considered in establishing the mean value was varied from a single event to 21 events, with an equal number of observation taken before and after the individual event being considered. For example, for a clustering of 15 events, seven events would be considered before the individual observation, and seven events after the individual observation. This sliding window, of varying size, was applied to the stream of speed, headway, and derived density data, such that an appropriate number of observation for completing the aggregation process could be established. The appropriate number of observations was based on the stability of the computed route mean squared (RMS) error term.

The results of this process, for distance headway data, are presented in Figure G-5. As expected, the RMS headway for a mean value based on a single observation is zero, and as such, a mean based on a sample size of three observations (one event before, the event, one event after) represents a more appropriate point at which any trend analysis may begin. One may note that as the number of observations considered in determining the sample mean, the RMS headway value for the complete data set begins to stabilize. A similar trend was noted for the density (Figure G-6) and speed (not shown) data sets. It was decided to proceed with aggregating the event data into clusters of 11 events such that each data point represented the behavior of the five vehicles preceding vehicles and the five following vehicles. The impact of this aggregation process on density, for the median lane only, is illustrated in Figure G-7. Clearly, the aggregation process effectively transformed the inconsistent raw event density data into a form more compatible with the classical S-shaped portrayal of the macroscopic speed-density relationship (Figure G-1). However, note that densities less than 20 veh/km have been essentially eliminated as a result of this aggregation process. This lack of feasible density estimates suggests that an alternative aggregation process should be pursued.

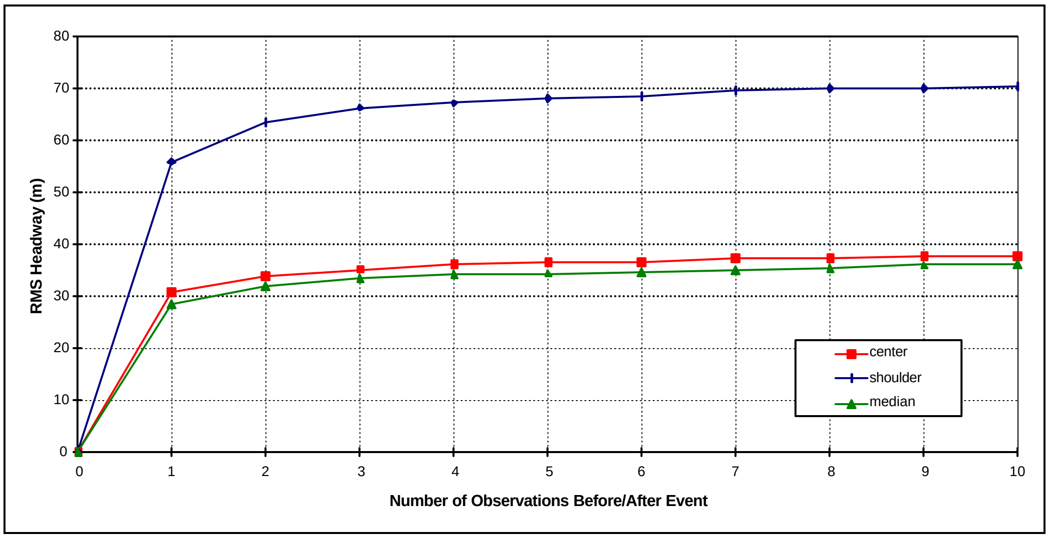


Figure G-5 Impact of Data Aggregation on RMS Headway (I-75, Michigan)

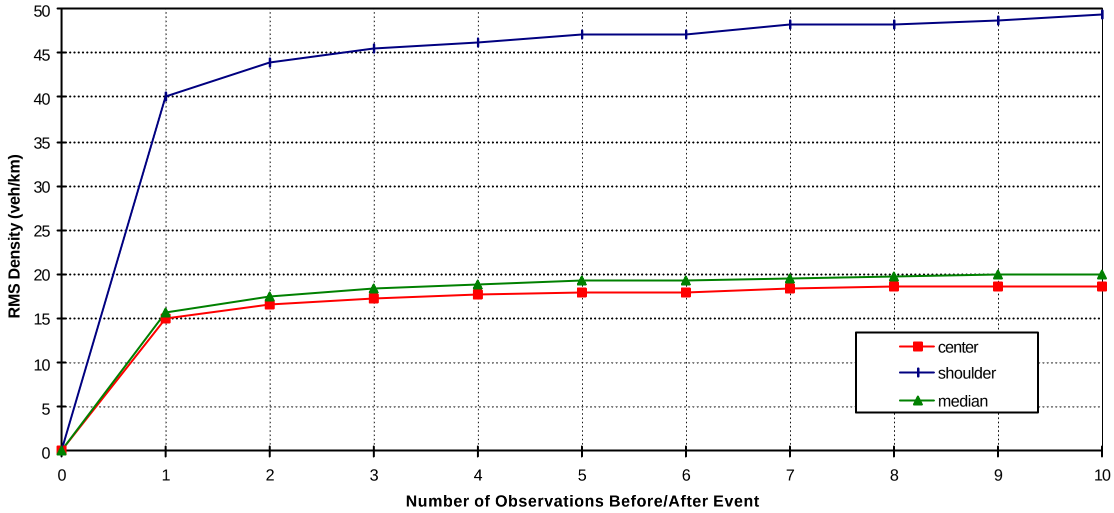


Figure G-6 Impact of Data Aggregation on RMS Density (I-75, Michigan)

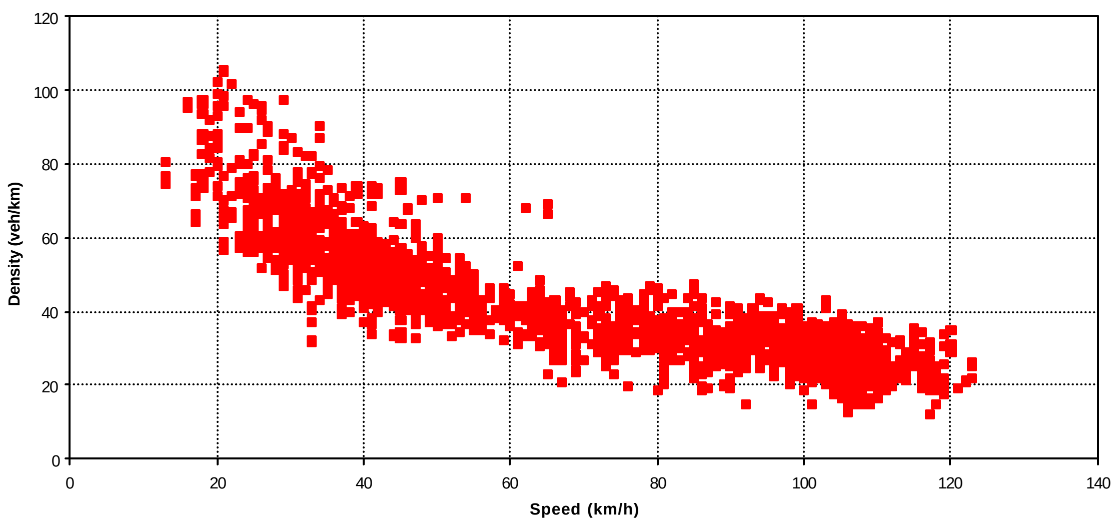


Figure G-7 Sample Event Speed - Aggregated Density Data (median lane only I-75, Michigan)

G-3.2.1.2 Aggregation based on time

A more traditional approach to traffic data aggregation involves defining time intervals during which the individual observations within the bin are averaged. Bin sizes may range from 20 seconds to 60 minutes, but typically the field data are aggregated at intervals of 1 minute or less. Figure G-8 and Figure G-9 show, for I-75 data, the impact of aggregation at 20 second and 1 minute intervals, respectively. One may note that the variability in the data decreased as the aggregation period increased, and that densities less than 20 veh/km are retained as a result of the aggregation process. These observations indicate that a reasonable aggregation procedure has been utilized.

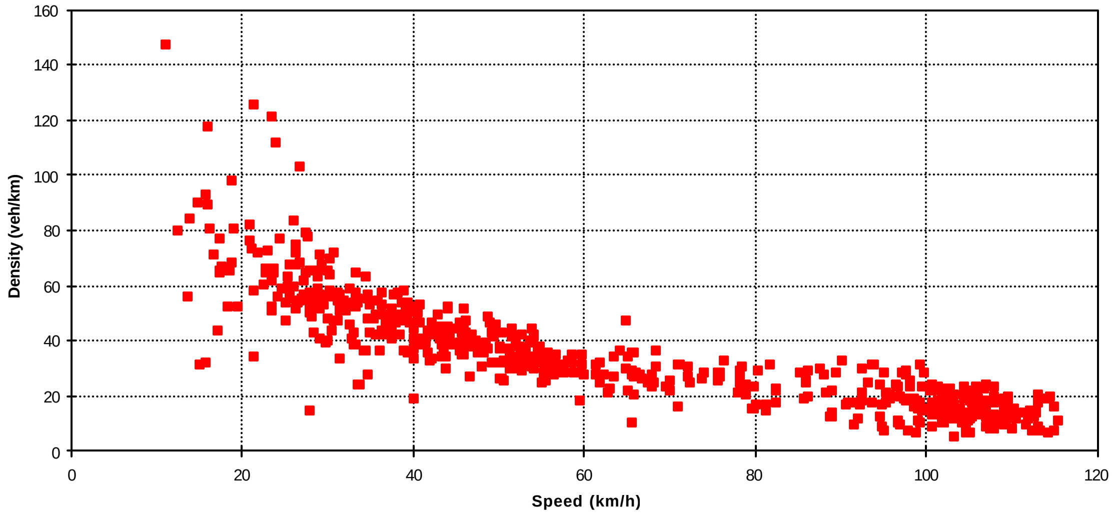


Figure G-8 Sample Aggregated Speed and Density Data (20 sec, median lane I-75, Michigan)

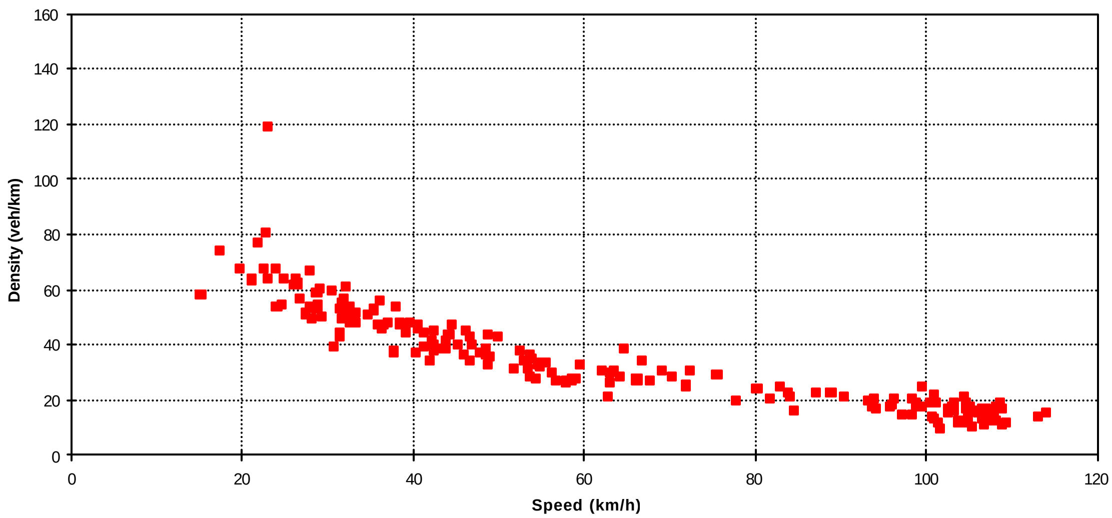


Figure G-9 Sample Aggregated Speed and Density Data (1 min, median lane I-75, Michigan)

G-3.2.2 Arterial Environment

In Section G-2.2, it was noted that the HCM recommends the use of average speed when determining LOS on urban arterial environments. However, the availability of headway data from the Autoscope System™ permitted an analysis approach similar to that described for the freeway environment. Figure G-10 represents sample speed and headway data processed for the Autoscope System™ for a Class I urban arterial located in Kingston, Ontario, while the corresponding speed and density data is shown in Figure G-11. Again, these data indicate the nature of the variability inherent in driver behavior, and subsequently, the need to consider the sensitivity of event data aggregation. For these urban arterial data, only time based aggregation was considered.

Figure G-12 and Figure G-13 illustrate the impact of speed and density data aggregation at 20 second and 1 minute intervals, respectively. Following the aggregation process, there are relatively few points to define the low speed (congested) portion of the speed density curve, but the presence of extremely high density observations noted in the event data have been eliminated.

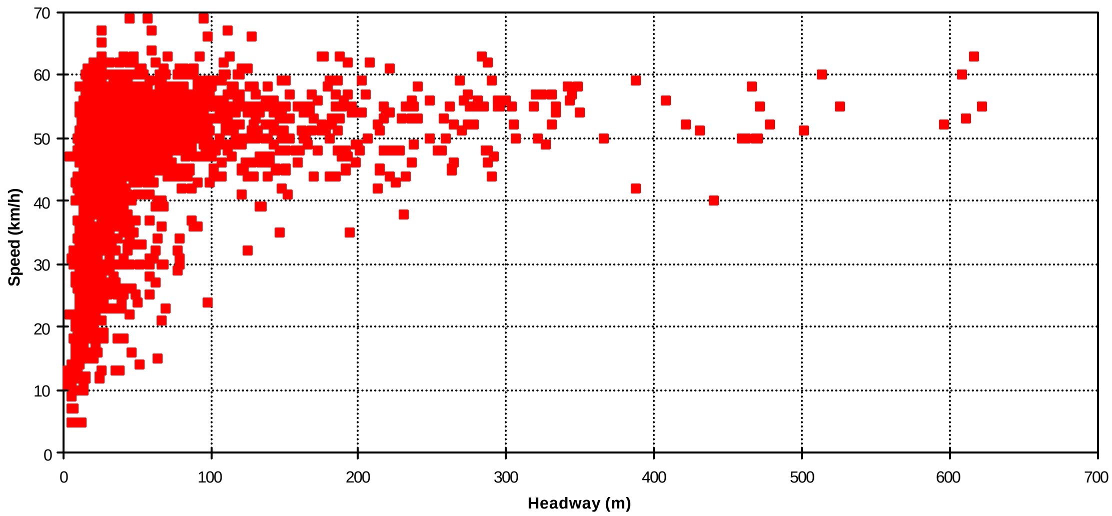


Figure G-10 Sample Event Speed - Event Headway Data (H2, Kingston, Ontario)

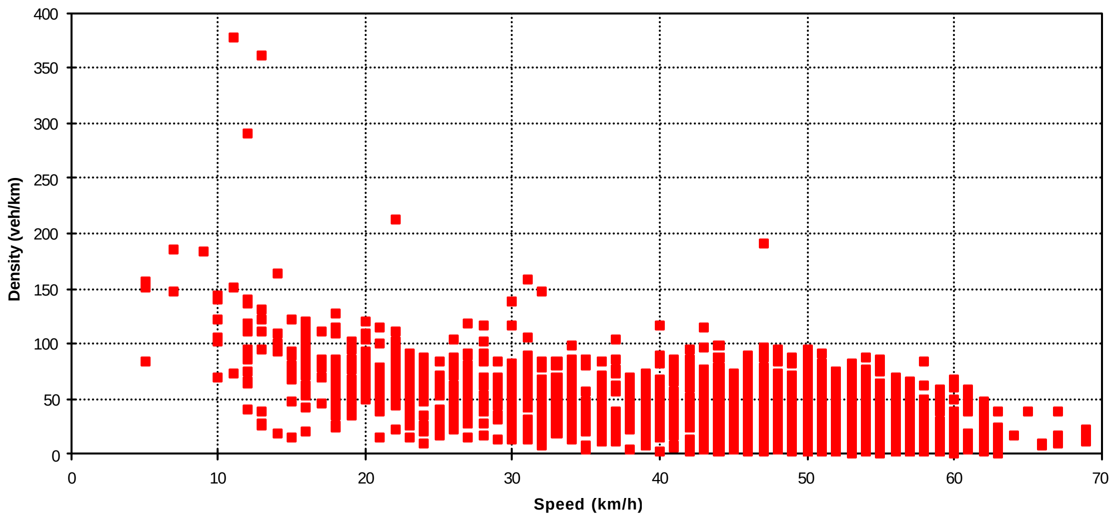


Figure G-11 Sample Event Speed - Event Density Data (H2, Kingston, Ontario)

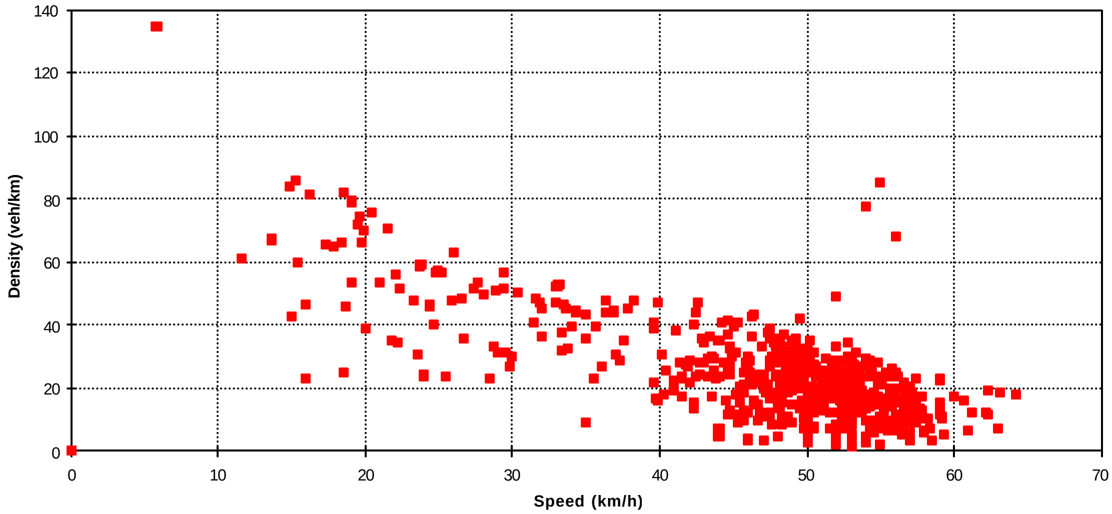


Figure G-12 Sample Aggregated Speed and Density Data (20 sec, H2, Kingston, Ontario)

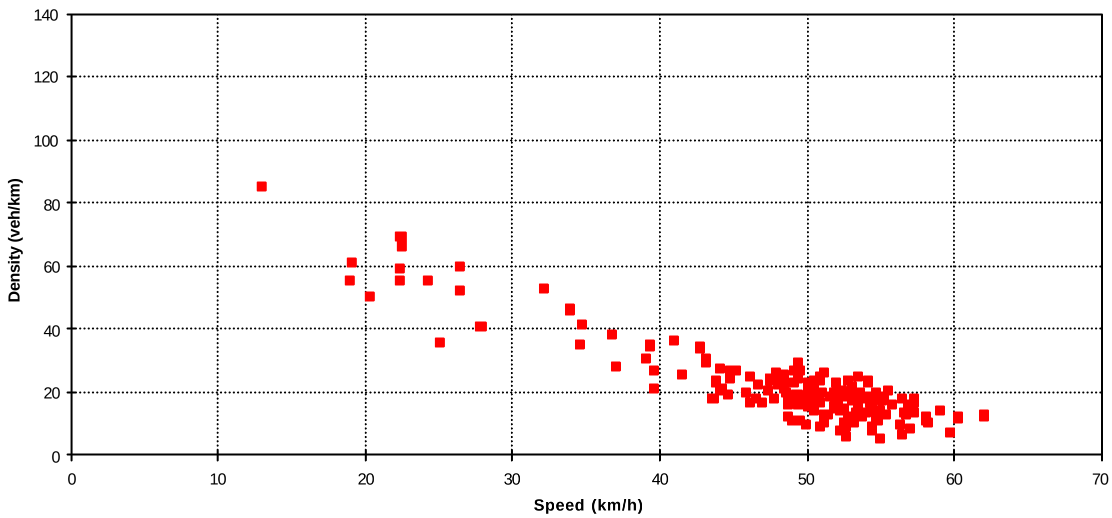


Figure G-13 Sample Aggregated Speed and Density Data (1 min, H2, Kingston, Ontario)

G-3.3 Statistical Modeling

The impact of data aggregation was found to eliminate much of the variability within the observed data. However, it was evident that the mechanism by which the data was aggregated, either on a count basis or a time basis, may have a significant impact on observations at the extremes of the relationship. Based on counts of vehicles, the aggregation process yielded points in a linear or quadratic shape that may be most conducive to modeling with some form of regression. Based on time increments, the aggregation process yielded points in an S-shape, more suited for a more sophisticated curve fitting technique. Each technique is discussed next.

G-3.3.1 Regression Approach

A series of regression analyses were considered in order to derive a functional congestion model based on freeway data. The independent variables considered were first and second order event speed and event headway, and mean density, as presented in Figure G-7, was adopted as the dependent variable. Density was selected as the dependent variable in order to be consistent with the LOS methodology utilized by the HCM for characterizing freeway congestion.. The objective of this exercise was to derive a statistical model that yielded an acceptable combination of: a high coefficient of determination, a low standard error, a large F-value, and a realistic constant term. The constant term may be interpreted as the jam density, which according to the literature (May,1990), should be in the range of 110-150 vehicles per lane km for a freeway facility. The results of this analyses are summarized in Table G-6. It should be noted that all models presented in Table G-6 contain statistically significant variables, according to the t-distribution, at the 95 percent confidence level.

Table G-6 Summary of Regression Results

Model	Independent Variables	Coefficient of Determination	Standard Error	F-Value	Constant Term
A	v	0.76	7.8	8542	73
B	h	0.19	14.3	618	48
C	v and h	0.76	7.7	4329	73
D	v, h, and vh	0.79	7.2	3412	83
E	v and v^2	0.81	6.9	5817	95
F	v, v^2, and h	0.82	6.8	4029	96
G	v, v^2, h, h^2, vh, vh^2, v^2h, and v^2h^2	0.83	6.5	1670	113

Model *A*, a first order speed model, yielded a surprisingly good coefficient of determination (0.76), but was rejected due to the rather low estimate of jam density (73 veh/km). Intuitively, one would expect event headway to be a reasonable indicator of density, but the statistics associated with Model *B* suggested otherwise. When both event speed and headway were combined as independent variables, the coefficient of determination was considered reasonable, but the jam density estimate was not acceptable. A purely quadratic model (Model *E*), incorporating first and second order speed terms as the independent variables, yielded promising statistical indicators and an acceptable estimate of jam density (95 veh/km). However, this quadratic relationship, as illustrated in Figure G-14, was incapable of producing a line passing through the x-axis (x-intercept is representative of the facility free speed). This deficiency warranted pursuing more sophisticated regression techniques.

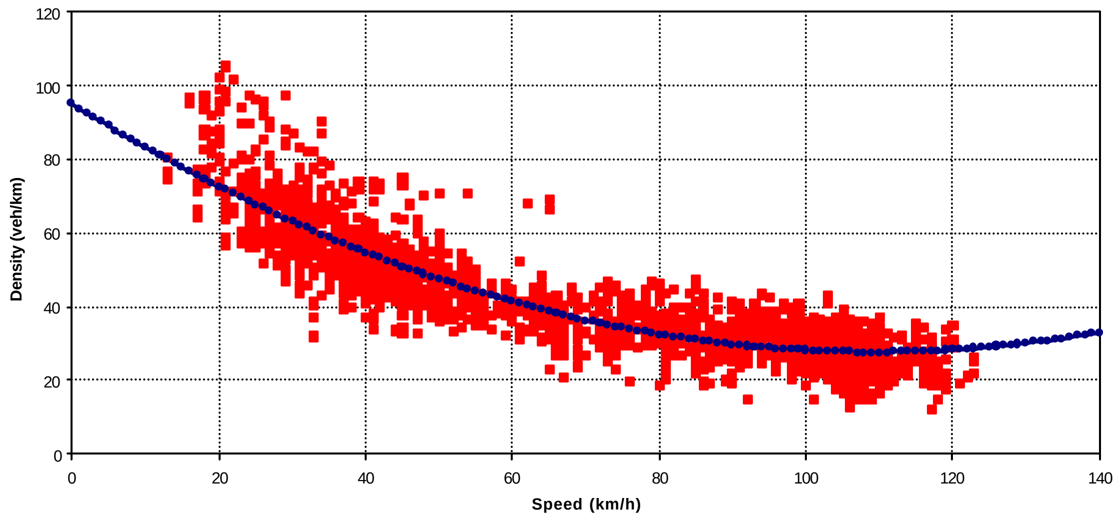


Figure G-14 Observed and Predicted Density (regression model E, I-75 Michigan)

The sequential process of adding additional independent variables was carried out, and eventually the most sophisticated model that included all first and second order speed and headway terms was developed (Model *G*). This particular model provided the greatest coefficient of determination of the models considered (0.83) and the most desirable estimate of jam density (113 veh/km).

At this stage, mention must be given to the appropriateness of incorporating headway as an independent variable, given that the control objective of the ICC system is to maintain a fixed time headway. The data being used within this analysis is based on vehicles being driven in the absence of any headway keeping devices. Furthermore, the regression techniques described above, despite being statistically valid, are generally unable to produce a curve that is consistent with the general S-shape of the classical speed-density relationship. For this reason, a more sophisticated technique was considered, as described next.

G-3.3.2 Multivariate Speed Density Relationships

A multivariate procedure, developed by Van Aerde (1995) for performing automated fitting of speed-flow relationships for different roads based on loop detector data, was employed. The procedure is capable of representing different types of roads and provides a fit that is reasonable for all data regimes, unlike many other single regime models that only fit free-flow or forced flow conditions data. This single-regime model provides a quality of fit that is consistent with most multi-regime models, without the need to deal with the complexities associated with the selection of regime break points. Figure G-15 illustrates the general shape of three potential speed-density curves for different road classes. The functional form of the model is presented as Equation 1. The curve fitting technique produces a series of constants (c_1 through c_3) and an estimate of free speed, forming an equation that predicts density as a function of vehicle speed.

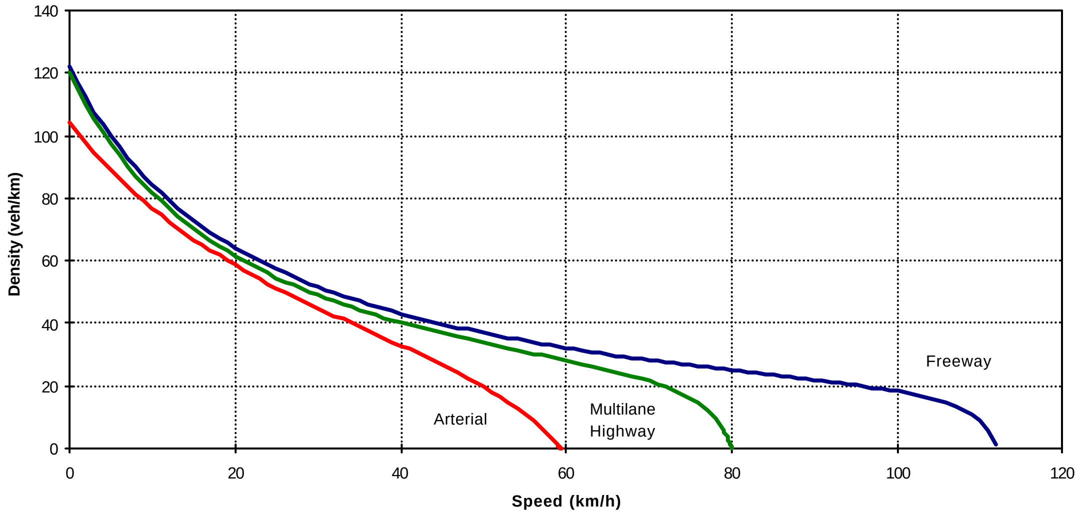


Figure G-15 Multivariate Speed Density Relationship for Three Facility Types

$$d = \frac{1}{c_1 + \frac{c_2}{s_f - s} + c_3 s} \qquad (1)$$

where:

d = density (veh/km) or the inverse of the vehicle distance headway (km/veh)
s = speed (km/h)
s_f = free speed (km/h)
c_1 = fixed distance headway constant (km/veh)
c_2 = first variable headway constant (km^2/veh-h)
c_3 = second variable distance headway constant (h/veh)

This curve fitting procedure was applied to both the observed 60 second I-75 freeway and H2 arterial data sets, as demonstrated in Figure G-16 and Figure G-17, respectively. It can be noted that the technique provided realistic estimates of jam density and free speed for specific road classes, and unlike the regression approach discussed previously, the complete range of densities ranging from 0 to the jam density can be represented. The estimated free speed for the freeway was 122 km/h, and the estimated free speed for the arterial was 57 km/h. It should be noted that the validation in the next section is based on these multivariate models.

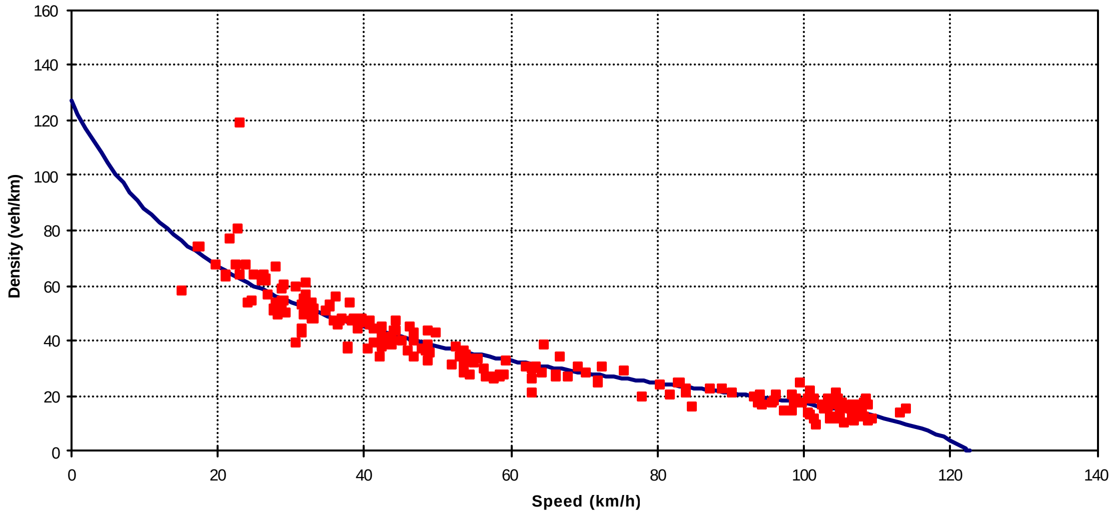


Figure G-16: Observed and Predicted Density (multivariate freeway model, I-75 Michigan)

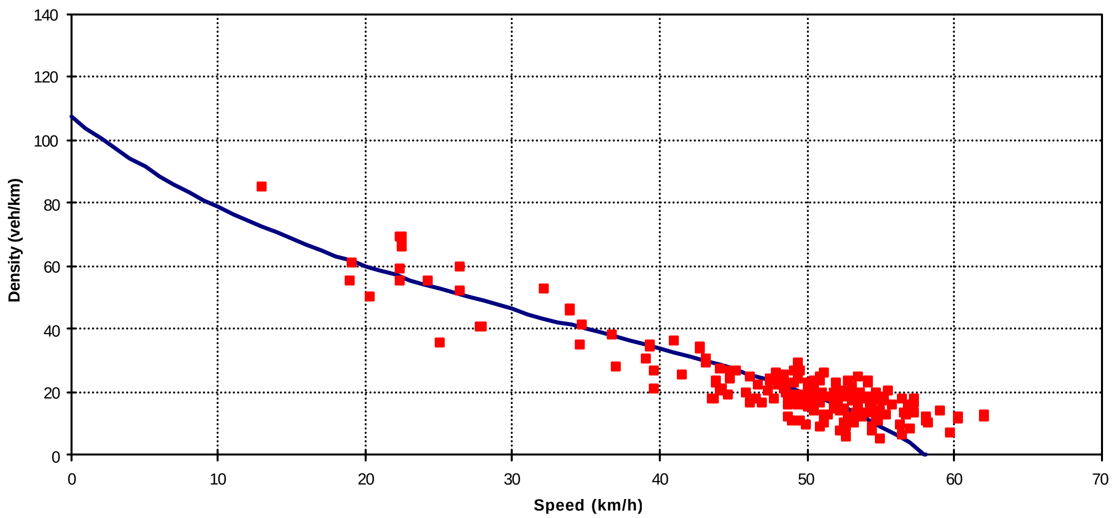


Figure G-17: Observed and Predicted Density (multivariate arterial model, H2 Kingston, Ontario)

G-4 Model Validation

The following section describes the procedures followed to validate the candidate congestion model, and the results of this validation process.

G-4.1 Validation Procedures

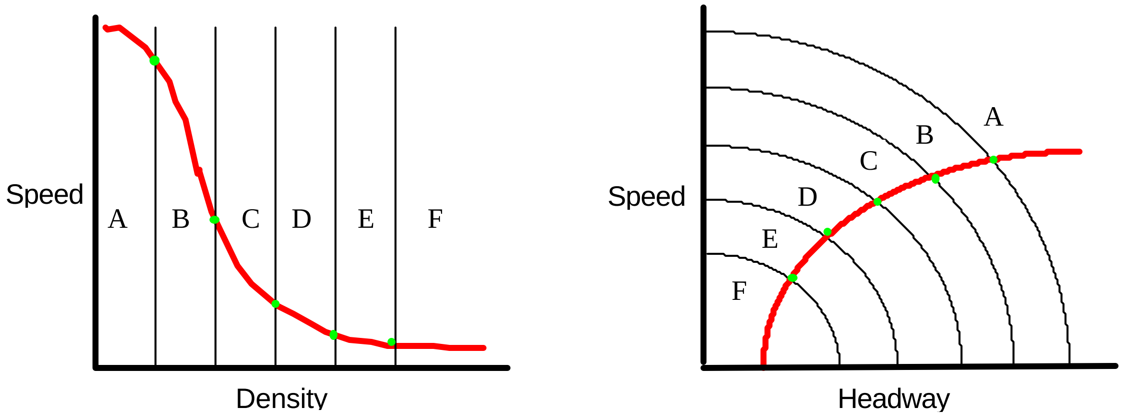
A preliminary validation of the candidate congestion model was completed in order to provide a sense for the overall applicability of the proposed approach. Given the preferred functional form of the multivariate speed-density model, congestion estimates based on this approach were compared to the observed conditions. Two sources of observed conditions were considered in the validation procedure: continuous video data collected during the pilot testing period; and video exposure clips gathered for a driver during a two week period of the field operational test.

However, prior to discussing the results of these validation procedures, the terminology utilized during the process will be defined. It should be noted that members of the video analysis team classified both the continuous video and the exposure clips. Table G-7 provides a comparison of the terminology used by the video analysts in classifying the observed congestion on freeways and the HCM. The analysts were instructed to classify each exposure in terms of none, light, moderate, heavy, or congested conditions. Details regarding this process, and a justification for the classification categories, can be found in the document entitled *Video Classification Training Manual* (Robinson *et al.*, 1997). Each of these qualitative terms has an associated LOS, as defined by the HCM, and numerical code which was incorporated for the convenience of determining accuracy rates. A similar convention, based on HCM density specifications for multilane highway sections (see Table G-2), was adopted for all arterial environments.

Table G-7 Congestion Classification Terminology for Freeways

LOS	Maximum Density on Freeway (veh/km)	Video Classification Category	Video Classification Numerical Code
		none	1
A	6	light	2
B	10	light	2
C	15	moderate	3
D	20	moderate	3
E	25	heavy	4
F	n/a	congested	5

During a preliminary review of the validation results, and through casual observation during the video collection exercises, the impact of various driving behavior was noted. In one extreme, a certain sample of drivers would elect to travel in platoons even during practically free flowing conditions. In the other extreme, during heavier periods of traffic flow, another group of drivers would elect to drive at very long headways whenever possible. This behavior, which is not necessarily consistent with the LOS density characteristics utilized by the congestion model (see Part I of Figure G-18), should be recognized as a violation of the assumed car-following relationship. In an effort to identify such violations, the headway recorded by the ICC system was compared to the headway derived from the density estimated by the congestion model. This derived density estimate, recall, is based on current vehicle speed as recorded by the ICC system. If the distance headway was relatively short, then the LOS estimate based on the speed estimate was considered critical. Conversely, if the distance headway was relatively long, then the LOS estimate was based on the observed headway. This classification scheme can be illustrated in Part II of Figure G-18.



Part I *Part II*

Figure G-18 Typical and Modified LOS Bins for Speed-Density-Headway Relationships

G-4.2 Validation Results

It is important to note that in determining observed conditions, which may be interpreted as near truth conditions, the video classification process outlined above has an inherent amount of error. Given that density, and subsequently LOS, are quite subjective measures by nature, the ability to precisely define the truth was found to be difficult. An analysis of any potential video classification bias will be discussed later.

The continuous video collected during the pilot testing period did not provide a suitable sample of all congestion regimes, with the vast majority of coverage suggesting only moderate levels of freeway congestion. However, the video analyst did classify 15 1-minute segments of video, which when compared to the congestion estimates predicted by the model, yielded a 98 percent accuracy rate. This statistic indicates that the candidate model is quite capable of predicting observed LOS during non-congested freeway conditions.

Conversely, the video exposure clips for FOT Driver 14 provided a more diverse range of observed congestion over a variety of facility types. In total, 64 exposure clips, taken at 10 minute intervals, were classified. It should be noted that a filter was applied to the observed data to eliminate all non steady state data, namely those instances when acceleration/deceleration exceeded 0.04g. This filter, which effectively eliminated all data points on the arterial when the vehicle approached a traffic signal, yielded a total of 44 freeway observations. Table G-8 provides the success rate, by comparing the video classification estimate to the model's estimate, in terms of both an absolute match and a match to the adjacent bin. Based on the 44 freeway observations, the analyst and model were in exact agreement 34 percent of the time, but when the match criteria was expanded to include the adjacent classification bin, the success rate increased to 86 percent. These results warranted a more detailed analysis of the current freeway model.

Table G-8 Congestion Model Success Rate by Facility Type (driver 14)

Facility	n	Success Rate Absolute (%)	Success Rate Adjacent (%)
freeway	44	34	86
multilane highway	0	n/a	n/a
arterial	0	n/a	n/a

Table G-9 provides a breakdown of the analyst and model predictions for the 44 freeway observations. The levels of congestion observed were light, moderate, heavy and congested. The none category of congestion was not evident in this particular data set. For conditions classified by the analyst as light, the model classified a portion as light (33%), a portion as moderate (47%), a portion as either heavy or congested (20%). For conditions classified by the analyst as moderate, the two estimates were in exact agreement less than half (39%). The other observations were predicted as either light (44%) or congested (17%). For conditions classified by the analyst as heavy, the model was never in perfect agreement, but instead classified them as congested (100%). Finally, for those clips classified as congested by the analyst, an exact match was estimated for all observations.

Table G-9 Freeway Congestion Model Success Rate by Congestion Level (driver 14)

Video Analyst Predicted	n	Model Predicted			
		light	moderate	heavy	congested
light	15	5	7	2	1
moderate	18	8	7	0	3
heavy	8	0	0	0	8
congested	3	0	0	0	3

A similar analysis was conducted for FOT Driver 50. This driver exhibited a range of both freeway and arterial driving, as suggested by the number of observations listed in Table G-10. A total of 24 observations were noted to occur on the freeway, of which 11 estimates were in exact agreement with the analyst (46%), and 20 estimates were within the adjacent bin of the analyst (83%). No observations were noted on multilane highway facilities, but of the 17 observations recorded on arterials, an exact match by the model was noted to occur 13 times (77%), and 16 matches (94%) were made when the match criteria was expanded to the adjacent bin.

Table G-10 Congestion Model Success Rate by Facility Type (driver 50)

Facility	n	Success Rate Absolute (%)	Success Rate Adjacent (%)
freeway	24	46	83
multilane highway	0	0	0
arterial	17	77	94

A more detailed analysis of FOT Driver 50, as provided in Table G-11 (freeway) and Table G-12 (arterial), indicates the potential source of any analyst/model discrepancies. On the freeway environment, the model performed quite reliably in the light and moderate regimes of congestion, but did predict both heavy and congested conditions when an analyst predicted light conditions. The model performed very well on arterials for conditions predicted as light.

Table G-11 Freeway Congestion Model Success Rate by Congestion Level (driver 50)

Video Analyst Predicted	n	Model Predicted			
		light	moderate	heavy	congested
light	20	8	8	3	1
moderate	4	1	3	0	0
heavy	0	0	0	0	0
congested	0	0	0	0	0

Table G-12 Arterial Congestion Model Success Rate by Congestion Level (driver 50)

Video Analyst Predicted	n	Model Predicted			
		light	moderate	heavy	congested
light	14	13	0	0	1
moderate	3	3	0	0	0
heavy	0	0	0	0	0
congested	0	0	0	0	0

G-4.3 Validation Error Sources

As noted earlier, the ability to accurately capture absolute truth conditions in the field is very difficult, and as such, the validation results may not necessarily reflect the quality of the candidate congestion model. The process by which the video analyst determined actual field conditions is highly qualitative, and therefore susceptible to misrepresentation. The analyst may have difficulty in determining the road class, or more likely, have difficulty in properly classifying the level of congestion. Figure G-19 illustrates a systematic biased that the video analyst apparently developed in predicting LOS. One may note, based on actual observed speeds, that the analyst consistently predicted a higher LOS than is considered practical by the HCM for that regime.

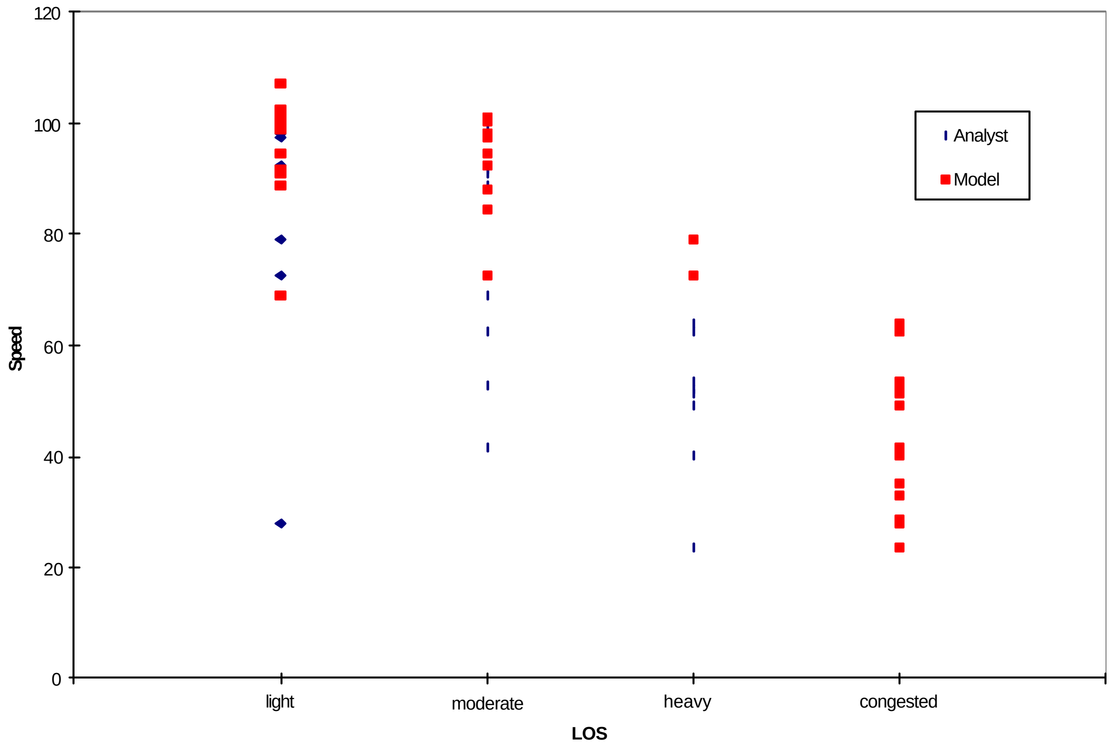


Figure G-19 Comparison of Video Analyst and Congestion Model Estimates of Congestion

G-5 Summary

The analyses conducted above would seem to indicate that the headway a particular driver chooses may not necessarily be representative of the general traffic stream. This finding, which is consistent with the literature, was confirmed by aggregating event headway data derived using an Autoscope System^{TM} video imaging unit. These data indicated that vehicle headway was quite variable during all regimes, but especially during uncongested conditions when drivers have more control over the speed and headway settings they select. During more congested conditions, a particular driver has minimal control over the speed their vehicle travels within the traffic stream, but can, to a greater extent, control the distance they travel behind the preceding vehicle. This driver behavior aspect has a significant impact on a derived estimate of density that is based on measures observed by a single probe vehicle.

The congestion model was derived based on sample data collected on both freeway and arterial environments, but the nature of the multivariate speed-density relationship will permit the extension of the candidate model to other types of facilities. In general, the model would appear to have the ability to discern between periods of near free flow conditions, moderate congestion and heavier congestion periods.

G-6 References

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Baker, M., Carter, M., Goodspeed, C., and Robinson, M.(1997), *ICC Field Operational Test: Pilot Test Data Collection and Characterization*, Technical report submitted to the VOLPE Center, Cambridge, Mass.

Robinson, M., and Goodspeed, C.,(1997), *ICC Field Operational Test: Video Classification Training Manual*, Technical report submitted to the VOLPE Center, Cambridge, Mass.

Appendix H

Video/Digital Data Integration Tool

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H-1 Introduction

A major source of data collected in the Intelligent Cruise Control (ICC) Field Operational Test (FOT) was the video data recorded using the on-board camera. The video data recorded was stored as video clips. There were two types of video clip recorded - Exposures and Episodes. An exposure video clip has a duration of 2 seconds and is recorded once every 5 minutes that the vehicle is on for the two-week drivers, and every 10 minutes for the five-week drivers. An episode video clip has a duration of 30 seconds and is recorded not on a regular basis, but whenever one of the video trigger thresholds is exceeded. Brake interventions, near encounters and a press of the concern button all have the potential of triggering the recording of an episode video. For brake interventions and near encounters, the video is recorded for 15 seconds before and 15 seconds after the event which triggered the video to be recorded. A concern button press is recorded somewhat differently in that the computer records the 30 seconds of video captured before the button is pressed.

In determining the ways in which the data available from the FOT would be analyzed, the evaluation team specified several different measures that were only available or were most easily measured through analysis of the video clips. The evaluation team realized that there would need to be some formal procedure for completing this analysis which would result in consistent and accurate recording of the measures of interest. It was this identified need which spawned the development of the video/digital data integration tool.

This appendix describes the purpose and development of the video/digital data integration tool, provides an overview of pre and post classification data control, and describes how the classification information was used in the safety analysis of the ICC system. Appendix I *Video Classification Training Manual* provides instruction on the use of the tool.

H-2 Purpose of the Video /Digital Data Integration Tool

The purpose of the Video/Digital Data Integration Tool was to allow a human to classify visual data in an efficient, consistent and accurate manner. A similar procedure can be followed using a paper and pencil as recording instruments and a movie viewer to view the clip. However, the evaluation team felt that classifying the video clips using the paper and pencil method would make the task very tedious, and potentially increase the risk of inaccuracy. The evaluation team felt that the use of a computer interface tool would decrease the effort involved in recording/using the classification data as it would allow automatic recording of classifications without having to write things down, and would record the classification data in a format which does not require future manual input in order to use the classifications. In addition, the use of a computer interface would allow the analyst to view certain variables in real time to aid in deciding between particular classifications.

H-3 Development of the Computer Interfaces

Development of the computer interfaces began with determining the exact functions they needed to perform. In order to determine these functions, two members of the evaluation team reviewed the study plan for the individual benefits evaluation to determine exactly what information needed to be recorded. They then used a movie viewer to run through a set of video clips, and classified those video clips using a pencil and paper to record the required information. The evaluation team members found the paper and pencil method to be extremely tedious, and very prone to error due to the fact that it is much easier to not write down information on marginal events that it is to record it. This procedure did, however, provide many insights on what functions the interfaces would need to provide, what information they would need to provide, and what information they would need to record.

During the initial paper and pencil exercise, the evaluation team decided to create separate interfaces for analyzing exposure clips and episode clips to reduce confusion and to help the video analyst concentrate on the specific measures needed from each type of video clip. Specifically, the exposure video classification interface would need to be designed to allow the classification of road class and level of congestion. The episode video classification interface would need to be designed to allow the classification of driving states, close calls (frequency and severity), inattentive events, driving scenarios and the measurement of response times. Both interfaces would need to allow the analyst to identify whether or not the video clip was a weather event (rain, road spray, snow).

The question of what information, or data, the interfaces would need to provide was complex. On a basic level, it was decided that the episode interface would need to provide information on what triggered the video to be recorded, the magnitude of the triggering event, and a timeline or time display to track the time into a video clip. The evaluation team also determined that it would be very helpful to have several of the variables collected by the ICC vehicle displayed on the interface to help differentiate between different driving situations and to help accurately measure response times. Initially, the team members felt that the most useful variables would be V - the speed of the ICC vehicle, Vp - the speed of the preceding vehicle, tracking - a logical variable which is 1 when a vehicle is being tracking, brake - a logical variable which is 1 when the brake is being applied, and CDOT - a variable which basically tells you if the steering wheel is being moved. The evaluation team members also felt that the most useful way to represent these variables in the interface was to have them plotted on screen, time synchronized with the video clip. With respect to the exposure interface, the evaluation team members did not feel that it was necessary to provide any additional information on the driving situation to the analyst other than the actual exposure video clip.

With the above lessons learned and decisions made, the next step in development of the interfaces was to create hand-drawn paper mock-ups of the interfaces (see Figures H-1 and H-2). The purpose of these paper mock-ups was to provide the team programmer with a better understanding of what the video analysis team wanted the interfaces to do, and the basics of how they should look. These paper mock-ups were forwarded to the team programmer, who began programming the actual interfaces.

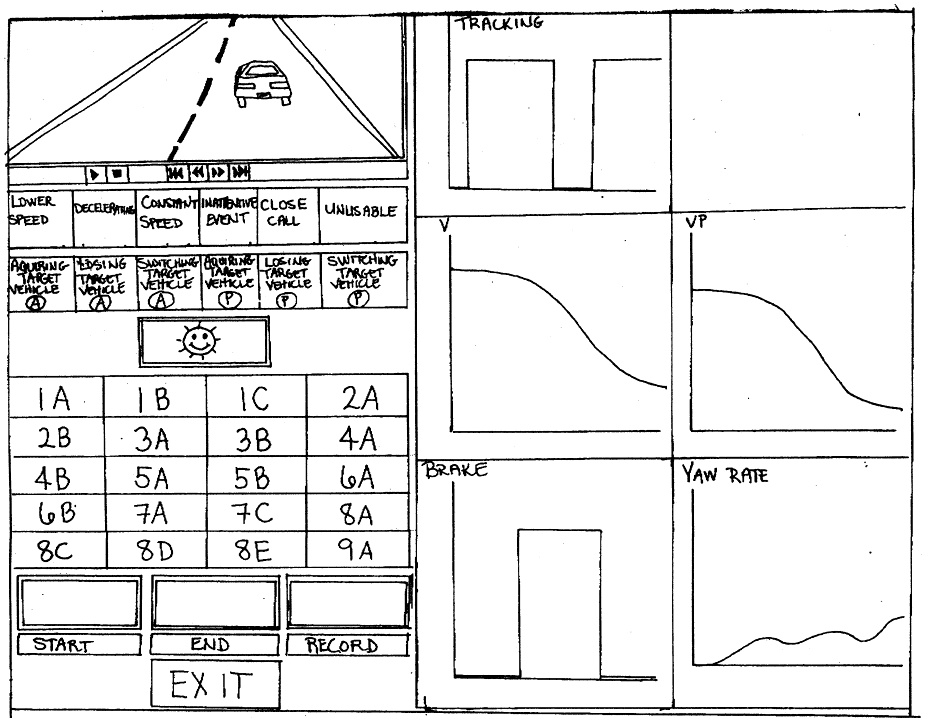

Figure H-1 Paper Mock-Up of Episode Video Classification Screen

While the initial computer driven interfaces that the evaluation team received from the team programmer looked quite a bit different than the original hand-drawn paper mock-ups, their functionality was as requested. Figure H-3 displays a sample screen of the initial episode video interface, while Figure H-4 displays a sample screen of the initial exposure interface.

The episode classification interface has 3 levels, of which only one can be open at any time. The current level is controlled by selecting one of the three folders labeled as “Scenarios”, “Key Scenarios” and “Reaction Time”. In Figure H-3 the “Scenarios” level is shown as being open. It can be noted in Figure 3 that all of the information that the evaluation team identified as being required is present. The information on what triggered the video appears in the channel information box at the top of the interface and the magnitude of the event appears in the video box as “importance” in the initial information. The elapsed time into the video appears just under the video box, and in Figure H-3 reads 00:00 as the video has not been started. The five requested variables have been plotted in the right two thirds of the screen. As the video plays, a thin black line moves across each of the plots to inform the analyst of the values of the variables at the point in time shown in the video.

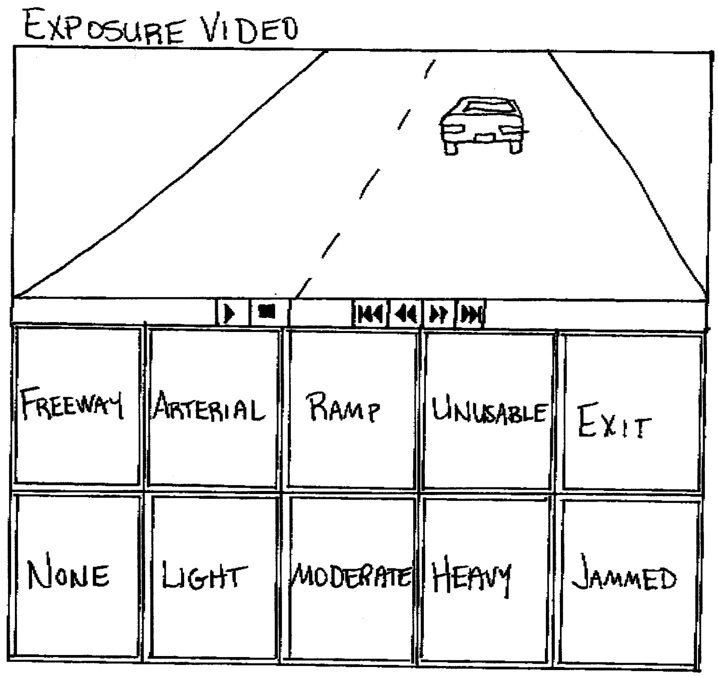

Figure H-2 Paper Mock-Up of Episode Video Classification Screen

The episode video classification interface is capable of recording all of the required classification information that was identified in the initial paper and pencil procedure. In the “Scenario” folder, driving states, close calls and inattentive events are recorded. The scenarios are recorded using the buttons in the “Key Scenarios” folder, and response times are measured using the tools available in the “Reaction Time” folder. The video clip is controlled using the playback speed control and the control buttons under the video box. Classification information can be viewed by selecting the appropriate “View ...” button from the bottom left of the screen.

As can be seen in Figure H-4, the exposure video classification interface is much simpler than the episode interface. The video is controlled using the “Play”, “Pause”, and “Rewind” buttons. Road class is chosen from the top 4 classification buttons and level of congestion is chosen from the bottom five classification buttons.

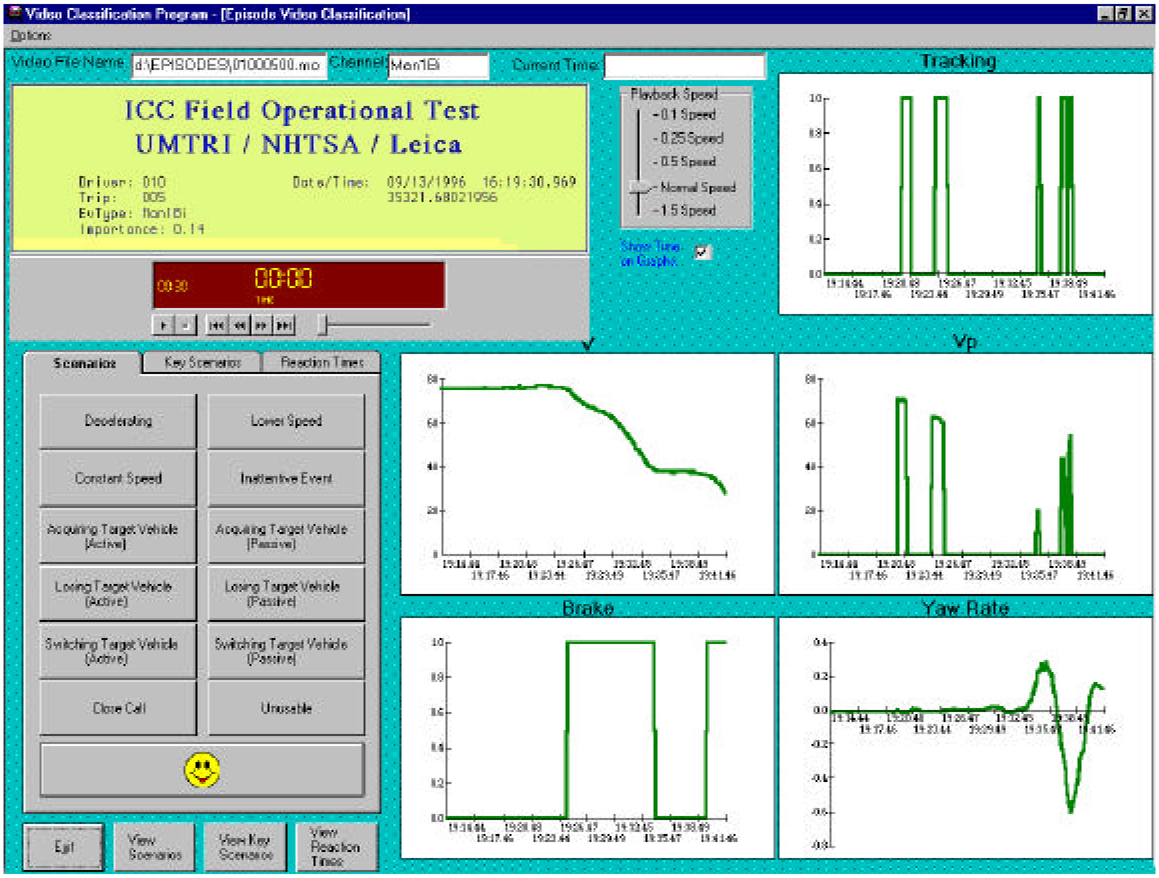

Figure H-3 Initial Episode Video Classification Screen

Functionally, these initial interfaces worked very well. There were some minor problems with recording certain classification information as well as some non-functional errors such as spelling errors (as can be noted in Figure H-4).

As the project evolved, so did the terminology used and the classification information needed, and as a result, the interfaces themselves evolved. Figures 5 and 6 show the interfaces in their final form.

It can be seen in Figure H-5, that the interface now has six plots - range vs. range rate, V and Vp, throttle, range rate, brake and tracking. The format of the brake and tracking plots was changed to the on (blue) vs. off (gray) format in order obtain the space needed for an additional plot. Through trial and error with a variety of hypothesized useful plotted variables, the video classification team found these six plots to be the most useful in classifying the episode video clips to give the desired information.

Figure H-4 Initial Exposure Video Classification Screen

The format of the information being collected using the interfaces has also evolved. It can be seen in Figure H-5 that the driving state classification options have been reduced to cruising or not-cruising. In addition, scenarios are now classified using the series of buttons found below the transitions buttons. The "scenario" folder is no longer used. Significant improvements have been made to the response time recording procedure, as well as the close call classification procedure. The ability to assign confidence ratings to the classification options selected has been added in all categories. This rating will help the evaluation team focus on high confidence classifications and will minimize the use of classifications containing uncertainty. All of these changes were made to maximize the accuracy and efficiency of the classification process.

Other apparent changes to the episode interface include the addition of a "weather" box, a "brake on/for exit ramp", and a general "comments" input box. These boxes were added to make the video analyst's task more efficient.

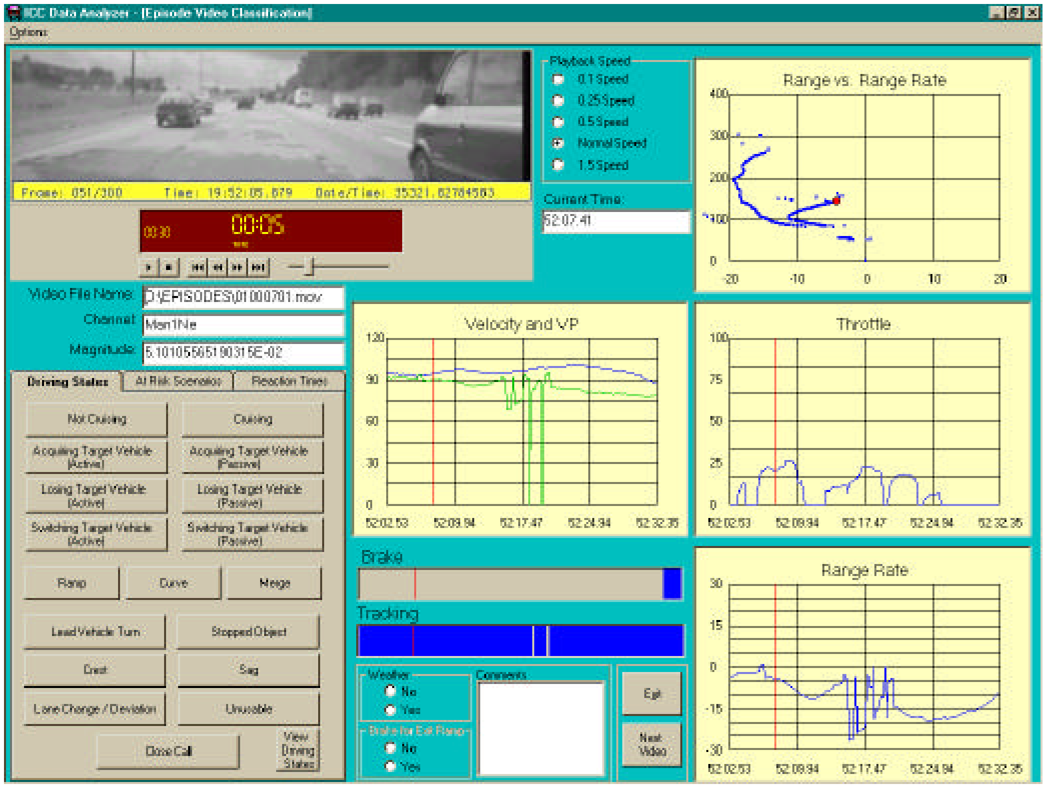

Figure H-5 Final Episode Video Classification Screen

During the interface evolution to its current format, there were also several functional improvements/error corrections made to the interface. However, these can not be seen by simply looking at a sample screen of the interface. The terminology used in the interface is now more consistent with the project terminology.

In comparing Figures H-6 and H-4, it is apparent that the Exposure Video Classification Interface has received some minor changes. The current interface features full video controls whereas the initial interface had only the bare essential video controls. A “Weather” box, a “Confidence” box and a general “Comments” box were added to the interface to make the video analyst’s task more efficient.

Figure H-6 Final Exposure Video Classification Screen

H-4 Pre and Post Classification Data Control

H-4.1 Pre-Classification

Pre-Classification data processing was done by the evaluation team before the video analysis was conducted. With respect to video classification, the important result of this processing was a set of CD's produced for each driver. The video CD contains the episode and exposure video clips for a driver, while the trip log CD contains data for the variables plotted by the episode interface. In order to provide the link between the video CD and the trip log CD, and to allow video analysis of multiple video clips to proceed in an orderly fashion, the team programmer created a series of menu-driven screens. These screens allowed the analyst to: 1) specify the location of the required information contained on the CD's; 2) specify where the classification data was to be stored; 3) add new drivers to the master database; and 4) conduct video analysis of episode and exposure clips in an orderly fashion.

H-4.2 Post - Classification

The information collected using the classification interfaces was stored in a Microsoft Access database. The classification information was linked to the FOT data to allow evaluation of the

ICC system. The important classifications that came from the interfaces were response times, close calls (event descriptions, severity, proximity) and scenario types. There was no other means of collecting this information.

H-5 Summary

The ICC evaluation team developed a video/digital data integration tool that includes video classification interfaces to take advantage of information available from the video clips captured by the ICC vehicles. The team developed one interface for classifying exposure video clips, and another interface for classifying episode video clips. The format, structure and functionality of the interfaces have evolved with the project.

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Appendix I

Video Classification Training Manual

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I-1 Introduction

This manual was prepared to instruct potential users of the Video/Digital Data Integration Tool on the procedures to be followed in classifying episode and exposure video clips generated by the ICC Field Operational Test (FOT). The manual outlines the steps to be followed to fully analyze episode and exposure video clips in an orderly, efficient and consistent manner.

I-2 General Description of the Video/Digital Data Integration Tool

The Video/Digital Data Integration Tool consists of 3 main interfaces:

- the video/data control interface;
- the episode video classification interface; and
- the exposure video classification interface.

The use of each of these interfaces is described in the following sections.

I-3 Video/Data Control

The video/data control interface allows the analyst to specify the location of the numerical and video data for the driver to be analyzed. Typically, the numerical data is saved to the computer's hard drive, and the video data CD is placed in the CD drive. The analyst should complete the following steps to "load" a driver:

- insert numerical data CD for the desired driver into the CD drive;
- copy the driver database file (DriverXX.mdb) to the hard drive;
- remove numerical data CD from the CD drive;
- insert the corresponding video CD for the desired driver in the CD drive;
- start the Video Classification software package by double clicking on the appropriate user specified icon or by running the executable file;
- select "program settings" under the Options menu to verify that all paths are correct, then select the "OK" button (a screen capture of the program settings screen is shown in Figure I-1);
- select "view catalog" under the Options menu (a screen capture of the catalog screen is shown in Figure I-2);
- select the "add driver to catalog" button;
- define the path to the driver database file (DriverXX.mdb) copied to the hard drive in the second step (find the folder on the on-screen menu and double click on it);
- follow the directions given on-screen to complete loading the driver.

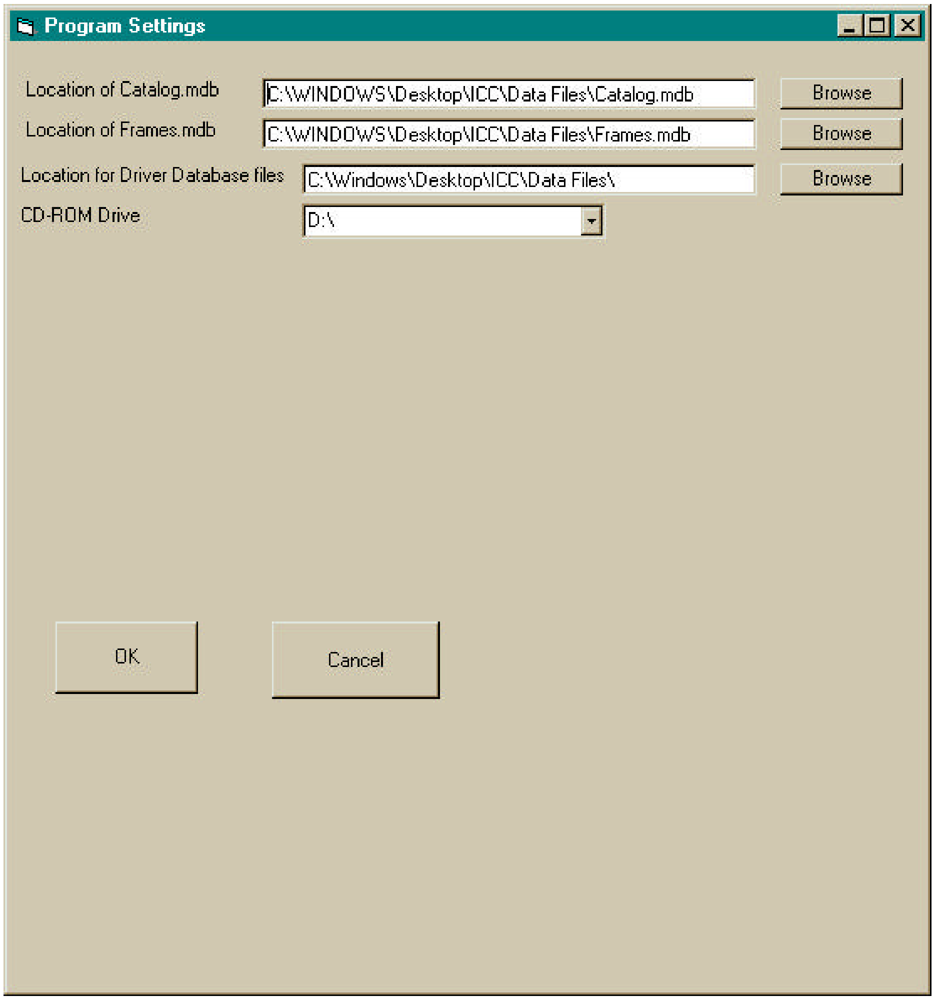


Figure I-1 Video/Data Control Interface - Program Settings Screen

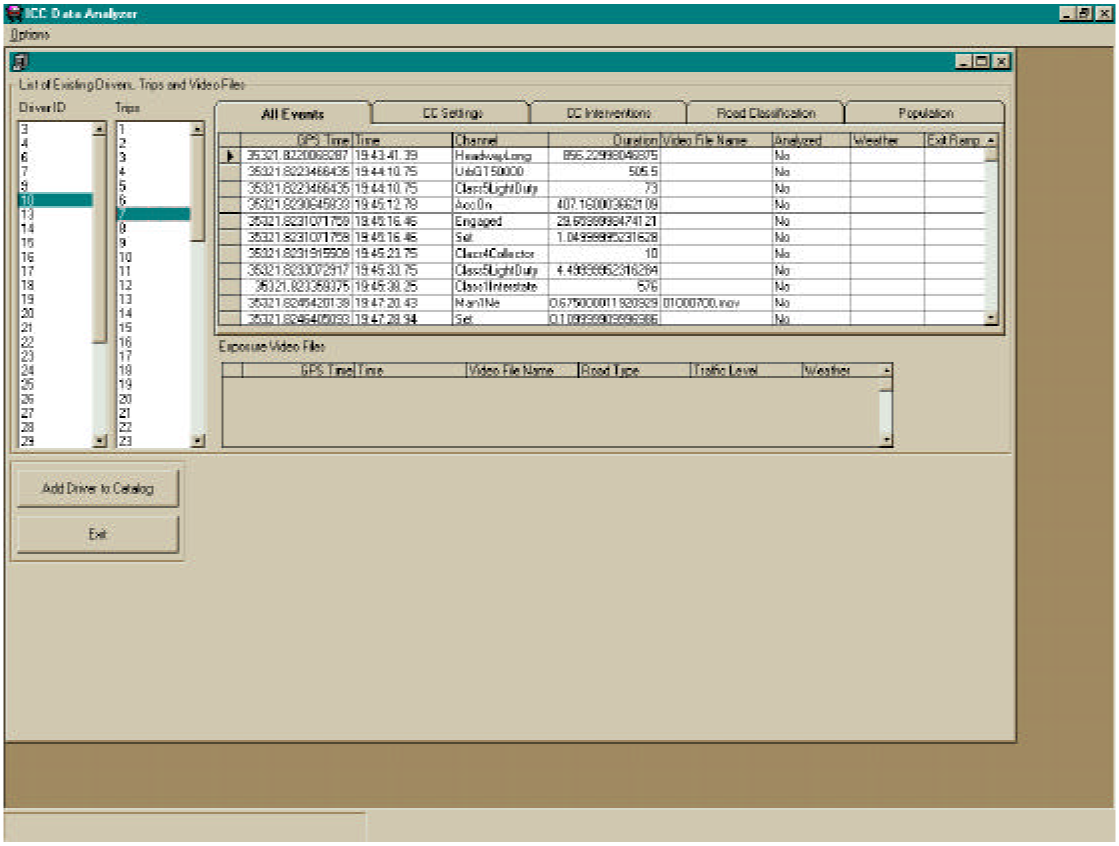


Figure I-2 Video/Data Control Interface - Catalog Screen

The video/data control interface is also used to access the classification interfaces in order to analyze video clips. The interfaces are accessed by completing the following steps:

- select "analyze videos" under the Options menu (a screen capture of the analyze videos screen is shown in Figure I-3);
- select the desired driver number from the Driver ID box (make sure appropriate video CD is in CD drive and appropriate driver database has been selected);
- select a trip number from the Trip box - this action will display all of the episode and exposure video clips in their respective display boxes;
- double-click on the desired video clip - double-clicking on an episode video will take you to the episode classification interface, while double-clicking on an exposure video will take the analyst to the exposure classification interface.

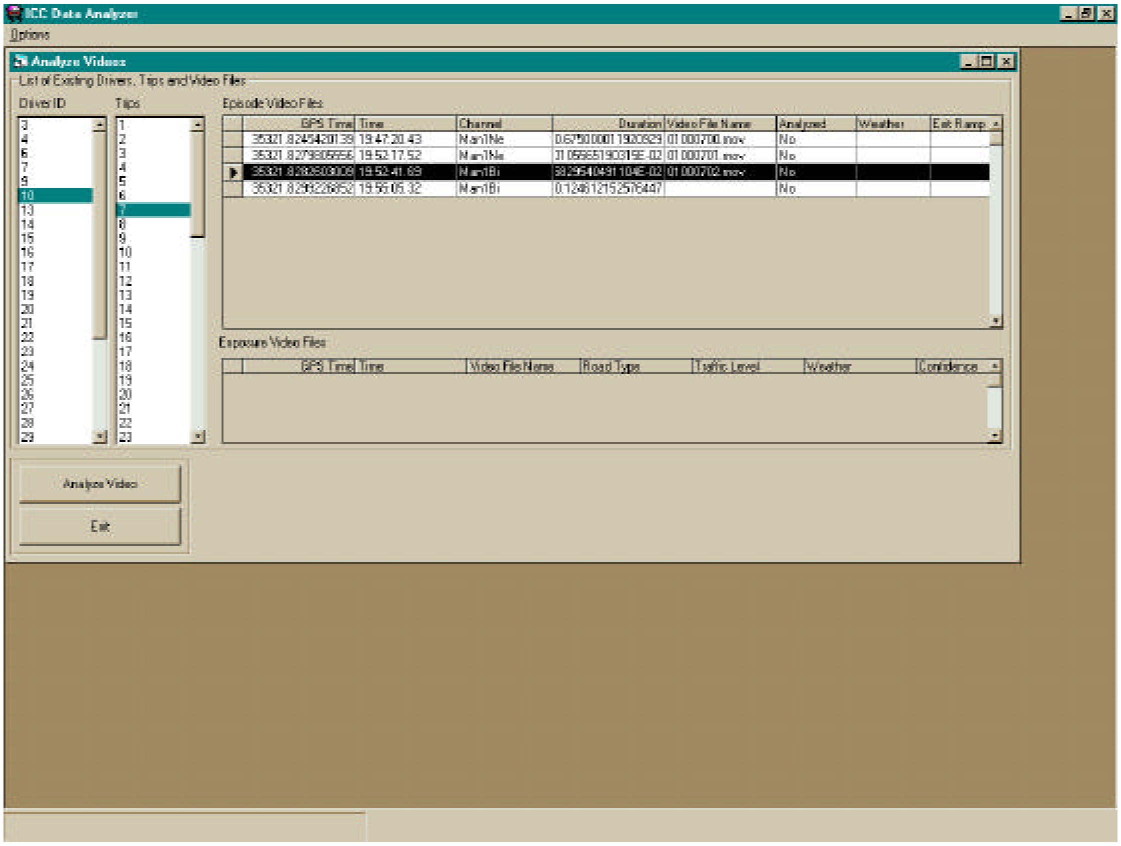


Figure I-3 Video/Data Control Interface - Analyze Videos Screen

The following sections describe the proper use of the episode and exposure video classification interfaces.

I-4 Episode Video Classification

The episode video classification interface consists of:

- video viewer and controller;
- seven plotted variables;
- classification tools.

A screen capture of the episode video classification interface is shown in Figure I-4.

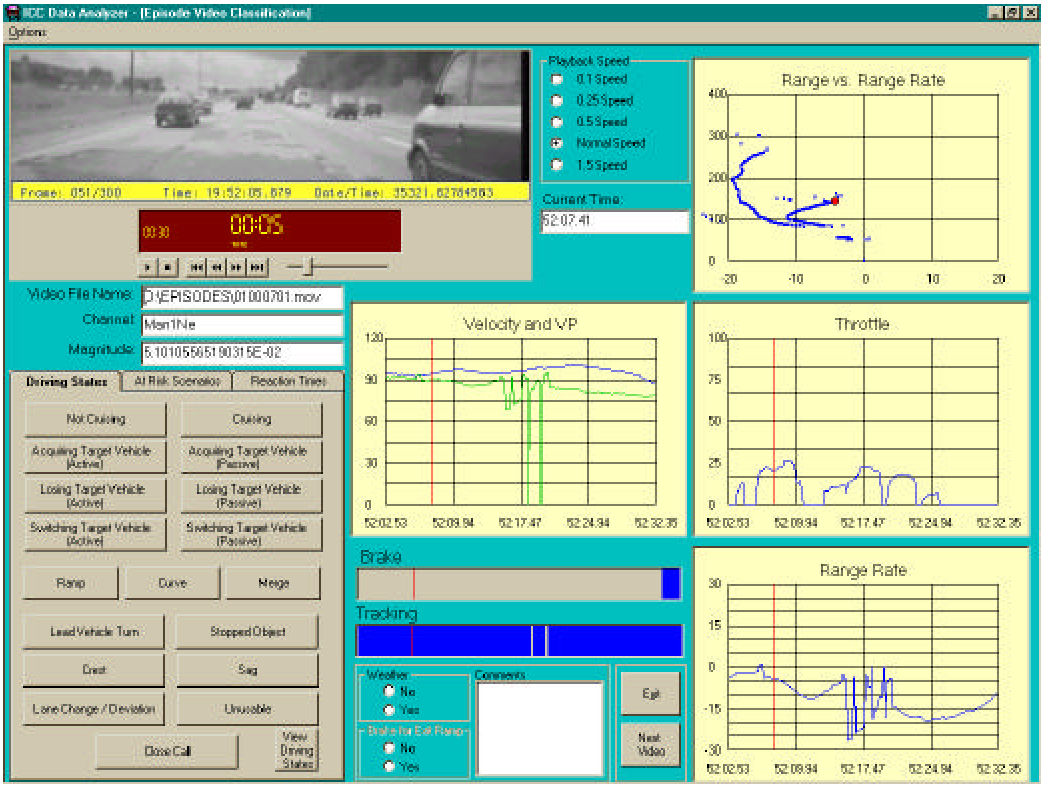


Figure I-4 Episode Video Classification Interface

The video viewer and controller allow the analyst to play, rewind, fast forward, stop or pause the video clip. They also allow the analyst to control the speed of the video and provide information on the event contained in the video (type, magnitude).

The current episode video classification interface displays the values of 7 variables recorded during the clip being classified. As the video progresses, a line moves across the plots to show the value of the variables at the displayed point in the video clip. These variables have been included to provide additional information to the analyst, however, classification of the video clip must be done according to what is happening on the video clip, and not what is happening in the plotted variables. In other words, if a discrepancy between the information displayed on the video and the information displayed on the plotted variables should arise, the analyst shall classify the video according to what is being viewed on the video clip.

The following section describes the procedure for analyzing episode video clips using the classification tools provided in the episode video classification interface. The steps that are outlined must be followed in their entirety by the analyst in order for the classification to produce accurate, complete results.

I-4.1Steps in Classification

The general procedure to be followed in classifying the episode video clips is outlined in Figure I-5. The sub-procedures for each identified step are outlined within the following sections.

STEP 1: View the Video at Normal Speed

Before completing any classifications or measurements, view the video in its entirety at normal speed to examine what events occurred. This will aid greatly in making the proper selections at the correct time.

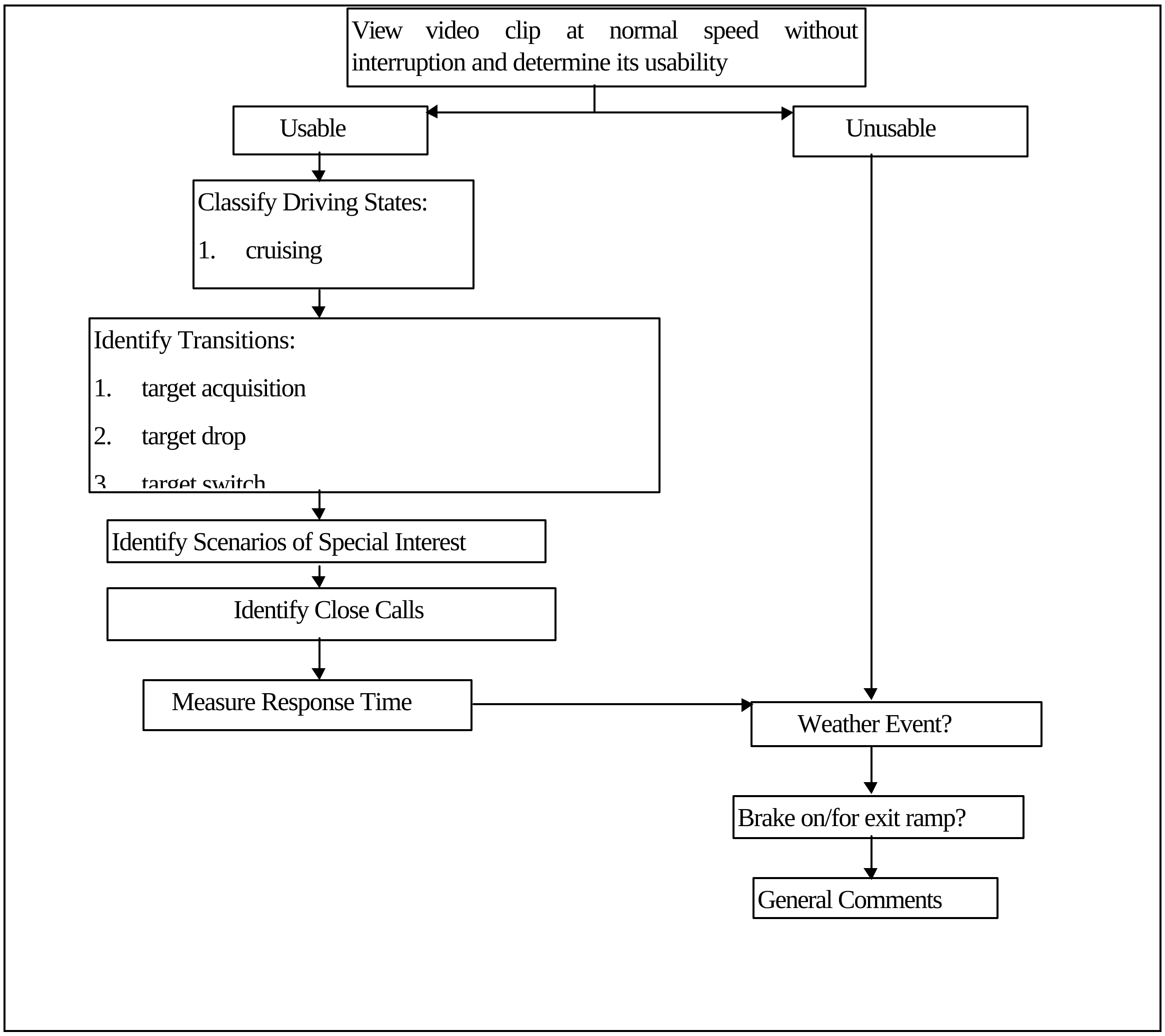


Figure I-5 General Procedure for Classifying Episode Video Clips

STEP 2: Usability

The usability of a video clip is determined by the clarity and content of the captured video. If the events captured in the video clip are not discernible due to weather, or no events occurred during the clip (car sitting in parking lot for example), then the clip is labeled unusable by selecting the "unusable" button. Once a clip has been labeled unusable, no further analysis is required with the exception of determining whether or not the clip showed evidence of being a weather event.

STEP 3: Classify Driving States

Four driving states have been identified as being of interest to this study. They are:

- following a same speed target vehicle
- closing on a target vehicle
- separating from a target vehicle
- cruising

The first three states represent non-cruising states (lead vehicle present) and can be differentiated accurately using algorithms created by the evaluation team. For this reason, the analyst will choose between two simplified driving states, cruising and not cruising. Driving states are identified by selecting the appropriate driving state button.

Cruising

Select the "cruising" button when there is no visible vehicle traveling in the same lane ahead of the ICC equipped vehicle. The plotted variable tracking will usually be 0 (gray) when cruising.

Not Cruising

Select the "not cruising" button when there is a visible vehicle traveling in the same lane ahead of the ICC equipped vehicle, unless the vehicle is barely visible and tracking is consistently 0 (gray), in which case the state is to be labeled cruising.

The appropriate button should be selected at the beginning of each driving state, and driving state identification should be continuous from start to finish of the video clip.

Upon selecting a driving state button, the video will pause to prompt the analyst for a confidence rating on the driving state selection. The confidence rating choices are as follows:

- high - the analyst is very confident that the driving state selection is correct for the driving situation currently being experienced by the ICC vehicle/driver;
- medium - the analyst is somewhat confident that the driving state selection is correct for the driving situation currently being experienced by the ICC vehicle/driver;
- low - the analyst is not confident that the driving state selection is correct for the driving situation currently being experienced by the ICC vehicle/driver, but it is more likely correct than the state not chosen.

More than one driving state can be recorded during a video clip, and either driving state may be selected more than once during a video clip. If driving state buttons are selected accidentally, they can be corrected by selecting the "view driving state button" and deleting the erroneous driving state.

Step 4: Identify Transitions

Three transitions have been identified as being of interest to this study. They are:

- acquiring a target vehicle;
- dropping a target vehicle; and
- switching target vehicles.

All three of these transitions require a lane movement to occur to qualify as a transition. If the lane movement was performed by the ICC driver/vehicle then the transition is classified as being active. If the lane movement was performed by another vehicle, then the transition is classified as being passive. Six interface buttons are provided for identifying transitions. They represent the various combinations of the three transitions and the two types of transitions. These buttons are to be selected when the vehicle changing lanes crosses the painted lane boundary. For example, given an active target acquisition where the ICC vehicle has a lane movement and acquires a new target vehicle, the active target acquisition button should be selected when the ICC vehicle crosses the painted lane boundary.

Changes in state from cruising to not cruising or vice versa in which no lane movement occurs must not be labeled as transitions. There are two general situations in which this can occur. In the first situation, the lead vehicle is traveling at a greater speed than the ICC vehicle and pulls away until a cruising state is achieved. Although the state has changed from not cruising to cruising, no transition should be recorded as no lane movement took place. In the second situation, the ICC vehicle is traveling faster than some vehicle which is traveling in the same lane as the ICC vehicle, but is out of sight (range). Eventually, if no lane movements occur, and the vehicles' speeds remain the same, the state will change from cruising to not cruising, but no transition should be recorded.

STEP 5: Identify Scenarios of Special Interest

Eight driving situations have been identified as being of special interest to this study.

They are:

- driving on ramps;
- "not cruising" on curves;
- freeway merges;
- lead vehicle turns (left or right);
- stopped object on roadway
- "not cruising" on crests;
- "not cruising" in sags; and
- unexplained lane movements or deviations.

Buttons are available on the Episode Video Interface to tag these scenarios of special interest. The following subsections describe the conditions under which the various special interest scenario buttons are to be selected. Some notes on some of the constraints in the definitions are:

- curves, crests and sags that occur on freeways are not of interest to this study;
- curves, crests and sags are difficult to determine on non-freeways unless another vehicle is present;
- curve, crest and sag exposure is not of interest to the evaluation team - the evaluation team is interested in a sample restricted by the above two bullets (biased sample).

Ramp

The "ramp" button is to be selected when the ICC vehicle begins to travel on a freeway access ramp (exit or on) or at the beginning of the video if the ICC vehicle starts the video on a ramp. The "ramp" includes all horizontal and vertical curvature experienced while on the ramp (the crest, sag and curve buttons should not be selected) and a lead vehicle does not need to be present for the button to be selected.

Curve

The "curve" button is to be selected when there is noticeable horizontal curvature and iff:

- the road is not a freeway,
- there is a lead vehicle present, and
- visual or sensor tracking is being affected by the curvature.

Merge

The "merge" button is to be selected when the ICC vehicle is merging onto a freeway (no other vehicle needs to be present), or when a vehicle is merging onto a freeway directly in front of the ICC vehicle (must be merging into the lane in which the ICC vehicle is traveling).

Lead Vehicle Turn

The "turn" button is to be selected when a lead vehicle turns off the roadway on which the ICC vehicle is traveling. Examples of when this button would be selected are:

- lead vehicle turns into a driveway
- lead vehicle turns into a parking lot,
- lead vehicle turns at an intersection.

Stopped Object

The "stopped object" button is to be selected when there is a stopped vehicle or stationary object in the path of the ICC vehicle. The button should be selected as soon as the object becomes visible on the video.

Crest

The "crest" button is to be selected when there is noticeable vertical curvature (crest - top of incline) and if

- the road is not a freeway,
- there is a lead vehicle present, and
- visual or sensor tracking is being affected by the curvature.

Sag

The "sag" button is to be selected when there is noticeable vertical curvature (sag - bottom of decline) and if:

- the road is not a freeway,
- there is a lead vehicle present, and
- visual or sensor tracking is being affected by the curvature.

Lane Movement/Deviation

The "lane movement/deviation" button is to be selected when the ICC driver/vehicle performs an unexplained lane deviation or lane movement. An unexplained lane deviation is an event in which the ICC vehicle crosses the painted lane boundary (but does not perform full lane movement) and the maneuver is not performed to avoid debris, another vehicle, a pedestrian, a bicyclist, or an animal. An unexplained full lane movement is an event in which the ICC vehicle has a lane movement and the maneuver is not performed to overtake a slower vehicle or recover position after overtaking a vehicle, to get in position to exit the roadway, or to avoid debris, another vehicle, a pedestrian, a bicyclist or an animal. It should be noted that full lane movements are rarely unexplained.

STEP 6: Identify Close Calls

If the video clip was triggered (brake intervention, near encounter, concern) due to a potential interaction with another vehicle or object, or a near run-off the road event, then select the "close call" button at the video midpoint. Figure I-6 provides an outline of the procedure for identifying close calls and assigning severity and proximity values to them.

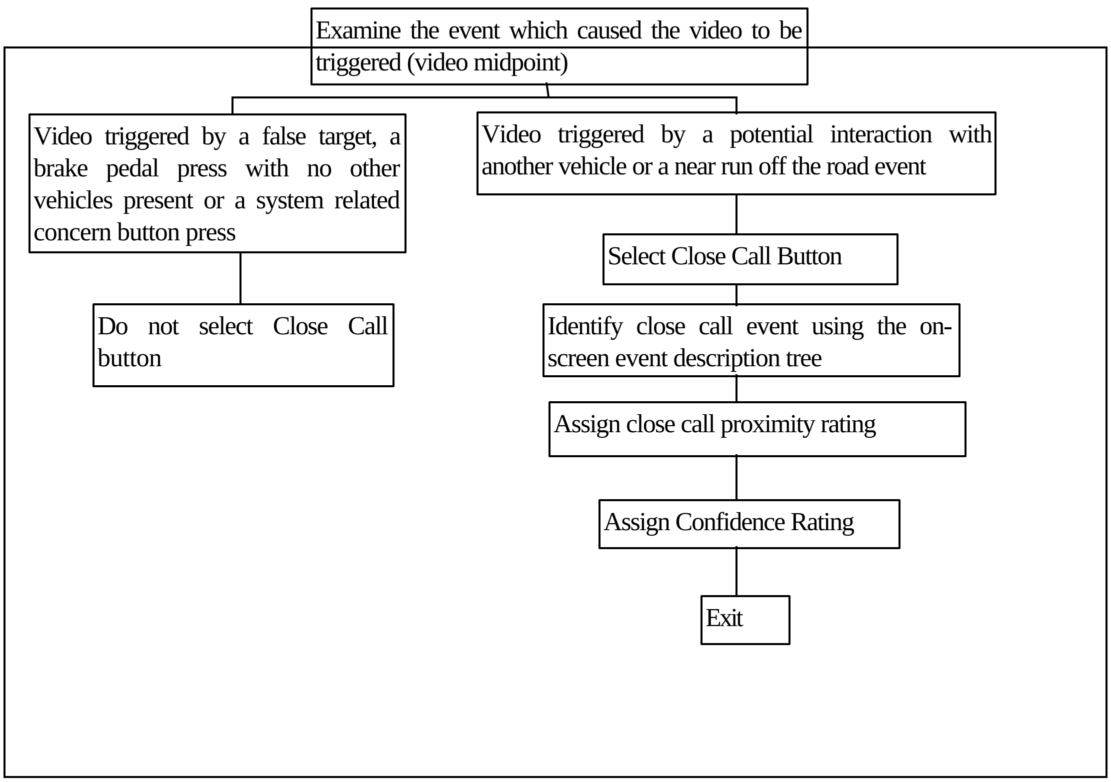


Figure I-6 General Procedure for Classifying Close Call Severity

Note: Only close calls which triggered video, or which were captured by a concern button press should be recorded. Other events which are observed during the video may trigger their own video clip if of sufficient magnitude.

STEP 7: Identify Type of Close Call and Proximity of Close Call

Close Call Event Tree

Once the "close call" button has been selected, a screen will come up that allows the analyst to identify the type of close call and proximity of the close call event. This identification is performed using the Close Call Event Tree. A description of this tree is provided in Appendix I-A. The analyst must move through the tree until the appropriate description of the close call is found. Upon selecting the appropriate close call description, severity is automatically assigned by the interface and displayed on the screen. This severity measure is the potential severity in the event of a crash. The severity values range from 1 to 4, where 1 is minor, 2 is marginal, 3 is critical and 4 is catastrophic. The severity values by event number that are used by the interface are provided in Appendix I-B.

Once an event has been chosen, a confidence rating needs to be assigned. A high confidence rating suggests that the analyst feels that the event chosen appropriately describes the observed close call. A medium confidence rating suggests that while the analyst feels that the event chosen is the most appropriate description of the observed close call, there are other events that also describe the observed close call. A low confidence rating suggests that the analyst feels that the event chosen is the most appropriate description of the observed close call, but does not describe the observed close call very well.

Close Call Proximity

Proximity is a subjective measure of "how close" the close call event was to a crash. The analyst assigns the proximity rating according to the following scale:

- Near miss - The driver is required to take immediate evasive action in order to prevent a crash.
- Hazard Present - The close call occurs when an object is present in the environment - requires that the object is in close enough proximity to represent a hazard to the ICC vehicle, but not close enough that an immediate evasive action must be taken to avoid it.
- No Hazard Present - The close call occurs when no close proximity obstacle is present in the environment.

Proximity is assigned by selecting the appropriate proximity button on the close call screen.

STEP 8: Measure Response Time

Response time should be measured for events in which there is a measurable stimulus that generates a measurable response from the driver of the ICC vehicle. The first step in recording a response time is the selection of the response time folder. A screen capture of the interface with the response time folder open in shown in Figure I-7. Following this step, the appropriate stimulus description must be selected. Choices for the stimulus include:

- Lead vehicle brake lights come on (visual);
- Lead vehicle deceleration with no brake light (marked decrease in Vp);
- Obstacle appears suddenly in ICC vehicle's path;
- Cut-in where slower vehicle crosses lane line into ICC vehicle's lane;
- Other.

If "OTHER" is selected, a comment is required in the reaction time comment dialogue box.

Similarly, the appropriate response description must be selected. Choices for the response include:

- ICC driver presses the brake pedal (brake variable goes from gray to blue)
- Marked deceleration begins (noticeable decrease in V), or throttle off (1 to 0).
- Start of lateral maneuver, e.g., driver swerves.
- Other.

The "OTHER" category will require inclusion of a text description of the response type.

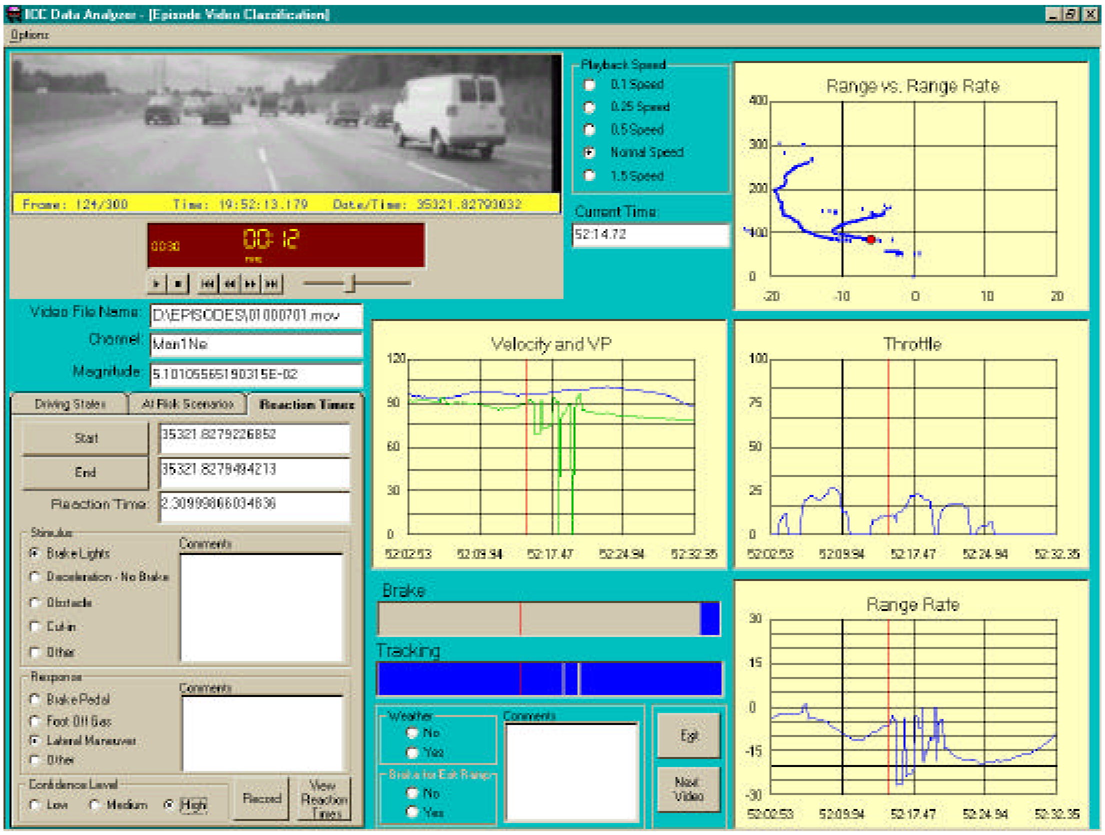


Figure I-7 Episode Interface with Response Time Folder Open

To measure the ICC driver's response time, the time of the stimulus and response must be marked. To mark the stimulus, select the "Start" button as close to the appearance of the stimulus as possible. Then, to mark the response, select the "End" button as close to the response as possible. Please note, the **video must be viewed at 0.1x speed** during response time recording. If the "Start" or "End" buttons are selected at the wrong time, or the video analyst is unhappy with their timing, they may redo the start-end sequence as many times as needed to record an accurate response time. Once the analyst feels that they have accurately captured the start and end times, a confidence rating should be assigned and the response time recorded. A high confidence rating suggests that the analyst feels that the stimulus and response times were measured accurately and that the event was highly appropriate for measuring response time. A medium confidence rating suggests that the analyst feels that either the stimulus or response could not be measured as accurately as the analyst would like, or that the event was not highly appropriate for measuring reaction time. A low confidence rating suggests that the analyst feels that either the stimulus and response times were not accurately captured or that the event was only marginally acceptable for measuring response time. The analyst should record some comments describing medium or low confidence ratings.

The analyst is encouraged to record response times for as many stimuli and for as many responses as appropriate for a single acceptable event, but should not expect to find a measurable response time in every episode video clip.

STEP 9: Weather Event

One of the final steps in episode video classification is to determine whether or not the video displayed events of precipitation or road spray. If rain, snow, or road spray was visible during the clip then mark the clip as a weather event by selecting the "yes" button in the weather box on the main interface.

STEP 10: Brake On/For and Exit Ramp

For video clips triggered by a brake intervention, the analyst will be required to input whether or not the video was triggered by a brake on or for an exit ramp. If the video was trigged when the ICC driver pressed the brakes to slow down in the deceleration lane of a exit ramp, or when he/she pressed the brakes while on the exit ramp, then select the "yes" button in the brake on/for exit ramp box.

STEP 11: General Comments

This input box allows the analyst to make any special notes about the video. If the video was triggered by a false target (barrels, guardrails, signs, broken down vehicle on the side of the road, etc.) then the analyst should make a note of this here. If the analyst feels that a close call occurred, but the event was not described in the close call event tree, then a brief note describing the event should be made here. In addition, if the ICC vehicle is following a motorcycle at any point in the video clip, the analyst should make a note of it here. The analyst should strive to keep these and all comments brief due to data storage considerations.

Note: The Scenario folder should not be used by the analyst.

I-5 Exposure Video Classification

The exposure video classification interface consists of:

- video viewer and controller;
- classification tools.

A screen capture of the exposure video classification interface is shown in Figure I-8.

The video viewer and controller allow the analyst to play, rewind, fast forward, stop or pause the video clip.

Figure I-8 Exposure Video Classification Interface

The following section describes the procedure for analyzing exposure video clips using the classification tools provided in the exposure video classification interface. The steps that are outlined must be followed in their entirety by the analyst in order for the classification to produce accurate, complete results.

I-5.1 Steps in Classification

The general procedure to be followed in classifying the exposure video clips is outlined in Figure I-9. The sub-procedures for each of these steps are outlined in individual sections found below.

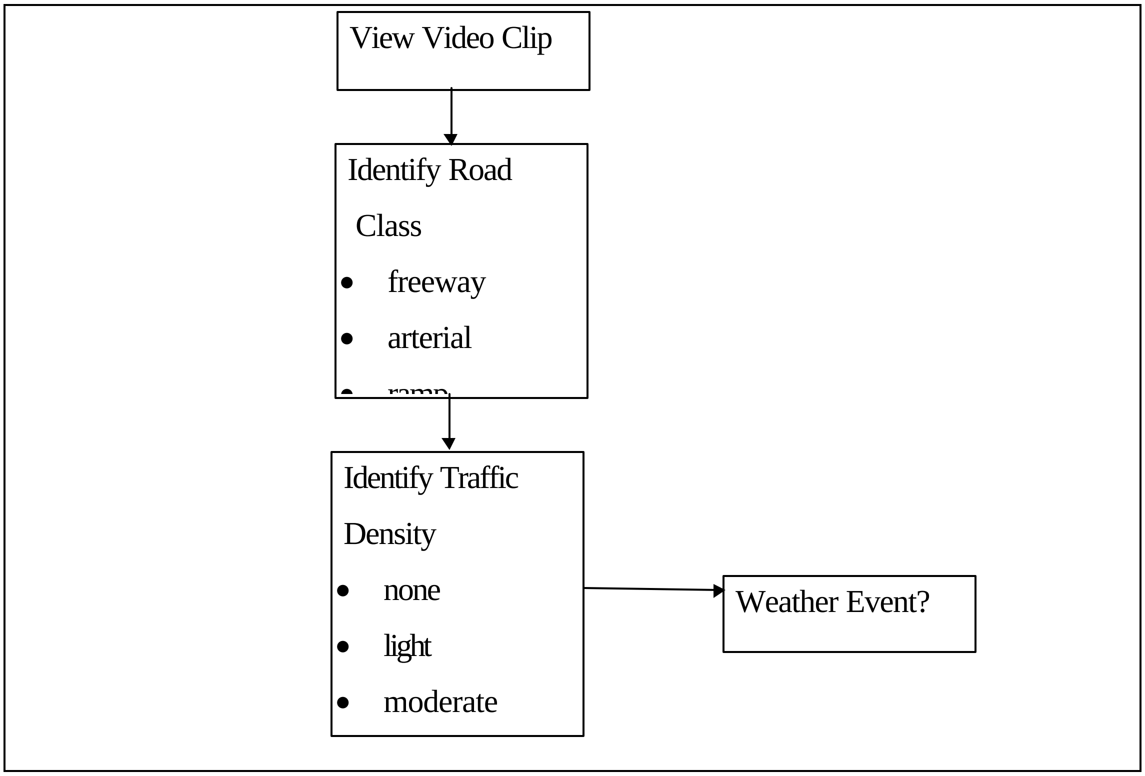


Figure I-9 General Procedure for Classifying Exposure Video Clips

STEP 1*:* View the Video

Before conducting any classification, view the video in its entirety to look for clues in identifying road class.

STEP 2: Identify Road Class

One of the variables of interest in this study is road class. The interface provides four choices for road class: freeway, arterial, ramp and unusable. The road should be classed as a freeway if the road is divided and access to the road is strictly by exit/entrance ramps. To classify the road as a freeway, select the “freeway” button. For simplicity, all other levels of roadway (with the exception of ramps, parking lots and driveways) will be classified as arterials. To classify a road as an arterial, select the “arterial” button. Freeway exit and entrance ramps should be classified as ramps by selecting the “ramp” button. If the video is of a parking lot, driveway or other unusable scene, select the “unusable” button. Some high class divided arterials will appear to look very much like freeways. Things to look for to determine if a road is an arterial or a freeway are driveways, at-grade intersections, and houses or utility poles very close to the edge of the road.

Once the road class has been assigned, a confidence rating needs to be assigned. A high confidence rating should be selected if the analyst is certain that the road class selected is correct for the road class observed. A medium confidence rating should be selected if the analyst feels that the road class selected is the most appropriate for the road class observed, but there is some uncertainty. A low confidence rating should be selected if the analyst feels that the road class selected is the most appropriate for the road class observed, but there is much uncertainty as to its correctness.

Note: If the ICC vehicle is stopped on an arterial for the exposure clip, then the road class should be identified as arterial, not unusable.

Step 3: Identify Traffic Density

The interface provides five choices for traffic density: none, light, moderate, heavy and congested. In order to provide assistance in choosing the most appropriate level, a figure from the Highway Capacity Manual (TRB, 1994) has been included in Appendix I-C. This figure shows visual examples of the 6 levels of service defined in the Highway Capacity Manual. For this study: LOS A and B will be classified as light; LOS C and D will be classified as moderate; LOS E will be classified as heavy; and LOS F will be classified as congested. One important thing to remember is that you should only be looking at the traffic traveling in the same direction that the ICC vehicle is traveling. If no visible traffic is traveling in the same direction as the ICC vehicle, select the "none" button. If the traffic appears to be at about the level shown in the LOS A or LOS B pictures, select the "light" button. If the traffic appears to be at the level shown in the LOS C or LOS D pictures, select the "moderate" button. If the traffic appears to be at about the level shown in the LOS E picture, select the "heavy" button. If the traffic appears to be at about the level shown in the LOS F picture, select the "congested" button. It may be difficult to discern between LOS E and LOS F. If the traffic is at LOS E, headways (the distance between vehicles) will be short, but traffic will still be flowing fairly smoothly. When the traffic reaches LOS F, the flow is usually not smooth and "stop and go" traffic is likely (lots of visible brake lights).

Once the traffic density has been assigned, a confidence rating needs to be assigned. A high confidence rating should be selected if the analyst is certain that the traffic density selected is correct for the density of traffic observed. A medium confidence rating should be selected if the analyst feels that the traffic density selected is the most appropriate for the density of traffic observed, but there is some uncertainty. A low confidence rating should be selected if the analyst feels that the traffic density selected is the most appropriate for the density of traffic observed, but there is much uncertainty as to its correctness. Since there is only one overall confidence rating for an exposure clip, the analyst should select the lower of the two confidence ratings.

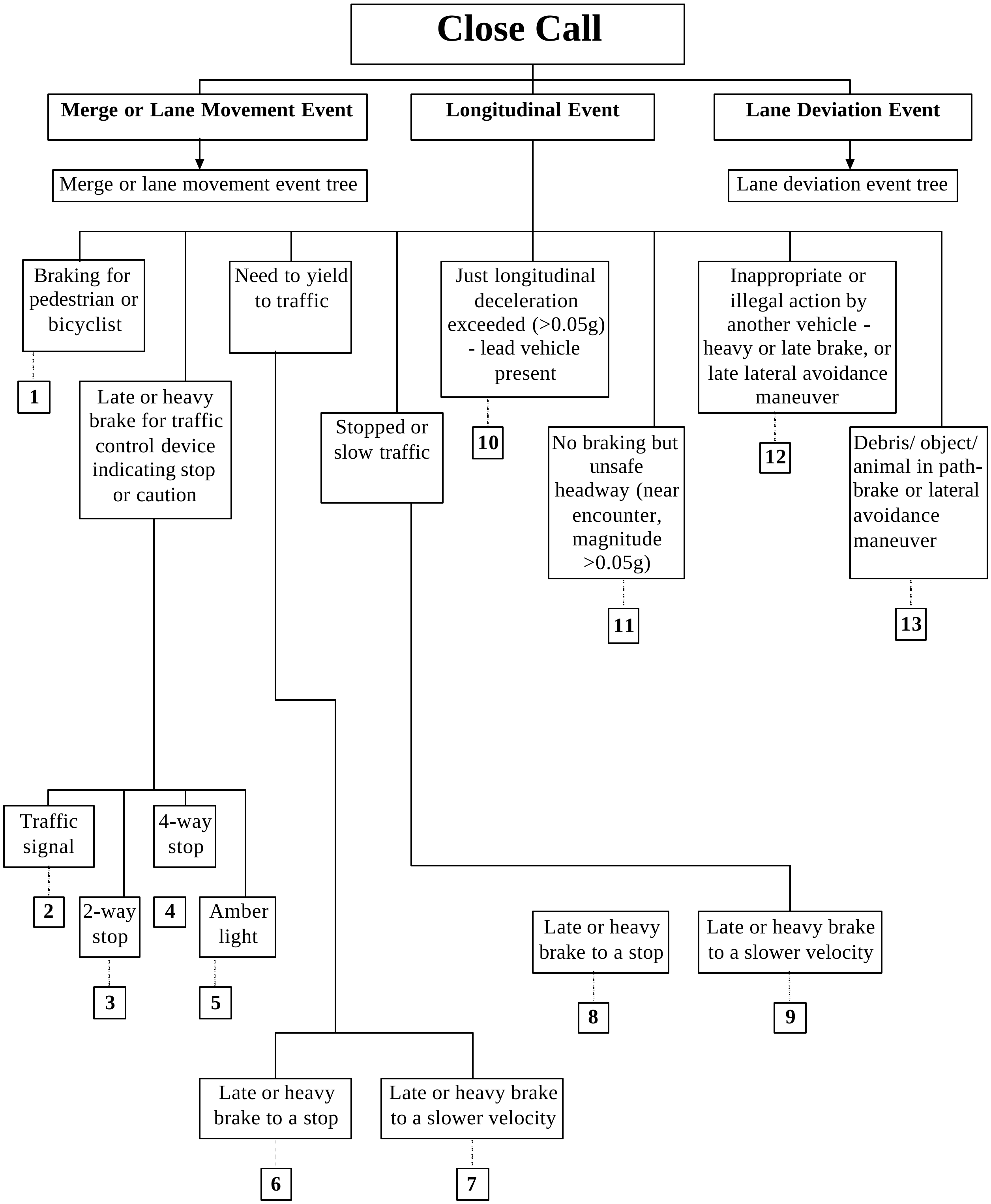
Note: The figures from the Highway Capacity Manual are looking back on the traffic, while the analyst will be looking ahead at the traffic. Keep this in mind when performing the classifications.

STEP 4: Weather Event

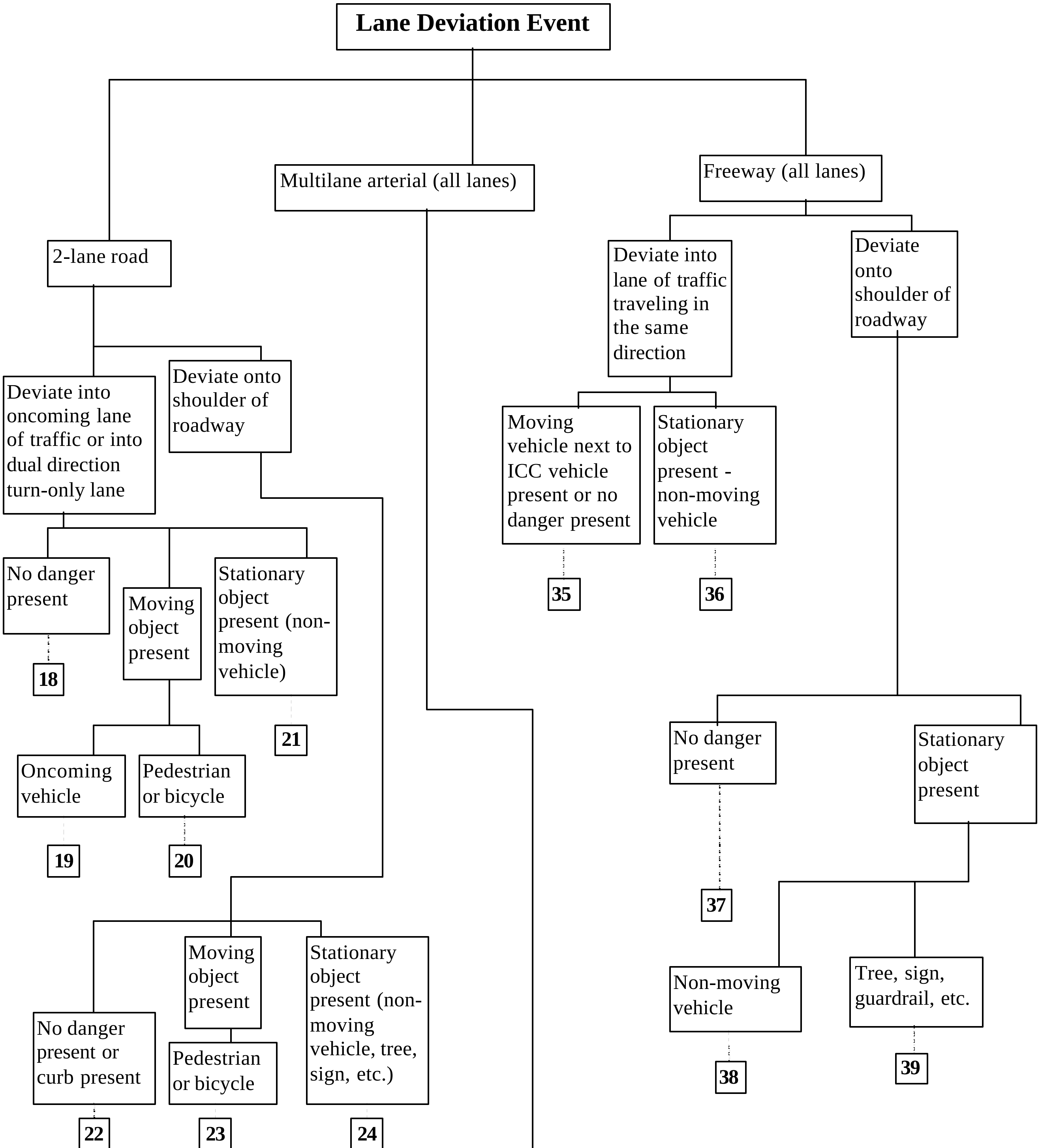
The final step in exposure video classification is to determine whether or not the video displayed evidence of precipitation or road spray. If rain, snow, or road spray was visible during the clip then mark the clip as a weather event by selecting the "yes" button in the weather box.

Appendix I-A

Close Call Event Trees



Close Call
Merge or Lane Movement Event
Longitudinal Event
Lane Deviation Event
Merge or lane movement event tree
Lane deviation event tree
Braking for pedestrian or bicyclist
1
Late or heavy brake for traffic control device indicating stop or caution
Need to yield to traffic
Stopped or slow traffic
Just longitudinal deceleration exceeded (>0.05g) - lead vehicle present
10
No braking but unsafe headway (near encounter, magnitude >0.05g)
11
Inappropriate or illegal action by another vehicle - heavy or late brake, or late lateral avoidance maneuver
12
Debris/ object/ animal in path- brake or lateral avoidance maneuver
13
Traffic signal
2
2-way stop
3
4-way stop
4
Amber light
5
Late or heavy brake to a stop
8
Late or heavy brake to a slower velocity
9
Late or heavy brake to a stop
6
Late or heavy brake to a slower velocity
7



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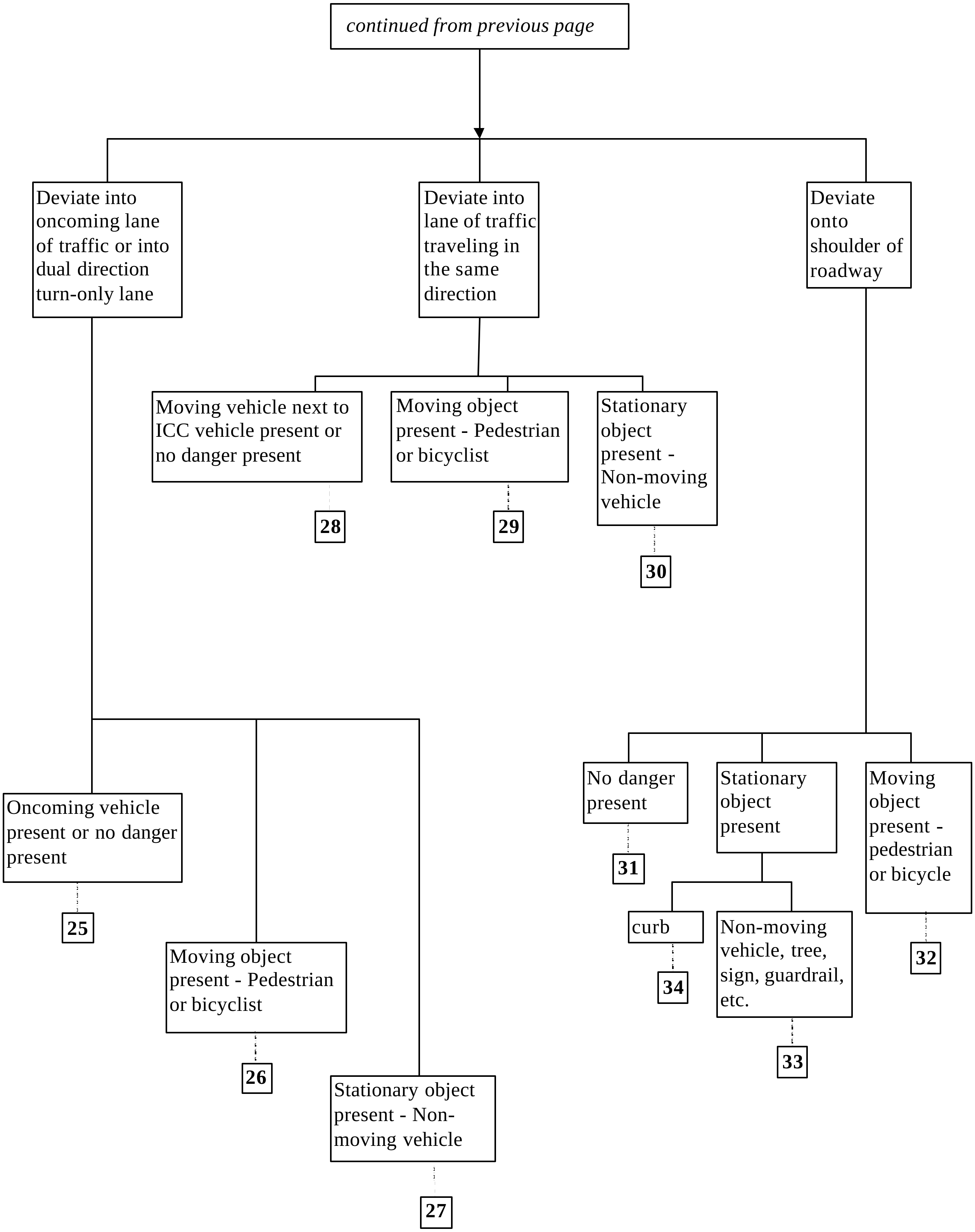
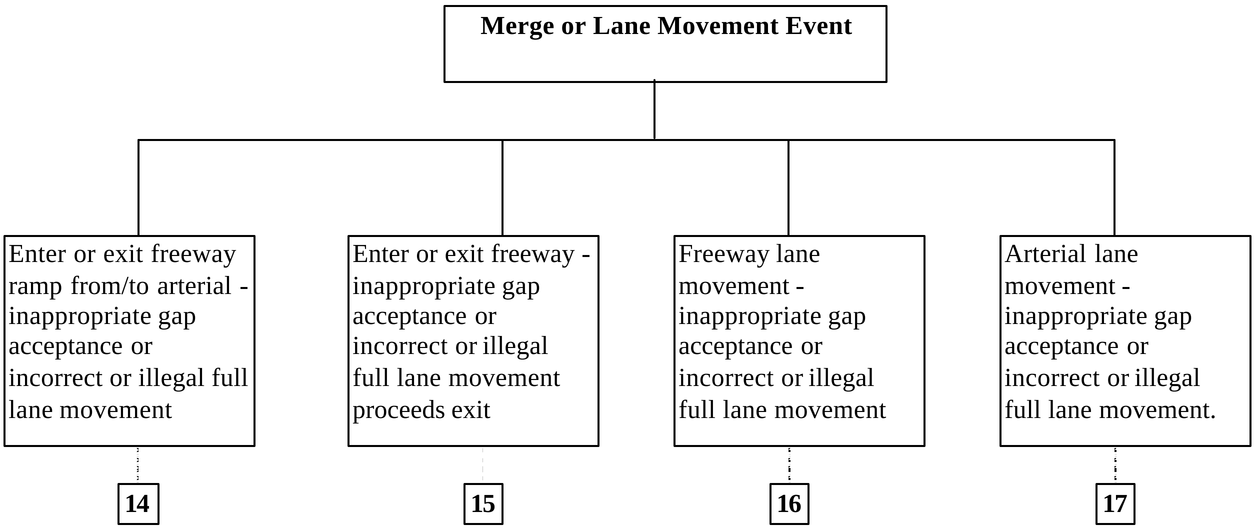

continued from previous page
Deviate into oncoming lane of traffic or into dual direction turn-only lane
Deviate into lane of traffic traveling in the same direction
Deviate onto shoulder of roadway
Moving vehicle next to ICC vehicle present or no danger present
Moving object present - Pedestrian or bicyclist
Stationary object present - Non-moving vehicle
28
29
30
Oncoming vehicle present or no danger present
25
Moving object present - Pedestrian or bicyclist
26
Stationary object present - Non-moving vehicle
27
No danger present
31
Stationary object present
Moving object present - pedestrian or bicycle
32
curb
34
Non-moving vehicle, tree, sign, guardrail, etc.
33


Merge or Lane Movement Event
Enter or exit freeway ramp from/to arterial - inappropriate gap acceptance or incorrect or illegal full lane movement
Enter or exit freeway - inappropriate gap acceptance or incorrect or illegal full lane movement proceeds exit
Freeway lane movement - inappropriate gap acceptance or incorrect or illegal full lane movement
Arterial lane movement - inappropriate gap acceptance or incorrect or illegal full lane movement.
14
15
16
17

Appendix I-B

Close Call Severity by Event Number

Event No.	Longitudinal Event	Velocity of the ICC vehicle	Potential Severity Value
1	Braking for pedestrian or bicyclist	40 kph 56 kph 72 kph	4 4 4
2	Late or heavy brake for traffic control device indicating stop-traffic signal	40 kph 56 kph 72 kph	3 3 4
3	Late or heavy brake for traffic control device indicating stop - 2-way stop	40 kph 56 kph 72 kph	3 3 4
4	Late or heavy brake for traffic control device indicating stop - 4-way stop	40 kph 56 kph 72 kph	2 2 3
5	Late or heavy brake for traffic control device indicating stop - amber light	40 kph 56 kph 72 kph	1 1 2
6	Need to yield to traffic - late or heavy brake to a stop	40 kph 56 kph 72 kph	2 3 3
7	Need to yield to traffic - late or heavy brake to a slower velocity	40 kph 56 kph 72 kph	2 3 3
8	Stopped or slow traffic - late or heavy brake to a stop	40 kph 56 kph 72 kph 88 kph	3 3 4 4
9	Stopped or slow traffic - late or heavy brake to a slower velocity	40 kph 56 kph 72 kph 88 kph	2 2 3 3
10	Just longitudinal deceleration exceeded (>0.05g) - lead vehicle present	40 kph 56 kph 72 kph 88 kph	2 2 3 3
11	No braking - but unsafe headway (near encounter magnitude>0.05g)	40 kph 56 kph 72 kph 88 kph	2 2 3 3
12	Inappropriate or illegal action by another vehicle - heavy or late brake, or late lateral avoidance maneuver	40 kph 56 kph 72 kph 88 kph	3 3 4 4
13	Debris/Object/Animal in path - brake or lateral avoidance maneuver	40 kph 56 kph 72 kph 88 kph	1 1 1 2

Event No.	Merge or Lane Movement Event	Velocity of the ICC vehicle	Potential Severity Value
14	Enter or exit freeway ramp from/to arterial - inappropriate gap acceptance, or incorrect or illegal full lane movement	40 kph 56 kph	2 2
15	Enter or exit freeway - inappropriate gap acceptance, or incorrect or illegal full lane movement proceeds exit	40 kph 56 kph 72 kph 88 kph	4 3 3 3
16	Freeway lane movement - inappropriate gap acceptance or incorrect or illegal full lane movement	40 kph 56 kph 72 kph 88 kph	4 3 3 3
17	Arterial lane movement - inappropriate gap acceptance or incorrect or illegal full lane movement	40 kph 56 kph 72 kph	2 2 2

Event No.	Lane Deviation Event	Velocity of the ICC vehicle	Potential Severity Value
18	2-lane road - deviate into oncoming lane of traffic or into dual direction turn-only lane - no danger present	40 kph 56 kph	3 4
19	2-lane road - deviate into oncoming lane of traffic or into dual direction turn-only lane - moving vehicle present - oncoming vehicle	40 kph 56 kph	3 4
20	2-lane road - deviate into oncoming lane of traffic or into dual direction turn-only lane - moving vehicle present - pedestrian or bicycle	40 kph 56 kph	4 4
21	2-lane road - deviate into oncoming lane of traffic or into dual direction turn-only lane - stationary object present - non moving vehicle	40 kph 56 kph	2 3
22	2-lane road - deviate onto shoulder of roadway - no danger present or curb present	40 kph 56 kph	1 1
23	2-lane road - deviate onto shoulder of roadway - moving object present - pedestrian or bicycle	40 kph 56 kph	4 4
24	2-lane road - deviate onto shoulder of roadway - stationary object present - non-moving vehicle, tree, sign guardrail, etc.	40 kph 56 kph	2 3
25	multilane road (all types, all lanes) - deviate into oncoming lane of traffic or into dual direction turn-only lane - oncoming vehicle present or no danger present	40 kph 56 kph 72 kph	3 4 4
26	multilane road (all types, all lanes) - deviate into oncoming lane of traffic or into dual direction turn-only lane - moving object present - pedestrian or bicyclist	40 kph 56 kph 72 kph	4 4 4
27	multilane road (all types, all lanes) - deviate into oncoming lane of traffic or into dual direction turn-only lane - stationary object present, non moving vehicle	40 kph 56 kph 72 kph	2 3 3
28	multilane road (all types, all lanes) - deviate into lane of traffic traveling in the same direction - moving vehicle next to ICC vehicle present or no danger present	40 kph 56 kph 72 kph	2 2 3

Event No.	Lane Deviation Event	Velocity of the ICC vehicle	Potential Severity Value
29	multilane road (all types, all lanes) - deviate into lane of traffic traveling in the same direction - moving object present - pedestrian or bicycle	40 kph 56 kph 72 kph	4 4 4
30	multilane road (all types, all lanes) - deviate into lane of traffic traveling in the same direction - stationary object present - non moving vehicle	40 kph 56 kph 72 kph	2 3 3
31	multilane road (all types, all lanes) - deviate onto shoulder of roadway - no danger present	40 kph 56 kph 72 kph	1 1 1
32	multilane road (all types, all lanes) - deviate onto shoulder of roadway - moving object present - pedestrian or bicycle	40 kph 56 kph 72 kph	4 4 4
33	multilane road (all types, all lanes) - deviate onto shoulder of roadway - stationary object present (non-moving vehicle, tree, sign, guardrail, etc.)	40 kph 56 kph 72 kph	2 3 3
34	multilane road (all types, all lanes) - deviate onto shoulder of roadway - stationary object present - curb	40 kph 56 kph 72 kph	1 1 1
35	freeway (all lanes) - deviate into lane of traffic traveling the same direction - moving vehicle present next to the ICC vehicle or no danger present	40 kph 56 kph 72 kph 88 kph	4 3 3 4
36	freeway (all lanes) - deviate into lane of traffic traveling the same direction - stationary object present - non-moving vehicle	40 kph 56 kph 72 kph 88 kph	2 3 4 4
37	freeway (all lanes) - deviate onto shoulder of roadway - no danger present	40 kph 56 kph 72 kph 88 kph	1 1 1 1
38	freeway (all lanes) - deviate onto shoulder of roadway - stationary object present - non-moving vehicle	40 kph 56 kph 72 kph 88 kph	2 3 4 4
39	freeway (all lanes) - deviate onto shoulder of roadway - stationary object present - tree, sign guardrail, etc.	40 kph 56 kph 72 kph 88 kph	3 3 4 4

Appendix I-C

Level Of Service Figures

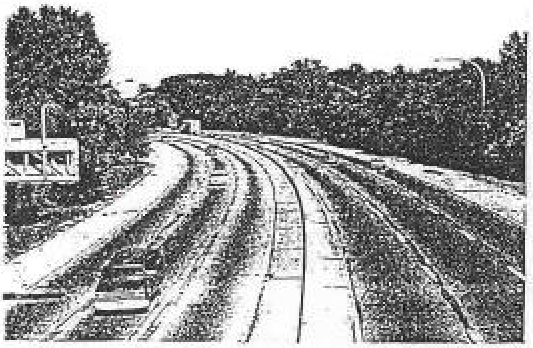


Illustration 3-5. LOS A.

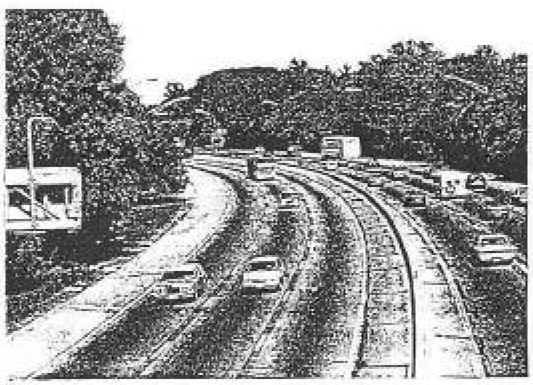


Illustration 3-6. LOS B.

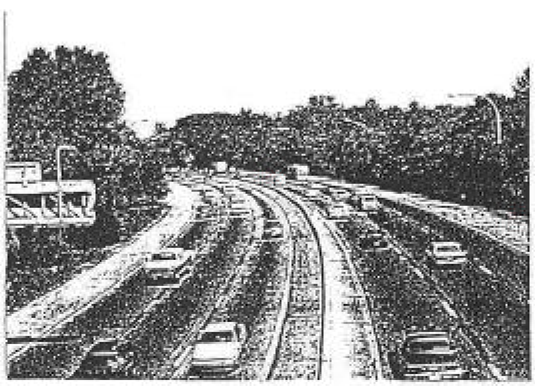


Illustration 3-7. LOS C.

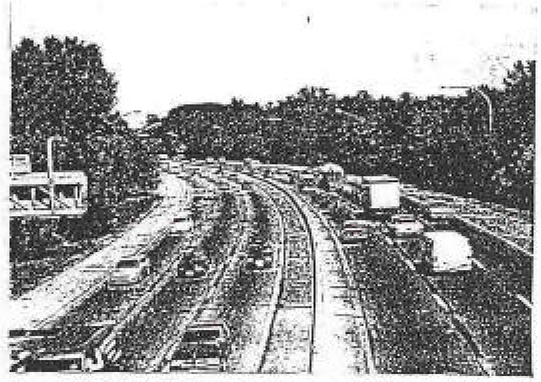


Illustration 3-8. LOS D.

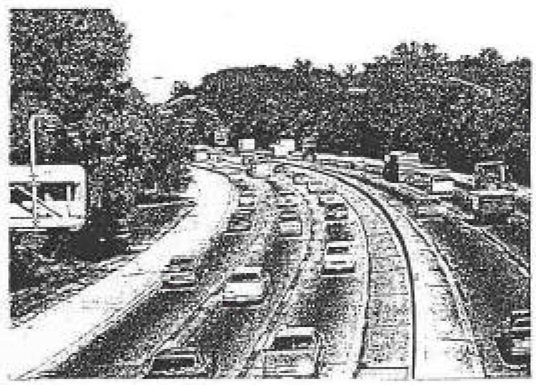


Illustration 3-9. LOS E.

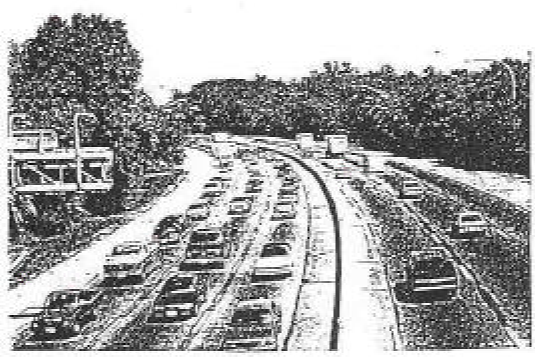


Illustration 3-10. LOS F.

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Appendix J

State Space Boundary Definitions

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This appendix presents and describes a set of range/range rate state space boundaries that can be used to evaluate the potential safety benefits of longitudinal collision avoidance systems from field operational test data. In the absence of collisions during the field tests, surrogate measures, such as the ones described in this report, must be established that can give an indication of the relative safety effectiveness of new Intelligent Transportation Systems (ITS) devices that are emerging. The surrogate measures need to be robust enough to discriminate safety effects between comparable devices as well as between different road types, driver ages, driving experiences, and environmental conditions. The state space boundaries, it is felt, provide a basis for formulating such surrogate measures.

The state space boundaries, as shown in Figure J-1, are represented by a set of curves in the (relative) range vs. (relative) range rate state space that are spread somewhat uniformly above the abscissa. The closer the curves are to the abscissa, the closer the driving situation, represented by a point on that curve, is to a collision situation. In other words, the curves closer to the abscissa are indicative of a relatively higher hazard potential.

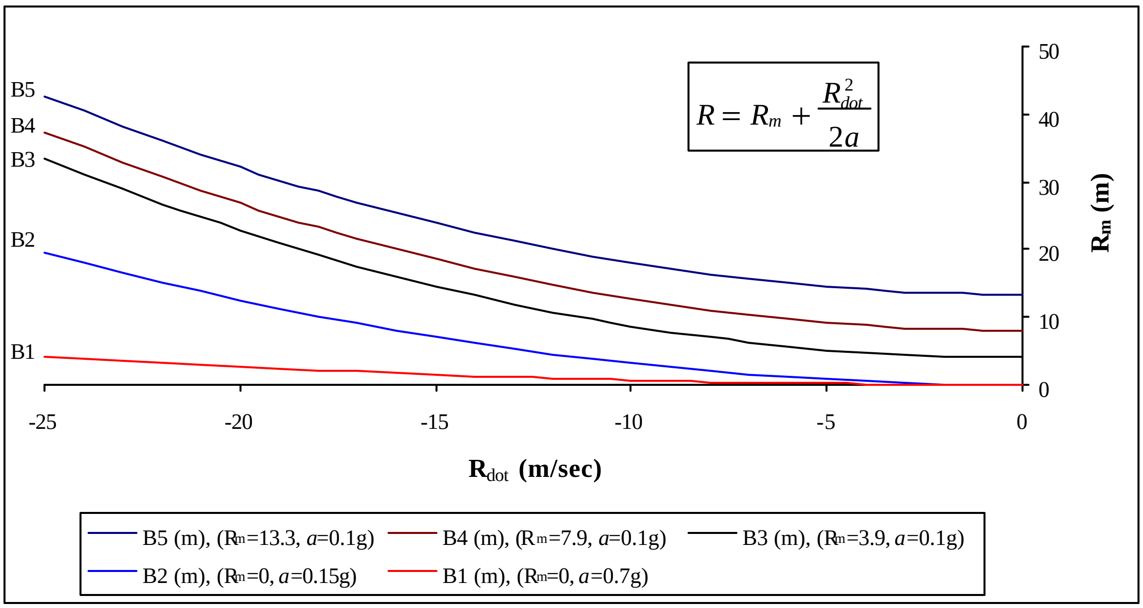

Figure J-1. State Space Boundaries

The equation for the set of curves is as follows:

$$R = R_m + (R_{dot})^2 / 2a$$

where

- R_m = minimum range separation
- R = range between lead and host vehicles
- R_{dot} = range rate between lead and host vehicles
- a = host driver braking level

The equation and a set of parameters for the curves are also shown in the figure. It is the form of the equation that allows physical interpretation to be given to the curves. That is, the boundaries can be thought of as representing the constant deceleration required to bring a following vehicle, initially closing in on a lead vehicle at a constant range rate and range indicated by any point on the curve, to the range indicated by the intercept of that curve with the ordinate. Treating the curves as initial conditions for potentially hazardous driving scenarios can extend this interpretation further.

An example of a driving scenario is a cut-in of a lead vehicle traveling at a lower constant velocity. The curves would indicate the initial conditions required at a given and immediate braking level, to just avoid a collision (those curves that pass through the origin in the phase plane) or for a near miss (those curves that intercept the ordinate above the origin). It should be pointed out that these state space boundaries not only represent the initial conditions for the above mentioned scenarios, but also their time responses as well. Other state space boundaries are presented in Appendix K that represent different scenarios such as “lead vehicle deceleration” and include driver time responses. For these, the state space boundaries are different from their respective time responses.

The safety metric for the state space boundaries is the relative occurrence of exceeding (falling below) each of the boundaries. The occurrence can be either frequency or time. Appropriate normalization of driving exposure, of course, is required for proper interpretation of the results. This safety metric is readily calculable from the range and range rate data that are obtained with the use of instrumented vehicles.

Figure J-2 puts the state space boundaries in the perspective of the control objective and control authority of the ICC-equipped vehicles. It is assumed here that the vehicle is travelling at 96 km/h and that the set headway is 1.0 second. It is further assumed that the downshifting and coasting curves are positioned (to bring the vehicle to within one half of the set headway) as indicated. Higher velocities and set headways would raise the control objective and control authority curves. Thus from Figure J-2, all the state space boundaries fall below the control objective and control authority curves. At lower velocities (minimum set velocity is 56 km/h) this may not be the case. Figure J-3 shows the state space boundaries as well as the control objective and control authority curves for the condition where the vehicle is moving at 56 km/h and the set headway is 1.0 second. Again the relative positioning of the downshifting and coasting curves are assumed. In this case all the state space boundaries do not fall below the control objective and control authority curves. However for the lower set velocities, the design of the ICC system may be such that control authority curves would bring the vehicle to within the set headway itself and not one half of the set headway. If this were the case, as shown in Figure J-4, then once again all the state space boundaries would fall below the control objective and control authority curves.

The state space boundaries are intended to capture the hazard potential of different driving conditions. As such the safety metric is a relative measure. By also relating to actual driving scenarios and incorporating parameters for specific conditions, the safety metric quantifies the violation of the conditions in an absolute sense. From both perspectives, the safety boundary metric provides a meaningful measure for evaluating the potential safety effects of Intelligent Transportation Systems (ITS) such as collision warning/avoidance system.

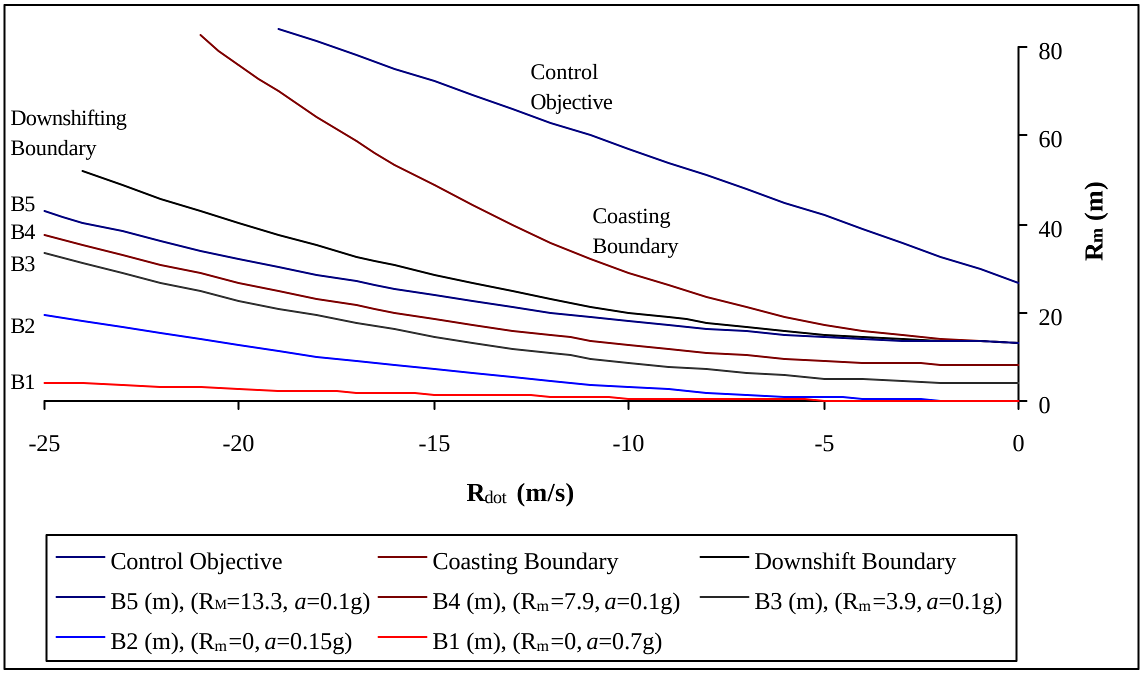

Figure J-2. State Space Boundaries with Control Objective, Coasting Boundary and Downshifting Boundary, V = 96 km/h, Hs = 1.0 second

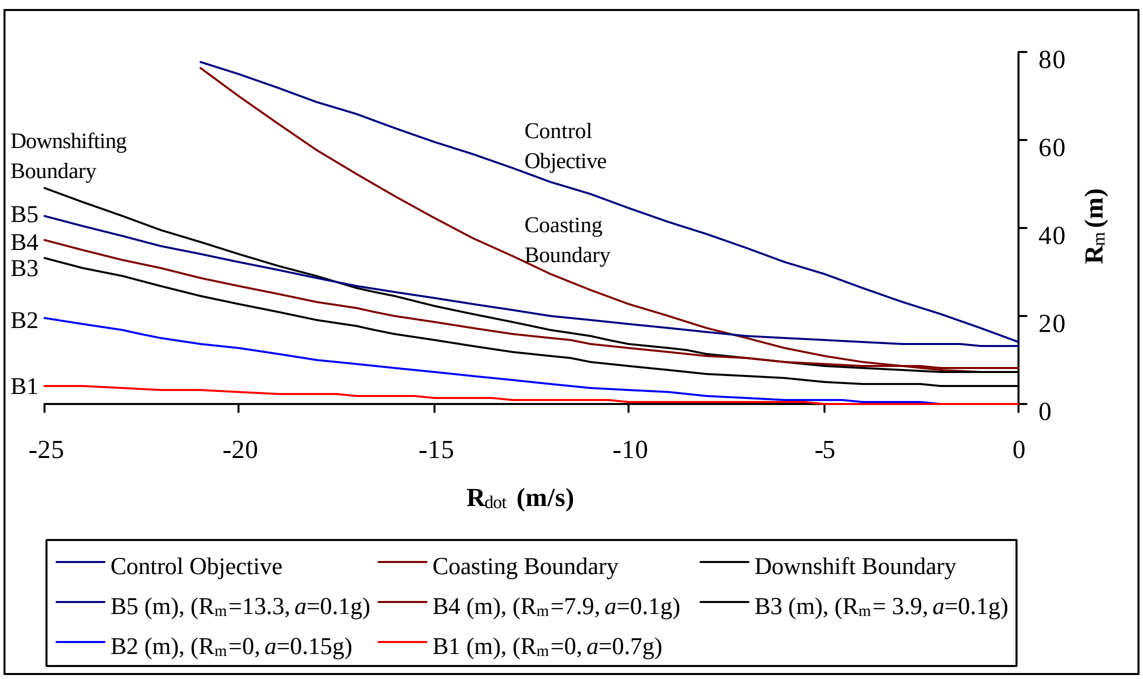

Figure J-3. State Space Boundaries with Control Objective, Coasting Boundary and Downshifting Boundary - Coasting Boundary and Downshifting Boundary Intercept Ordinate at Half Set Headway, V = 56 km/h, Hs = 1.0 sec.

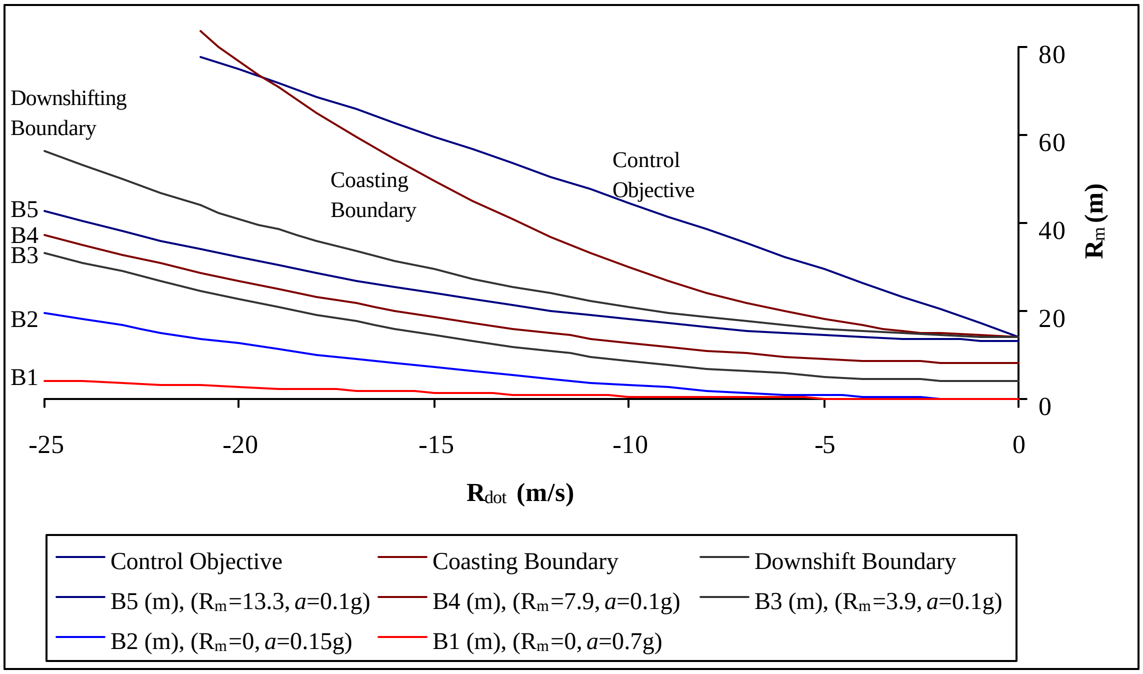

Figure J-4. State Space Boundaries with Control Objective, Coasting Boundary and Downshifting Boundary - Coasting Boundary and Downshifting Boundary Intercept Ordinate at Set Headway, V = 56 km/h, Hs = 1.0 second

In summary,

- the state space boundaries are curves spread in the range, range-rate state space,
- physical interpretations may be given to them depending on the equations and parameters used to represent them,
- the safety metric for the state space boundaries is the relative occurrence of exceeding (falling below) each of the boundaries,
- the safety metric provides a measure of the safety effect of a particular device or system under study, and for the conditions and situations examined, and
- specific state space boundaries may be matched with specific driving scenarios observed in field operational tests for more direct comparisons and analyses. This is covered more in the next appendix, Appendix K - *State Space Boundary Crossing Analysis*.

Appendix K

State Space Boundary Crossing Analysis

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K-1 Introduction

This appendix conducts additional state space boundary crossing analyses for the four specific pre-crash scenarios based on data from the field operational test. The four pre-crash scenarios are *lane change*, *cut-in*, *approach,* and *lead vehicle deceleration*. Two types of analyses are conducted:

1) A set of critical pre-crash scenarios, as described in Section 3.9.2.2 and further discussed in Appendix L, is examined by type against the general state space boundaries (boundaries without driver response time) presented in Section 3.9.1.6 The scenarios are first examined individually and directly with respect to the general boundaries in order to illustrate the safety metrics and describe appropriate constraints. The scenarios are then examined collectively (due to the small number of individual pre-crash scenarios) in terms of boundary crossings.

2) Specific state space boundaries (boundaries with driver response time) are developed for constant velocity closing situations, and for situations where the lead vehicle decelerates. Driver response times are incorporated into both of these types of boundaries. Again, select critical pre-crash scenarios are examined against these boundaries in order to illustrate the safety metrics and describe appropriate constraints.

A third type of analysis, which is in progress and not reported herein, applies the specific state space boundaries to their respective pre-crash scenarios with the appropriate constraints imposed. All the digital data from the field operational test are utilized in this analysis. The analysis is thus not just restricted to the critical pre-crash scenarios.

K-2 State Space Boundaries

The set of general state space boundaries is shown in Figure K-1. These boundaries were used in the body of the report and can be thought of as representing the deceleration required to bring a following or host vehicle, closing in on a lead vehicle at a constant rate, and starting at initial conditions indicated by any point on the curve, to the range indicated by the intercept of that curve with the ordinate. Furthermore, the initial conditions may be interpreted as initial conditions for potentially hazardous driving scenarios. The scenarios may be a particular driving situation or condition that suddenly confronts the driver of the host vehicle. It may be a cut-in or a realization of an in-lane situation involving a lead vehicle traveling at a lower constant velocity. The curves would indicate the initial conditions required at a given and immediate braking level, to just avoid a collision (those curves that pass through the origin in the phase plane) or for a near miss (those curves that intercept the ordinate above the origin).

The state space boundaries thus provide an integrated set of near miss measures expressed in terms of the state space variables, range and range rate, and a required deceleration level to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings.

It should also be pointed out that these state space boundaries not only represent the initial conditions for the above mentioned scenarios, but also their theoretical time tracks in the state space as well. (The time variable is implicit in the state space.) From a boundary perspective, any point on any curve represents the initial conditions for a constant velocity closing situation, that would result in the indicated minimum range and for the indicated deceleration level. The boundary condition can be also thought of as addressing the question "How far back of the lead vehicle (initial range) must the host vehicle be to result in the desired minimum range, for a given initial range rate and constant deceleration by the host vehicle?"

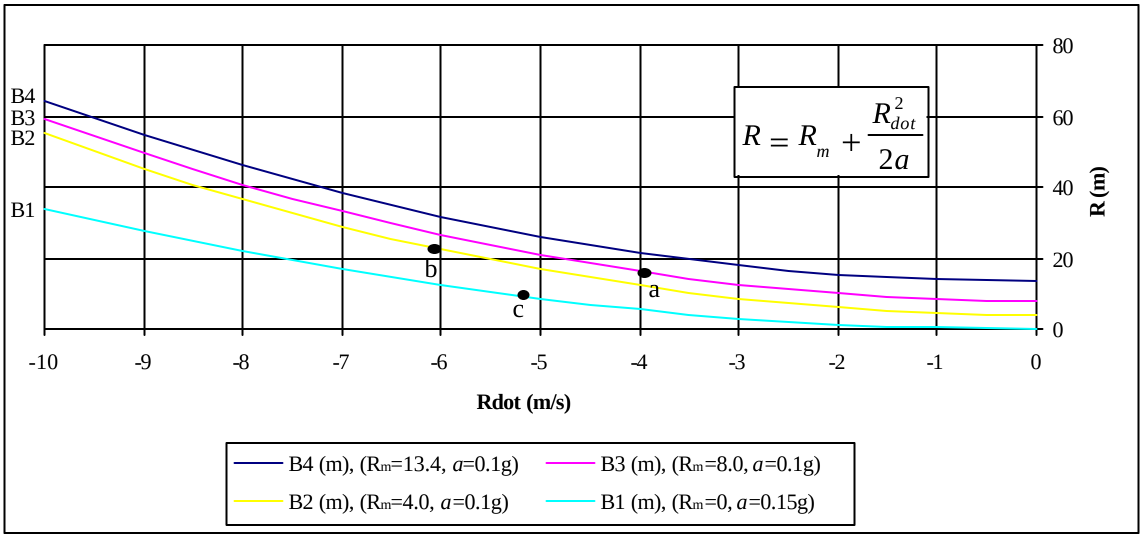

Figure K-1 State Space Boundaries

From a time track perspective, points on any single curve represent motion in time and space with the motion proceeding down along each of the curves in the state space. From any point on any curve (initial conditions) the motion will proceed to another point lower on that curve until reaching the minimum range.

The safety metric for the state space boundaries is the relative occurrence of exceeding or violating (falling below) each of the boundaries. The occurrence can be either the number of times a boundary is crossed or the time spent below a boundary. The resulting data would be normalized with respect to driving exposure. This safety metric is readily calculable from the range and range rate data that is obtained with the use of instrumented vehicles.

K-3 Analysis of a Set of Critical Pre-Crash Scenarios with respect to the General State Space Boundaries

A total of 41 critical pre-crash scenarios involving 29 drivers are examined in this section. The scenarios include 2 *lane changes*, 14 *cut-ins*, 12 *approaches*, and 13 *lead vehicle decelerations*. These scenarios were the same as those examined in Section 3.9.2.2 and discussed in more detail in Appendix L, *Video Analysis of Critical Pre-Crash Scenarios*. The pre-crash scenarios are defined in this study as involving closing situations with a lead vehicle. The critical scenarios were determined from an analysis of the video episodes. First, for each driver the captured videos episodes were searched, and the cases with the highest observed braking and the highest required braking force (near encounters) were selected. Furthermore, at the time the video was triggered there had to be a lead vehicle present in the video and that lead vehicle had to come within 30.5 meters of the host vehicle during the scenario.

Figures K-2 through K-5 show, for each scenario type, the critical pre-crash scenarios superimposed on the state space boundaries given in Figure K-1. The key points for each scenario type are discussed next:

Lane Change. There was only 1 case for CCC and 1 case for ICC. The were no cases for manual driving.

It is to be noted that none of the time tracks (for *lane change* or any of the other critical pre-crash scenarios below) are perfectly constant velocity closing situations. Otherwise the time tracks would appear as vertical lines in the state space. For purposes of this study, therefore, a range rate band of 1.5 m/s, was used as the criterion to distinguish between constant velocity closing situations from non-constant velocity closing situations. Note that this criterion is similar to that used to distinguish between the *following* driving state and the *closing* and *separating* driving states.

The interpretation of the boundary crossings, referencing the specific deceleration levels and minimum range, as discussed above, for each time track requires the assumption of a constant lead vehicle velocity at the moment of the crossing. The more the lead vehicle's motion departs from this assumption the less valid the interpretation. If the lead vehicle's motion is characterized more by a constant deceleration then other state space boundaries may be more appropriate. (This type of scenario is discussed below).

The lead vehicles' velocities for the two *lane change* cases were relatively constant at the times of each of the crossings (This was determined from the velocity profiles of the lead vehicles and not the range-versus-range-rate diagram.) falling within the 1.5 m/s band, so the interpretations of the crossings of each of the boundaries may be used. Overall, Figure K-2 shows that both cases were within the upper and lower boundaries.

Cut-In. There was 1 manual case, 2 CCC cases, and 11 ICC cases. Since once again, the lead vehicles' velocities for these *cut-in* cases were relatively constant at the times of each of the crossings, the interpretations of the crossings of each of the boundaries may be used. Thus, as an example, when the manual *cut-in* case just reached the top boundary, a deceleration level of 0.10g at that instant would have brought the host vehicle to 13.4 meters behind the lead vehicle. As it turned out, the host vehicle driver did brake at about this level and tracked the top boundary closely until one of the vehicles made a lane movement to end the scenario.

Without making reference to the specific parameters for each boundary, the state space boundaries as a set provide an overall reference that do not impose any motion constraints on the lead or following vehicles, and from which the hazard potential of the time tracks can be assessed. In this context, Figure K-3 shows that all 11 ICC cases tended to produce a relatively narrow band of time tracks that was bounded by the upper and lower boundaries. The ICC cases tended to be lower than the CCC and manual cases (although there were too few to generalize). It is worth pointing out here that the one extreme case that started below the lowest boundary but ended up with a minimum range of over two car lengths was a CCC case. The driver braked at over 0.2 g to attain this minimum range.

Approach. There were 3 manual cases, 5 CCC cases and 4 ICC cases. Practically all the cases started substantially above the boundaries and most ended within the boundaries. From Figure K-4 it can be seen what cases violated (fell below) what boundaries.

It is to be further noted from Figure K-4 that most of these time tracks also show a relative deceleration of the following vehicle from the start of the scenario. (The state space portrays the relative motion between the lead and following vehicles). That is, the time tracks tend to slope downwards from left to right. The one exception is the left time track in the top figure. Here there is a relative deceleration of the lead vehicle at the start of the scenario, then changing briefly to what might be a constant velocity motion until there is a lane movement by one of the vehicles to end the scenario. Overall, since this scenario fell within the 1.5 m/s range-rate band, it was considered an *approach*.

Since the lead vehicles' velocities for these *approach* cases were relatively constant at the times of each of the crossings, the interpretations of the crossings of each of the boundaries may be used. Thus, as an example, when the ICC *approach* case just reached the lower boundary, a deceleration level of 0.15g would have been required to just avoid a collision.

Relative to the state boundaries as a set, the main finding from Figure K-4 is that, similar to that for cut-ins, the ICC cases tended to cross more of the lower boundaries than either the CCC cases or the two manual cases.

Lead Vehicle Deceleration. There were 3 manual cases, 6 CCC cases and 4 ICC cases. Since the lead vehicles' velocities for these cases were changing by definition, the interpretations of the crossings of each of the boundaries cannot be made with respect to the designated parameters. However, the *lead vehicle deceleration* cases may still be assessed relative to the state boundaries as a set. In the next section, *lead vehicle deceleration* boundaries are developed specifically for *lead vehicle deceleration* scenarios.

All the *lead vehicle deceleration* cases shown in Figure K-5 had initial conditions well above the state space boundaries. The minimum ranges were all above two car lengths with the exception of one case for manual driving which was closer to one car length. It is to be noted that the CCC cases and ICC cases tended to spread to the left compared to the manual cases. This indicates that the host vehicle drivers tended to wait longer before responding. Only one case went below the lowest boundary and this was a CCC case.

Figure K-6 shows the violation rate of the boundaries aggregated over all the pre-crash scenario types for each of the three modes. Although there tended to be a similar pattern for the individual pre-crash scenario types the relatively few cases did not lend themselves to meaningful comparisons. Overall, the violation rate, expressed as a percentage of cases for each mode, shows a substantially higher violation rate for ICC and CCC. Although the lowest boundary had no violation for ICC or manual driving, the next two lowest boundaries showed substantially higher violation rates for ICC compared to both CCC and manual driving. These results seem to indicate that there are extreme driving situations that are characterized by a consistent pattern of delaying intervention, braking harder and reaching closer minimum ranges. Although potentially a sign of inattentiveness, the most likely explanation, taking into account the questionnaire and focus group results of the study, is that the drivers are waiting to see to what extent the ICC system will resolve the situation.

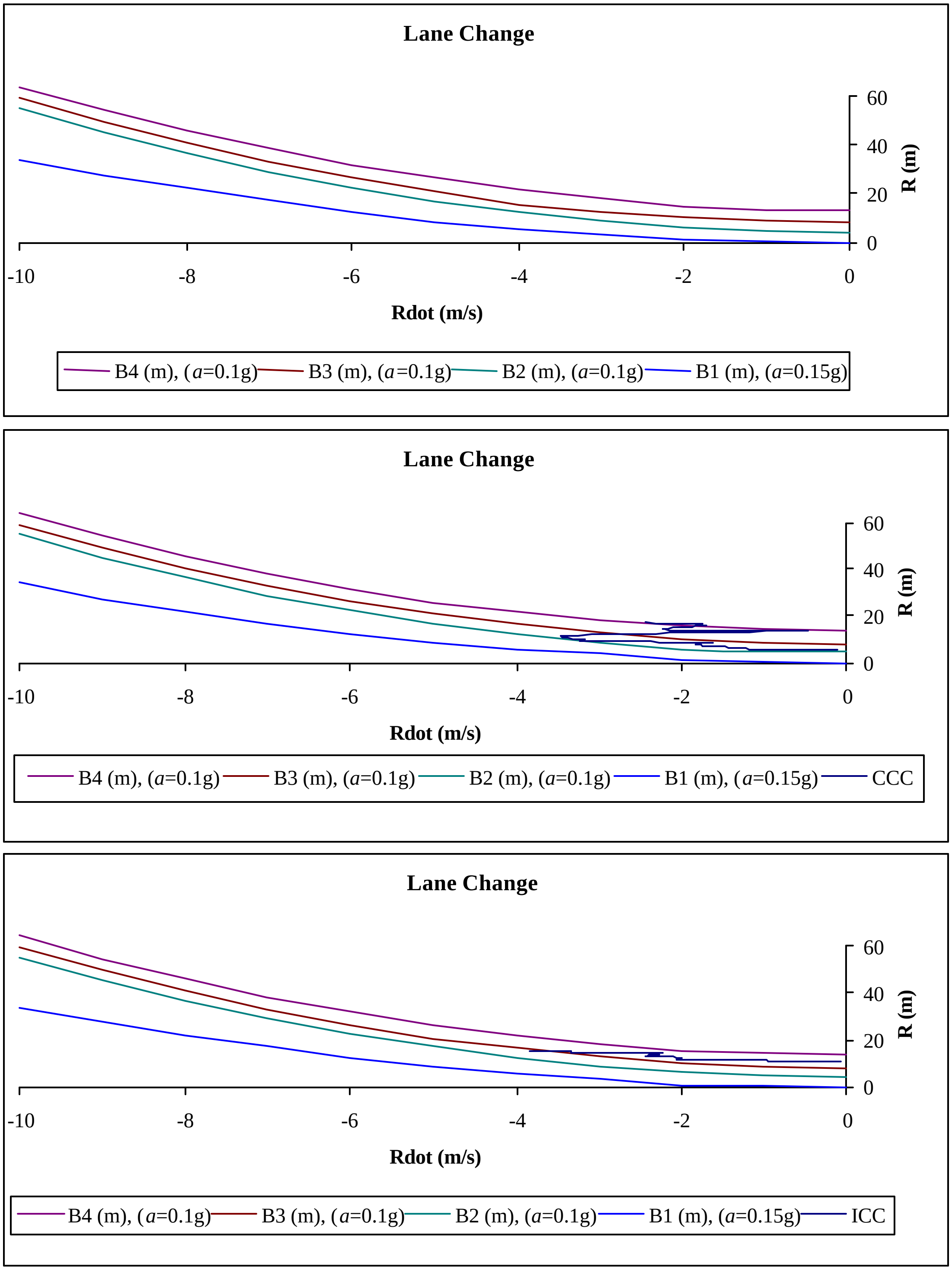

Figure K-2 State Space Boundaries and Critical *Lane Change* Scenarios

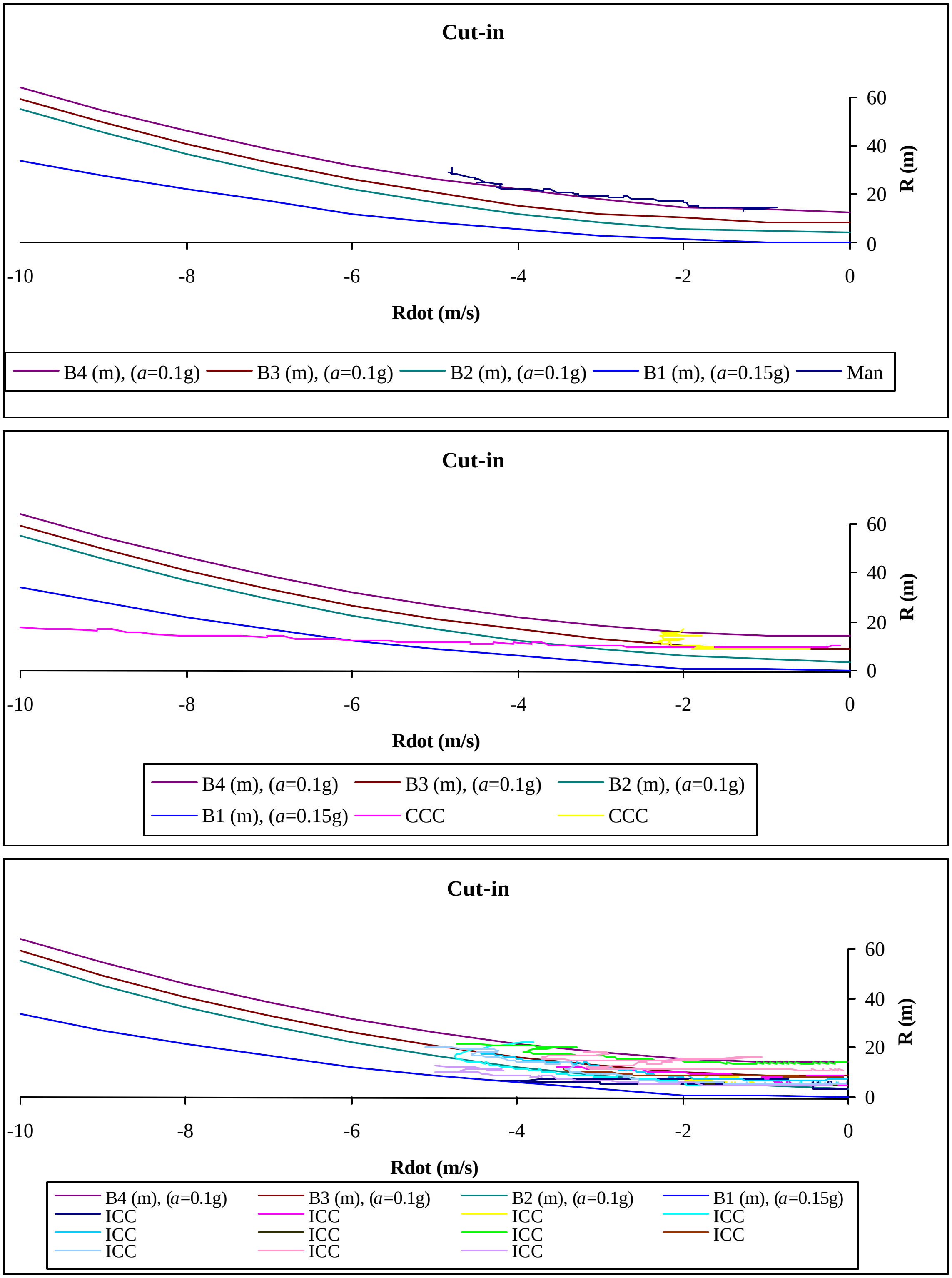

Figure K-3 State Space Boundaries and Critical *Cut-in* Scenarios

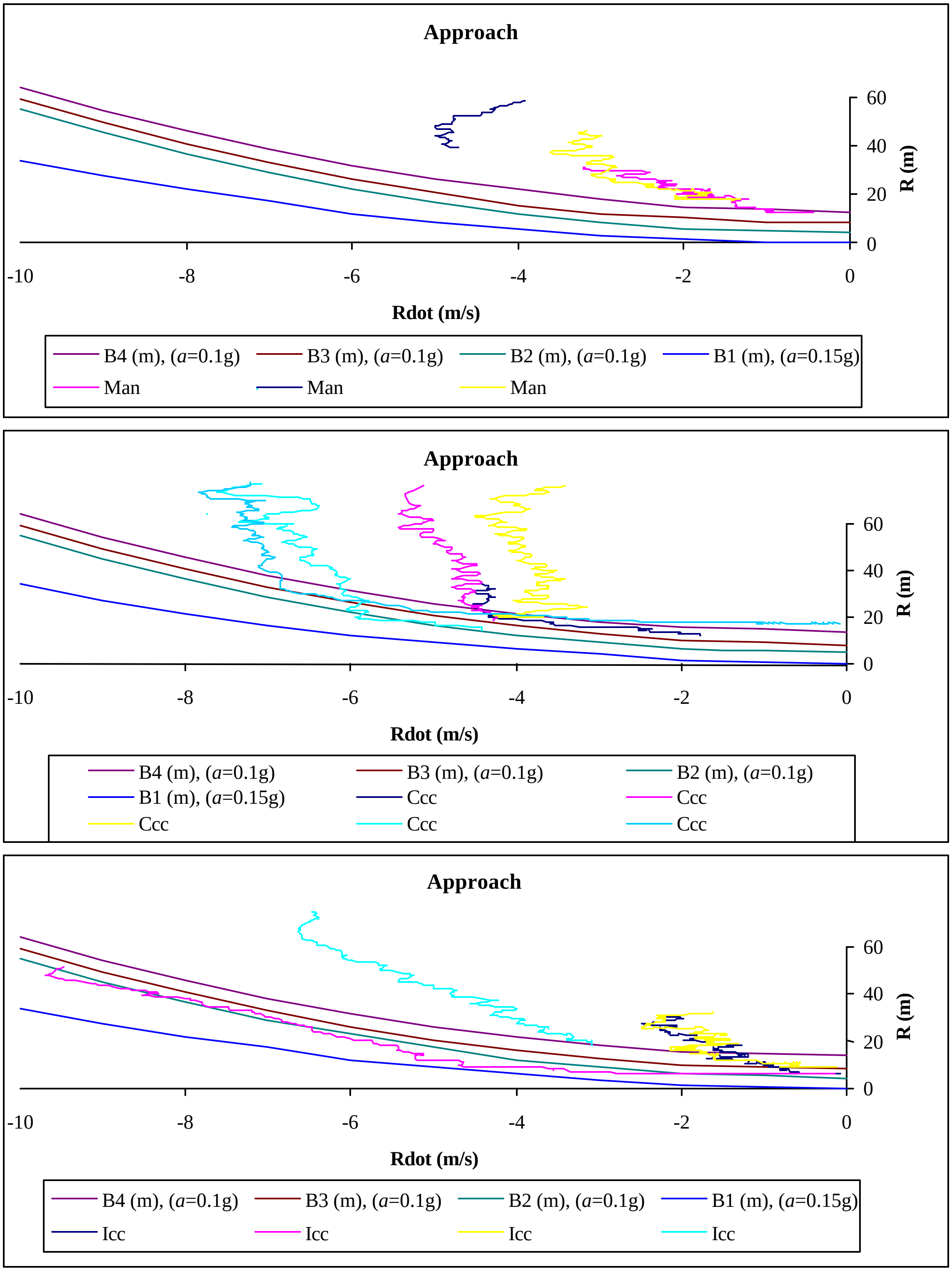

Figure K-4 State Space Boundaries and Critical *Approach* Scenarios

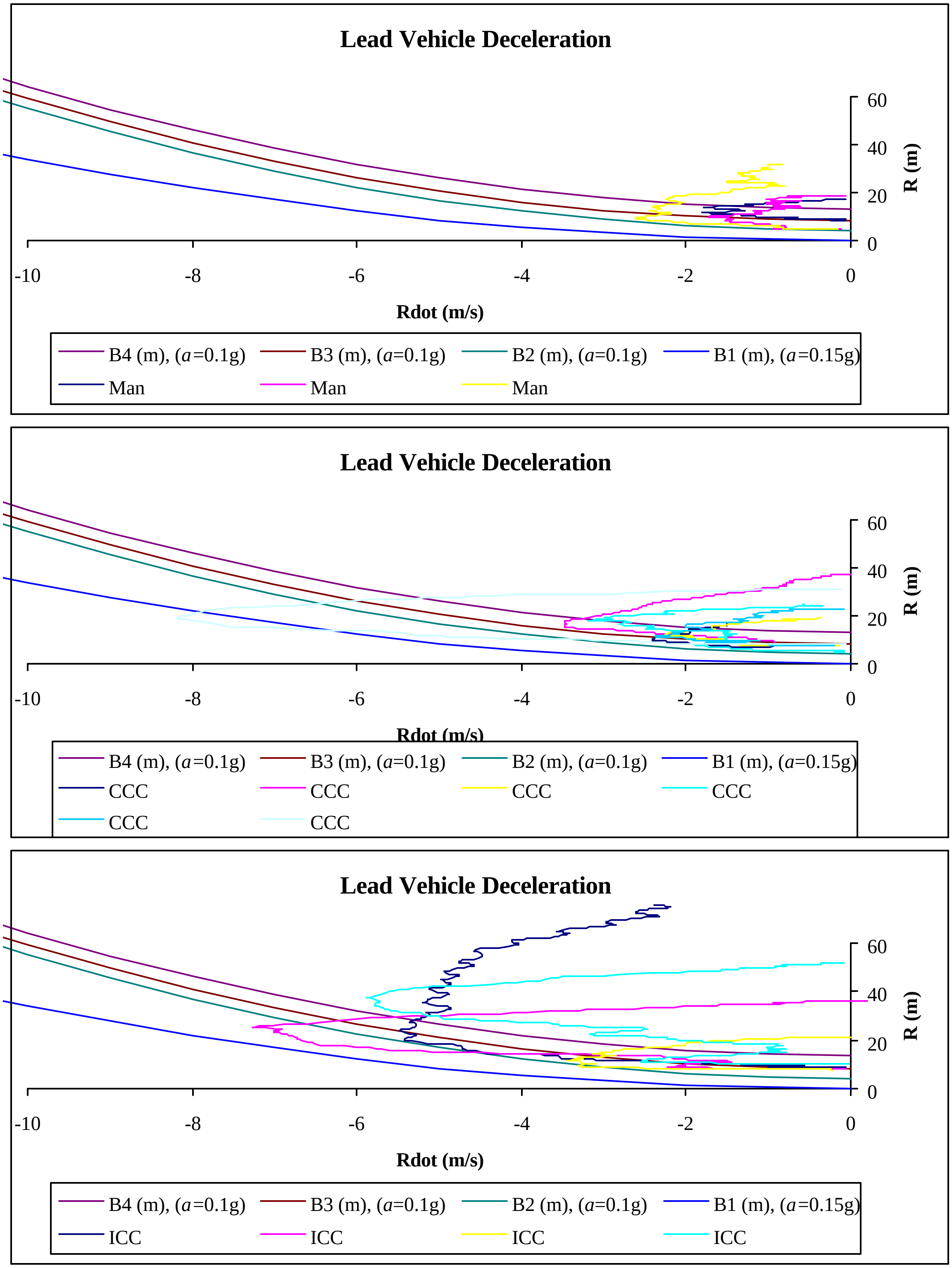

Figure K-5 State Space Boundaries and Critical *Lead Vehicle Deceleration* Scenarios

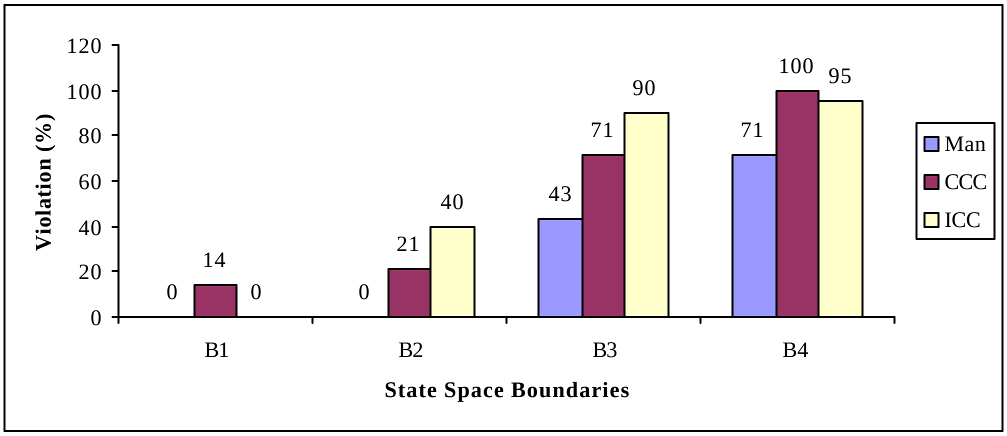

Figure K-6 State Space Boundaries Violations – Critical Pre-Crash Scenarios

K-4 Analysis of Select Critical Pre-Crash Scenarios with Specific State Space Boundaries (Boundaries with Driver Response Time)

K-4.1 Constant Velocity Closing Situations With Driver Response Time

Figure K-7 first describes the specific state space boundaries used in this study to examine constant velocity closing situations that include host driver response times. By introducing driver response time, these safety boundaries can be used to facilitate the understanding of the potential impact of this added factor. For example, with these boundaries a determination can be made from the operational test data of the occurrence of situations where specific driver response time are required to just avoid a collision, assuming the indicated braking level. However, it needs to be pointed out that use of these boundaries impose the constraint that both the lead and the following vehicles travel at constant speeds at the moment of the boundary crossing.

The state space boundaries represented in Figure K-7 are similar to the ones in Figure K-1 in that they represent the initial conditions for constant velocity, closing situations between the lead and host vehicles. They differ in two respects: 1) the boundaries include delays between the time the maneuver is initiated and the time the following vehicle decelerates. The delays may, in effect, be considered driver response times. The delays or driver response times shown in the figure are 1.0, 1.5, and 2.0 seconds respectively. 2) the deceleration level of the host vehicle in Figure K-7 is 0.25 g for all three boundaries. This higher deceleration level is intended to compensate for the driver response time.

Each of these boundaries thus represents the initial conditions to just avoid a collision, assuming the driver in the host vehicle responded to the initial conditions in the indicated time and braked at a constant level of 0.25 g. Similar boundaries can be constructed that implement a minimum range criteria by simply adding a value to the ordinate that represents the desired minimum range. The equation for the state space boundaries is also shown in the figure.

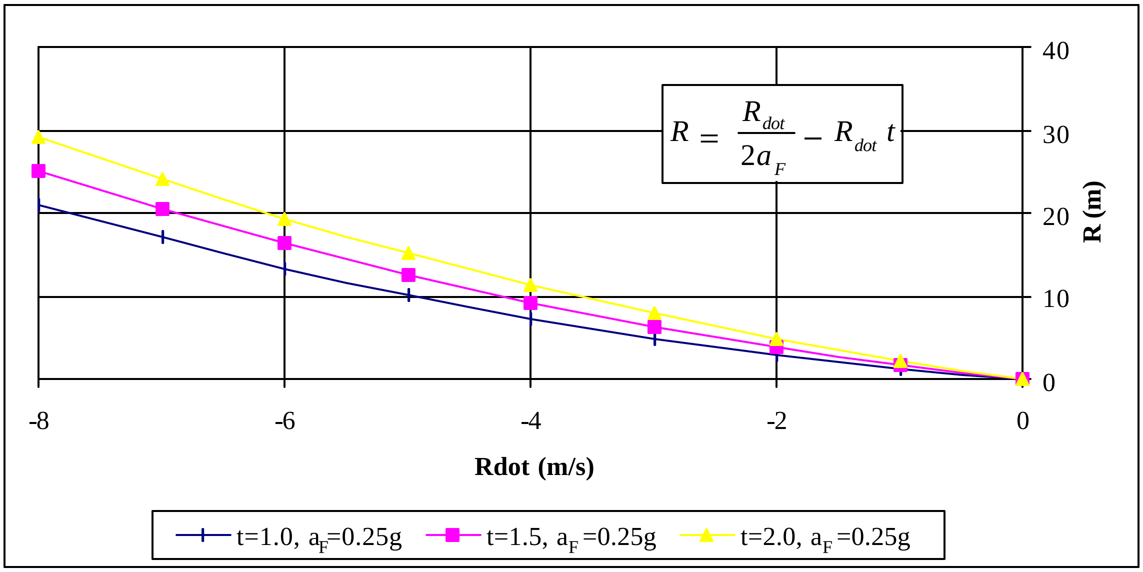

Figure K-7 State space boundaries for Constant Velocity Closing Situations With Driver Response Time

With the addition of time delay, these state space boundaries thus provide an integrated set of near miss measures expressed in terms of the state space variables, range and range rate, as well as the time response and deceleration level required to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings. This set of boundaries is not unique. Other response times, deceleration levels and minimum ranges may be used.

The application of these state space boundaries is illustrated next using the same scenarios examined in the previous section. Only the approach case had scenarios that met the added imposition of constant velocity for the host vehicle when the boundaries were crossed. Hence, only the approach cases are examined here

Approach. Figure K-8 shows the critical approach cases where the lead and the host vehicle were both traveling at constant velocities, that is, each falling within the 1.5 m/s band before crossing the state space boundaries. (This was determined from the velocity profiles of the lead and host vehicles, and not the range-versus-range-rate diagram.) With the constant velocity constraints satisfied**,** the interpretations of the crossings of each of the boundaries may be used. There were five CCC approach cases where the lead and host vehicles were traveling at constant velocities before the host vehicle braked. None of the five cases ended up crossing any of the boundaries. At the time of braking for these five cases, the figure shows that drivers all had more than 2.0 seconds available to respond and brake at a 0.25 g level to just avoid a collision. There was a similar finding for the two ICC cases. Thus, there are no boundary crossings for this limited set of data. Applying this methodology to the full set of digital data from the field operational test could produce valid boundary crossings with the given interpretation. It should be noted that the boundaries could be adjusted to give a higher spread in the range-versus-range-rate space, but this would be at the expense of reducing their criticality.

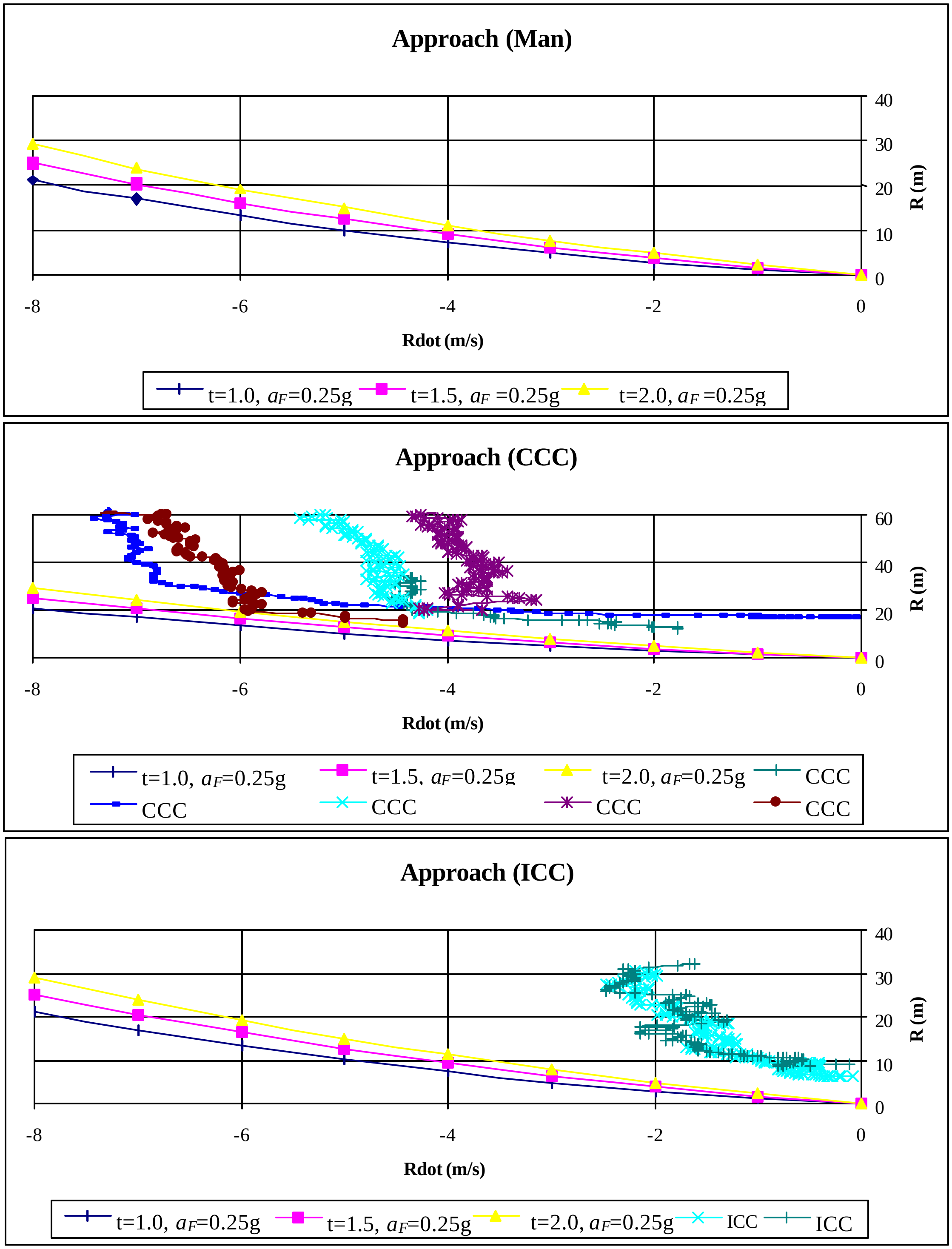

Figure K-8 State Space Boundaries for Constant Velocity Closing Situations with Driver Response Time and Critical Approach Scenarios

K-4.2 Lead Vehicle Deceleration Situations With Driver Response Time

Figure K-9 describes specific state space boundaries used in this study to examine *lead vehicle deceleration* situations. These state space boundaries include host driver response times. Without allowing for a host driver response time, the classical locked-pair *lead vehicle deceleration* scenario cannot be formulated as a near miss problem. With driver response time included as part of the scenario, these safety boundaries can be used to facilitate the understanding of its potential impact. These state space boundaries also introduce another parameter, namely, the deceleration level of the lead vehicle. Use of these boundaries impose a number of constraints that are discussed below.

A more stringent factor in this state space boundary analysis, compared to that for the other scenarios, is the need to assure that the lead vehicle does not decelerate to zero velocity (this would produce a different set of equations and state space boundaries, and hence warrant a separate analysis). However, for the ICC evaluation, where emphasis is on higher initial velocities (the system will not engage below 56 km/h), the factor is not overly restrictive. High decelerations would be needed for long time periods in order to result in a stopped vehicle condition. Observations from the field operational test data indicate that indeed, decelerating to a stop from higher velocities as a continuous scenario and in the absence of intersections is a rare event.

Figure K-9 shows a set of state space boundaries for the *lead vehicle deceleration* scenario. Similar to analyses conducted for the constant velocity situations, these state space boundaries may be used for specific analyses of the *lead vehicle deceleration* scenarios to compare different cases and to facilitate the understanding of parameters associated with the boundaries. Again, this set of boundaries is not unique and different sets of boundaries are needed to better understand and interpret the impact of different parameters. Use of these state space boundaries also does not preclude the use of the general state space boundaries in Figure K-1 to examine the potential hazardousness of any or all driving situations.

The three state space boundaries in Figure K-9 are for the following situations: (1) lead vehicle decelerates at 0.20 g, and the host vehicle delays 1.0 second and decelerates at 0.50 g; (2) lead vehicle decelerates at 0.40 g, and the host vehicle delays 1.0 second and decelerates at .60 g; and (3) lead vehicle decelerates at 0.40 g, and the host vehicle delays 1.0 second and decelerates at 050 g. These three state space boundaries thus represent the initial conditions to just avoid a collision, assuming the driver in the lead vehicle braked at the indicated levels, and the driver of the host vehicle reacted in one second and braked at the indicated levels. Again, similar boundaries could be constructed that implement a minimum range criteria by simply adding a value to the ordinate that represents the desired minimum approach. The equation for the state space boundaries is also shown in the figure.

With the addition of another variable, namely the lead vehicle deceleration, these state space boundaries thus provide an integrated set of near miss measures expressed in terms of the state space variables, range and range rate, as well as the time response and deceleration level required to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings.

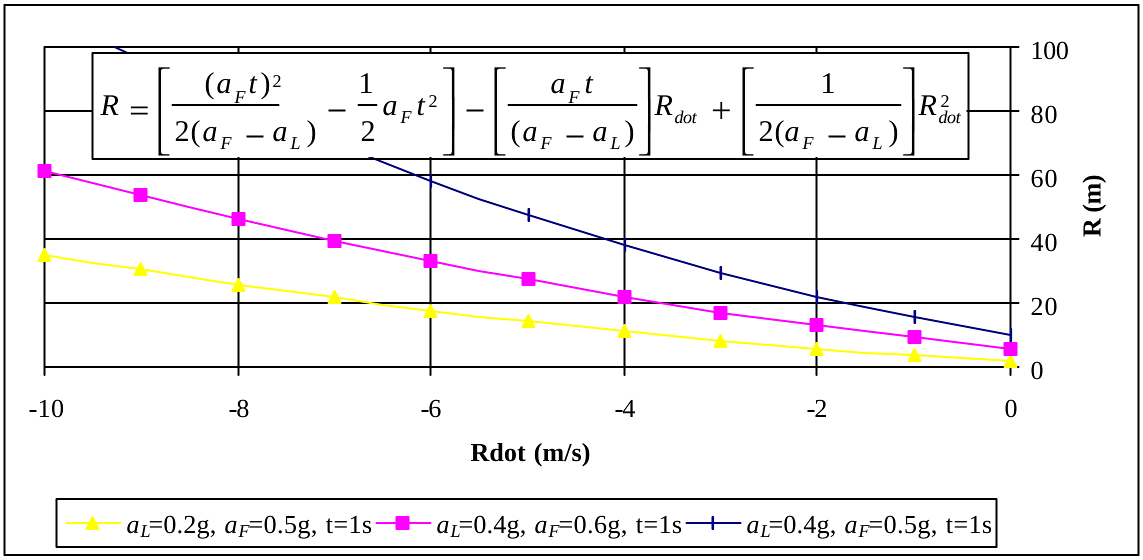

Figure K-9. State Space Boundaries For *Lead Vehicle Deceleration* Scenario

A few points are noteworthy from Figure K-9. First, the interpretation of the points where state space boundaries intercept the ordinate is that the lead and host vehicles are travelling at the same speed (locked-vehicle pair) when the lead vehicle decelerates. Since the state space boundaries represent initial conditions to just avoid a collision, the time tracks starting at these initial conditions and with the indicated vehicle delay and braking levels would thus produce a "just avoid collision" condition.

The second main point is that initial conditions off the ordinate means that there is, in effect, a closing situation at the time the lead vehicle decelerates. This closing situation only serves to compound the criticality facing the host vehicle. The initial conditions far to the left and above the origin (zero-zero point) illustrate the level of criticality. Very large separations would be required to just avoid a collision when only moderate initial closing conditions existed under certain braking and delay combinations that are not unreasonable. It might also be added that, from a practical point of view, an initial condition where two vehicles were closing moderately at the time the lead vehicle decelerated would be expected to be a somewhat rare event. As a matter of fact, in all the "worst case" *lead vehicle deceleration* scenarios that were examined in the field operational test, only a very few had a moderate initial closing condition. (None of these cases resulted in either high braking levels or close minimum ranges.)

With regard to the application of the *lead vehicle deceleration* state space boundaries with driver response time to analyze field operational test data, the following points are made:

1. Similar to any of the other boundaries described above, these boundaries can be used without parametric interpretation or constraints to examine the potential hazardousness of any or all driving situations. The metric is the crossing of the boundaries or the time spent below the boundaries. A uniform spread of boundaries near the abscissa in the upper left hand quadrant of the phase plane is desirable.

2. The boundaries can be used with parametric interpretation to gather further insights into potential near miss impacts.
3. When used in this manner, a number of constraints need to be considered. The lead vehicle must be decelerating at a constant rate while the host vehicle is traveling at a constant velocity. During this phase, boundary crossings and time spent below boundaries are appropriate measures, and interpretation of the actual time track data with respect to the boundaries may be given in terms of the parameters associated with the boundaries. When the following vehicle decelerates, the interpretation with respect to the boundaries ceases, but the crossing and time metrics are still relevant.
4. A number of boundary sets (templates) are needed to fully interpret the results. There should be a template for each level of lead vehicle deceleration. Each of these templates could in turn have sub-templates where, for example, the level of the host vehicle deceleration varies and the driver response time is held constant, or the driver response time varies and the level of the host vehicle deceleration is held constant.

To illustrate the application of the *lead vehicle deceleration* state space boundaries with driver response time in analyzing field operational test data, one of the ICC *lead vehicle deceleration* scenarios in Figure K-5 is superimposed on the state space boundaries given in Figure K-9. The results are shown in Figure K-10. The scenario is representative of the cases that can be analyzed with the safety boundaries since it meets the constraints mentioned above and illustrates some of the findings from this type of analysis.

The ICC driver was confronted with a lead vehicle deceleration level of 0.40 g at a range of 36 meters. Two of the state space boundaries in Figure K-10 incorporate this deceleration level. The response deceleration by the host vehicle driver was approximately 0.30 g. (In the figure, it is to be noted that the decelerations are the relative decelerations between the lead vehicle and the host vehicle.) Note that the lead vehicle deceleration was quite uniform and constant, while the response deceleration was somewhat uniform throughout the scenario. Note further that the response deceleration was substantially less than the g levels used in conjunction with the state space boundaries.

The two state space boundaries that incorporate the lead vehicle deceleration level of 0.40 g lend themselves to direct interpretation with the actual scenario. At the instant of the crossing of the top boundary, the driver would have 1.0 second to respond and brake at 0.50 g to just avoid a collision. At the instant of the crossing of the middle boundary, the driver would have 1.0 second to respond and brake at 0.60 g to just avoid a collision. Thus the boundary crossings and the time spent below this boundary indicate the degree to which the driver was in a near miss situation defined by this criteria.

Figure K-10 also lends itself to further interpretation of the results. Since the initial conditions for this scenario involve a zero closing rate, a comparison can be made of the initial point that intersects the ordinate. In can be seen from the figure that the ICC scenario has an initial range greater than the state space boundaries. The differences in the ranges between the ICC scenario initial conditions and the corresponding boundaries (with the lead vehicle deceleration levels of 0.40 g) may be considered safety margins. For example, the difference in range between the ICC scenario initial condition and the top boundary is 26 meters. This means that the ICC driver could delay 1.0 second, brake at 0.5 g and avoid the lead vehicle by a margin of 26 meters. Relative to the other corresponding state space boundary, the ICC driver could delay 1.0 second, brake at 0.6 g and avoid the lead vehicle by a margin of 29 meters.

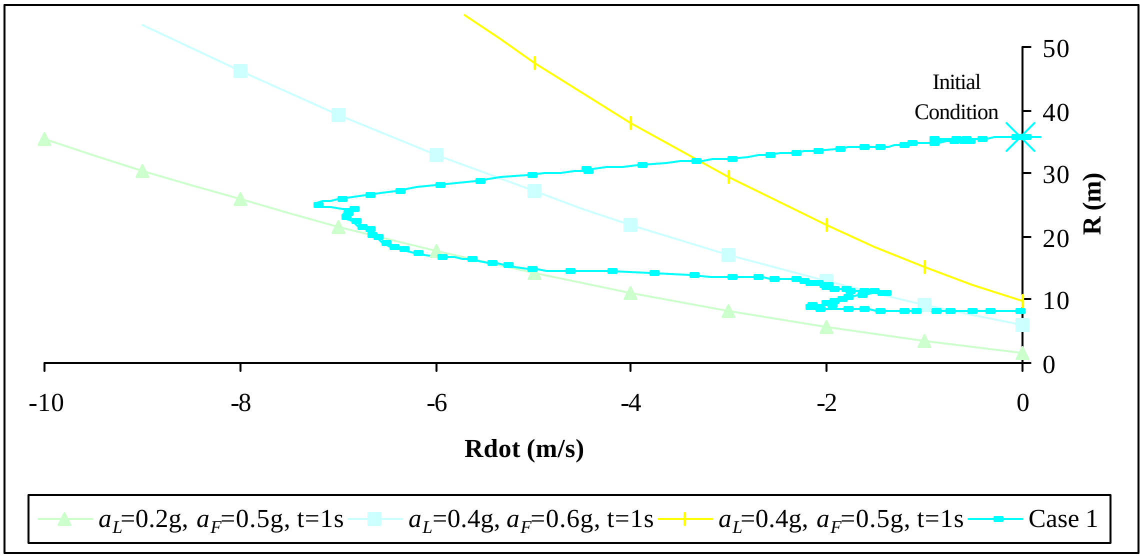

Figure K-10. *Lead Vehicle Deceleration* Space State Boundaries and ICC Scenario

In the actual scenario the driver delayed about 2.0 seconds and braked at 0.3 g. The resulting minimum approach was 9 meters. (As mentioned above, the deceleration levels were somewhat uniform but there appeared to be two stages of braking for each vehicle. The lead vehicle first decelerated at 0.40 g for 4.0 seconds and then at 0.15 g for another 4.0 seconds. The host vehicle first decelerated at 0.30 g for 4.0 seconds and then at 0.15 g for 3.0 seconds.) The scenario ended with a lane change by the lead vehicle. Since the initial braking by the host vehicle driver, and thus the disengagement of the ICC, occurred soon after the initiation of the lead vehicle deceleration and at a distance of 30 meters, this was not considered a hazardous case.

K-5 Analysis of All Pre-Crash Scenarios (Planned)

The intent of this future analysis is to first determine all the pre-crash scenarios from the digital data collected during the field operational test and then to apply the state space boundary concepts described above. The output will be an extensive near miss analysis expressed in terms of the boundary crossing metrics and the near miss parameters: deceleration levels, response times and minimum ranges. The data will be disaggregated by pre-crash scenario type.

The important independent variables that will be studied are cruise mode, road type, and prior cruise usage. Other independent variables that will be considered are driver age, ICC driving experience, gender, and congestion.

Whereas the critical pre-crash scenario analyses described above allowed a demonstration of the state space boundary crossings methodology and produced limited results, analysis of all the data from the field operational test should provide sufficient data for a fairly complete boundary crossing analysis. These will include the constant velocity situations and the *lead vehicle deceleration* situations, each with and without driver response times. Appropriate constraints will be applied in all analyses.

K-6 Summary

The application of the state space boundary concept has been developed and demonstrated with actual data from a field operational test. Several types of analyses involving state space boundaries were described.

1. The first was a general set of boundaries in the upper left quadrant of the range versus range rate state space. A uniform spread of the boundaries near the abscissa is desirable. The actual form or equations associated with the boundaries are not important. They may be developed for constant velocity closing situations or lead vehicle decelerating situations. Crossings of the boundaries gives a relative indication of the hazard potential, with crossings of boundaries closer to the abscissa being more hazardous than crossings of boundaries away from the abscissa.

2. A specific set of boundaries for constant velocity closing situations without driver response time was next developed. With this set of boundaries interpretation may be made with respect to near miss impacts defined in terms of the parameters associated with the boundaries. The main constraint with this set of boundaries is that the lead vehicle needs to be moving at a constant velocity at the moment of the boundary crossing. As suggested above, a criterion of 1.5 m/s for the velocity band may be used to establish a constant velocity situation. These state space boundaries thus provide an integrated set of near miss measures for constant velocity closing situations expressed in terms of the state space variables, range and range rate, as well as the deceleration level required to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings.

3. A specific set of boundaries for constant velocity closing situations with driver response time was then developed. With this set of boundaries interpretation may also be made with respect to near miss impacts defined in terms of the parameters (including response time) associated with the boundaries. The main constraint with this set of boundaries is that both the lead vehicle and the host vehicle need to be moving at a constant velocity at the moment of the boundary crossing. These state space boundaries thus provide an integrated set of near miss measures for constant velocity closing situations expressed in terms of the state space variables, range and range rate, as well as the time response and deceleration level required to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings.

4. Lastly, a specific set of boundaries for lead vehicle decelerating situations with driver response time was developed. (The situation involving *lead vehicle deceleration* without driver response was not examined since the vehicle locked-pair cases have no solution.) With this set of boundaries interpretation may also be made with respect to near miss impacts defined in terms of the parameters associated with these boundaries. The main constraint with this set of boundaries is that it applies to only the *lead vehicle deceleration* scenario. Also, the lead vehicle must be decelerating at a constant rate while the host vehicle is traveling at a constant velocity. When the

following vehicle deceleration, the interpretation with respect to the boundaries ceases. These state space boundaries thus provide an integrated set of near miss measures for the *lead vehicle deceleration* scenario expressed in terms of the state space variables, range and range rate, as well as the time response and deceleration level required to achieve a minimum range. Each boundary integrates these variables into a single measure of driving hazard, namely, the boundary crossings.

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Appendix L

Video Analysis of Critical Pre-Crash Scenarios

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L-1 Introduction

This section describes the analysis that was conducted with respect to critical pre-crash scenarios. Four pre-crash scenario types have been identified as appropriate to this study. The four pre-crash scenario types are *lane change*, *cut-in*, *approach,* and *lead vehicle deceleration*. Critical scenarios are defined in this report as those that result in the highest decelerations or closest encounters. This analysis was conducted with the aid of the videos that were collected. Recall that the videos were triggered by one of three conditions: 1) braking level of the host vehicle equal to or greater than .05 g, 2) breaking level required to bring the host vehicle to within 0.3 second of the lead vehicle equal to or greater than .05 g (near encounter), and 3) driver pushed the concern button.

There are several advantages of using the video analyzer for this type of analysis: 1) the scenario type is clearly identifiable from the video, 2) the beginning and end of the scenario are also determinable, 3) with the use of the integrated digital data displayed with the video, the parameters associated with each scenario can be readily captured, 4) with the pre-crash scenarios providing the framework for the analysis, the process is fairly efficient, and 5) although a manual process, there is little subjectivity in determining the scenario and it's associated parameters.

L-2 Purpose and Methodology

As the name implies, the focus of this analysis is on a select group of (critical) pre-crash scenarios. The motivation for the particular pre-crash scenarios selected is the evidence from collision databases that these scenarios are dominant in rear-end collisions, the type of collision most likely to be associated with the addition of an intelligent cruise control system. Furthermore, the Volpe Center (Najm, 1998) has recently been emphasizing the use of pre-crash scenarios in various safety analyses including benefits estimation. The pre-crash scenarios provide a uniform basis for categorization, comparison and analysis. It can be used as a dependent variable, providing an indication of the relative occurrence of scenarios that precede a crash. This is illustrated in Section 3.9.2.1. It can be used as an independent variable, compartmentalizing the driving experience, and allowing a more direct and meaningful comparison and analysis in terms of other dependent variables or safety surrogates such as minimum headway or braking level.

The motivation for critical cases as defined above is the rationale that severe brakings and closest approaches are accepted indications of the potential hazard of an event (Perez,1996; Najm, 1995). (A secondary motivation is efficiency - the most critical cases are considered to be the potentially most hazardous, and where the greatest safety impact would be expected to be seen. A similar analysis process could be conducted for all pre-crash scenarios with the attendant costs in time and effort.)

The pre-crash scenario types thus provide a basis for a safety analysis of video data. The most critical cases provide a prioritization for the analysis.

For each driver, the most critical cases (braking events and near encounters associated with the highest braking levels) were examined for each cruise mode . There were thus 6 resulting categories: Braking in the ICC mode; Braking in the CCC mode; Braking in the manual mode; Near Encounter in the ICC mode; Near Encounter in the CCC mode; and Near Encounter in the manual mode. The examinations were conducted separately for freeways, arterials and ramps.

Three separate analyses were conducted with respect to the pre-crash scenarios:

- Extreme value analysis (top single cases) of all drivers
- Extreme value analysis (top five cases) of 50 drivers
- Extreme value analysis (top five cases) of 50 drivers plus any additional cases involving a braking level greater than 0.25 g.

In addition, a subjective analysis was conducted on all the resulting ICC pre-crash scenario cases that had the highest decelerations and closest minimum headways to determine if use of the ICC contributed to the event.

Excluded from the pre-crash scenario analyses were those cases where the driver was already braking before the scenario developed and those cases where the relative range did not reduce to less than 30 meters (or 60 meters when the closing rate exceeded 3 meters per second). These latter cases were deemed not critical with respect to the pre-crash scenario.

Finally, it should be added that this video analysis provided a great amount of insight into the total driving experience, allowing the researchers to not only perform direct, video-based analyses, but also to determine requirements for the non-video analyses. For example, a better understanding was gained of the duration of the scenarios, the occurrence and distinctions of multiple scenarios, driver behavior patterns and their influence on the results, the correlation between the actual scenarios and the corresponding digital data, the issues with determining the beginning and end of particular scenarios, the occurrence of sensor-related problems, such as false alarms, missed detections, the effects of hills and curves on missed detections, and the positive detection of small objects such as motorcycles.

Before proceeding to the three separate analyses, the overall general characteristics of the braking events and near encounter events are first presented.

L-3 General Characteristics of the Triggered Video Data – All Drivers

The distributions for the braking events and the near encounter events from the triggered video data for all drivers for whom video data were available (there were 96 such drivers) is shown in Figure L-1. The distributions are also shown for each of the 6 categories. The distribution pattern is consistent across all 6 categories.

L-3.1 Braking Events

Most of the braking levels were below 0.3 g. There were only 56 events (out of 6485 with braking levels above 0.05 g) with braking levels above 0.3g. The highest (0.41 g) was a manual braking event and the next highest (0.40) was a CCC braking event. The others were 39 manual brakings between 0.30 g and 0.35 g, 2 CCC brakings between 0.30 g and 0.35 g, and 12 ICC brakings between 0.30 g and 0.35 g. As will be seen below, the braking events with higher g levels tended to occur either on arterials near intersections, in heavy traffic or on exit ramps of freeways.

Most of the braking events were during manual driving (70%) followed by ICC driving (22%) and CCC driving (8%). When normalized by test mode mileage for the 96 drivers the number of braking events greater than 0.05 g per kilometers was the same for ICC and CCC driving (0.026), and substantially more for manual driving (0.060). The number of braking events above 0.25 g were distributed as follows: ICC-83, CCC-14, and manual-236. The number of braking events above 0.25 g per kilometer were distributed as follows: ICC-0.0014, CCC-0.0006, manual-0.0029. These braking events do not take into account the driving scenario or roadway type.

L-3.2 Near Encounter Events

For the near encounter events, the distributions are also consistent across the three categories. Keep in mind that the g levels in Figure L-1 for near encounters refer to a calculated value according to the definition given above and are not actual braking levels. In many cases the near encounter scenarios did not result in any braking on the part of the host vehicle driver. (The near encounter may have been simply following too closely, or there may have been a lane change to avoid a potential collision.) The near encounter g levels extend up to 1 g. By convention, whenever the near encounter algorithm determined a value of “1” or higher, a “1” was assigned. The near encounter algorithm also defaulted to a value of “1” whenever the 0.3 second time headway was violated. This explains the emergence of values at the”1” level which is the top bin of the distribution. As will also be seen below, the near encounter events with higher g levels tended to occur on freeways, and in many cases were not followed by actual braking but rather by a lane change of either the lead vehicle or the host vehicle at the end of the scenario.

Most of the near encounter events were during manual driving (66%), followed by ICC driving (21%), and CCC driving (13 %). When normalized by test mode mileage for the 96 drivers, the number of near encounter events per kilometer (requiring a braking level of 0.05 g or greater to bring the host vehicle to within 0.3 second of the lead vehicle) was substantially less for ICC driving (0.015) compared to CCC driving (0.028) and manual driving (0.034).

L-4 General Characteristics of the Triggered Video Data – 50 Drivers

As indicated above, a separate analysis was conducted of 50 drivers. This extreme value analysis complemented that for the 96 drivers by including a range of extremes rather than a single extreme. The distributions of the braking events and near encounters from the triggered video data for the 50 drivers are shown in Figure L-2. The 50 drivers were selected from an earlier unfinished set of drivers that was available as the test progressed. There was no order in the selection of these drivers.

L-4.1 Braking Events

For the braking events, the distribution once again is consistent across the three categories. Most of these braking levels were also below 0.3 g. There were only 16 braking events (out of 2988 with braking levels above 0.05 g) with braking levels above 0.3g. The highest (0.41 g) was a manual braking event. The others were 10 manual braking events with braking levels between 0.30 g and 0.35 g, and 5 ICC braking events with braking levels between 0.30 g and 0.35 g. There were no CCC braking events with braking levels greater than 0.3 g.

The braking characteristics for the 50 drivers were very similar and consistent with that for the 96 drivers. Most of the braking events for the 50 drivers were during manual driving (72%). The value for ICC driving was 21%, and the value for CCC driving was 7%. When normalized by test mode mileage for the 50 drivers the number of braking events greater than 0.05 g per kilometer were about equal for ICC driving (0.033) and CCC driving (0.036) and substantially less than that for manual driving (0.063). The number of braking events above 0.25 g were distributed as follows: ICC-36, CCC-2, and manual-78. The number of braking events above 0.25 g per kilometer were distributed as follows: ICC-0.0018, CCC-0.0003, manual-0.0033. Again, these braking events do not take into account the driving scenario or roadway type.

L-4.2 Near Encounter Events

For the near encounter events for the same 50 drivers, the distributions once again, as was the case for the 96 drivers, were consistent across the three categories. Most of the near encounters for the 50 drivers were during manual driving (67%). The value for ICC driving was 20%, and the value for CCC driving was 13 %. When normalized by test mode mileage for the 50 drivers, the number of near encounter events per kilometer (requiring a braking level of 0.05 g or greater to bring the host vehicle to within 0.3 second of the lead vehicle) was substantially less for ICC driving (0.014) compared to CCC driving (0.028) and manual driving (0.029).

L-5 Extreme Value Analysis - Top Single Cases for All Drivers

Figure L-3 shows the breakdown of the braking events and the near encounter events for the top single cases for all (96) drivers by cruise mode and roadway type. Most of the braking events occur on arterials and most of the near encounter events occur on freeways. The near encounter algorithm is thus a more effective means of capturing safety-related events on freeways. Note that each cruise mode / event category does not include the maximum 96 cases. Not all drivers produced a case for all categories.

L-5.1 Freeways

The results of the extreme value analysis using the top single case for all drivers for freeway driving are shown in Figure L-4 and Tables L-1 and L-2. Figure L-4 shows the resulting distributions for the braking events and the near encounter events in terms of g levels. Table L-1 shows the resulting scenario data grouped by driving scenario type and cruise mode. Table L-2 shows similar results as Table L-1 but grouped by driver.

The following general observations can be made about the resulting data:

- A total of 41 cases were captured from 29 drivers. Sixty seven drivers did not produce any cases that met the requirements for this analysis.
- There were 20 ICC cases, 14 CCC cases, and 7 manual cases.
- The actual braking levels in this analysis ranged from 0.03 g to 0.3 g for ICC driving, from 0.06 g to 0.43 for CCC driving, and 0.02 g to 0.15 g for manual driving.
- The distribution data in Figure L-3 show that there were more higher braking events for ICC driving than CCC driving and manual driving.
- There were 2 lane change scenarios, 14 *cut-in* scenarios, 12 *approach* scenarios, and 13 *lead vehicle deceleration* scenarios.
- No single driver dominated. Most (19) drivers produced only one case. Nine drivers produced 2 cases. One driver produced 4 cases, a reflection perhaps, of this driver's driving style since all modes were represented in the four cases.

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The following observations are made by scenario type from the resulting data:

L-5.1.1 Lane Change

- There were only two lane change cases, one for CCC driving and one for ICC driving. Both of these cases were triggered by a near encounter and also resulted in a braking or throttle response by the host vehicle.
- Although not a sufficient number of cases to warrant a meaningful comparison, ICC driving produced a larger minimum headway.

L-5.1.2 Cut-In

- All these cases (14) were triggered by the near encounter algorithm. However most of these cases (13/14) also resulted in a braking or throttle response by the driver of the host vehicle. The one exception ended in a lane change of the lead vehicle.
- ICC driving this time tended to produce softer braking.
- The minimum headways tended to be substantially shorter for ICC driving although the ranges also tended to be somewhat shorter.
- There were not sufficient data on response times for these scenarios to make a meaning comparison.

L-5.1.3 Approach

- Most of these cases (11/12) were triggered by the near encounter algorithm. Slightly more than half of these cases (6/11) also resulted in a braking or throttle response by the driver of the host vehicle. (The triggering mechanism meant that the g level was higher for the near encounter event but did not preclude prior or subsequent braking at lower g levels).
- Five cases involved a lane change by the host vehicle at the end of the scenario to maneuver around the lead vehicle.
- ICC driving tended to produce slightly harder actual brakings compared to both manual driving and CCC driving.
- The minimum headways for ICC driving tended to be slightly lower than that for manual driving, and substantially lower than that for CCC driving. Part of the explanation for this difference may be in the different levels of initial conditions between the modes. The initial ranges, for example, tended to be lower for ICC driving.
- There were not sufficient data on response times for these scenarios to make a meaningful comparison. In most cases there was no clear stimuli as would be expected for this scenario.

L-5.1.4 Lead Vehicle Deceleration

- A greater number of these events were triggered by a near encounter (9) as were triggered by braking (4). All of the former cases (9) resulted in a braking or throttle response by the host vehicle. One case also involved a lane change by the host vehicle at the end of the scenario to maneuver around the lead vehicle.
- ICC driving tended to produce substantially harder braking compared to both manual driving and CCC driving. However, in these cases, ICC driving tended to encounter lead vehicles at substantially higher initial ranges.
- The minimum headways for ICC driving were greater than that for CCC driving, which in turn were greater than that for manual driving. Again, part of the explanation for this difference may be in the different levels of initial conditions between the modes.
- Regarding response times, there were more cases with distinct response times for this scenario (5) compared to the *approach* scenario (1), but still not a sufficient amount for a meaningful comparison. Part of the explanation for the lack of response times may be that nine of the cases had a lead vehicle decelerating at a level of 0.08 g or less, perhaps not large enough to provide a clear stimulus or prompt a clear response.

L-5.2 Arterials

The results of the extreme value scenario analysis using the top single case for all drivers on arterials are shown in Tables L-3 and L-4. Since there were only 10 resulting cases for the analysis, the g distributions for the braking events and the near encounter events are not shown. Table L-3 shows the resulting scenario data grouped by driving scenario type and cruise mode. Table L-4 shows similar results as Table L-3 but grouped by driver.

The following general observations can be made about the resulting data:

- A total of 10 cases were captured from 9 drivers.
- There were 3 ICC cases, 4CCC cases, and 3 manual cases.
- The braking levels in this analysis ranged overall from 0.04 g to 0.16 g.

The following observations are made relative to scenario type from the resulting data:

- There were too few cases to assess by scenario type.
- The *approach* scenario had the highest number of cases (5), followed by *lead vehicle deceleration* (3) and *cut-in* (2). There were no *lane change* scenarios.
- There were only three ICC cases. Two were *approach* scenarios, and one was a *lead vehicle deceleration* scenario.
- Nine of the ten cases were triggered by the near encounter algorithm. All of these cases also resulted in a braking or throttle response by the driver of the host vehicle.
- ICC driving tended to produce about the same level of brakings and minimum headways, particular for the *approach* scenario. The ICC case for the *lead vehicle deceleration* scenario resulted in a very low braking level and a very large minimum headway.

L-5.3 Ramps

The results of the extreme value scenario analysis using the top single case for all drivers on ramps are shown in Table L-5. There were only two resulting cases. Both involved ICC driving, and both were *lead vehicle deceleration* scenarios. One of the cases resulted in a moderate braking level and a very large minimum headway. The other case was somewhat more critical and is discussed further below in the reviewer-based analysis.

L-5.4 Freeways, Arterials and Ramps Combined

Overall there were 25 ICC cases, 18 CCC cases, and 10 manual cases that were examined in the resulting analysis of the top single cases for all drivers. Normalized by overall test mode mileage, the rate of occurrence is as follows: ICC – 0.00053 case per kilometer; CCC – 0.0016 case per kilometer; and manual – 0.00012 case per kilometer. By this measure, ICC driving produces a higher rate of critical pre- crash scenarios, compared to manual driving, but is bounded by CCC driving which produces the highest rate.

L-6 Extreme Value Analysis - Top 5 Cases for 50 Drivers

Figure L-5 shows the breakdown of the braking events and the near encounter events for the top 5 cases for 50 drivers by cruise mode and roadway type. Again, most of the braking events occur on arterials and most of the near encounter events occur on freeways. Note also once again, that each cruise mode / event category does not include the maximum 250 cases. There were not always 5 cases available in each category from the video data.

L-6.1 Freeways

The above results of the extreme value analysis using the top single case for all drivers did not produce a large number of cases for meaningful comparisons, particularly for driving on arterials and ramps. This section uses an alternative extreme value analysis approach. Namely, for each of the analysis categories defined above, the top 5 cases based on the g levels were analyzed from a random selection of 50 drivers.

The results of the extreme value scenario analysis using the top 5 cases for 50 drivers on freeways are shown in Figure L-6 and Tables L-6 and L-7. Figure L-6 shows the resulting distributions for the braking events and the near encounter events. Table L-6 shows the resulting scenario data grouped by driving scenario type and cruise mode. Table L-7 shows similar results as Table L-6 but grouped by driver.

The following general observations can be made about the resulting data:

- A total of 82 cases were captured from 32 drivers. Eighteen drivers did not produce any cases that met the requirements for this analysis.
- There were 31 ICC cases, 35 CCC cases, and 16 manual cases.
- The actual braking levels in this analysis ranged from 0.03 g to 0.3 g for ICC driving, from 0.05 g to 0.15 for CCC driving, and 0.01 g to 0.22 g for manual driving. The distribution data in Figure L-4 also show that there were more higher braking events for ICC driving than CCC driving and manual driving.
- The dominant scenario types were *lead vehicle deceleration* and *approach* which totaled 28 each.
- Driver 14 produced a disproportionately high number of cases. Most of these were near encounters and may be an indication of the normal driving behavior for this driver.
- Six other drivers produced 5 or 6 cases. One driver produced 4 cases, and the remaining drivers produced 1 or 2 cases. Taken together 7 drivers produced 47 cases or 57% of the total, a figure that tends to dominate the above results.
- Other repeated characteristics or similar patterns shown by individual drivers were the tendency to produce cases at nighttime, during inclement weather or on the same road. Often these repeats were on the same trip.
- An attempt was made to determine which like scenarios were similar enough for direct comparison. Using as a basis of similarity, the criteria of a 3 meter per second window for similar initial velocities, a 6 meter window for similar

initial ranges, and a 0.1g window for similar lead vehicle decelerations (for the lead vehicle deceleration scenario), a quick examination of the 82 cases reveals that, although there are a number of cases for pair-wise direct comparison, there were no situations where there were three or more cases for direct comparison. Many more cases beyond the 82 aggregated in this analysis (only 41 cases were obtained in the top single cases analysis for all drivers on freeways) need to be accumulated before meaningful direct comparisons can be made at a reasonably statistical significance level. This finding suggests that the more comprehensive digital data base may be the better source for analysis of similar pre-crash scenarios.

The following observations are made by scenario type from the resulting data:

L-6.1.1 Lane Change

- All these cases (8) were triggered by a near encounter. Six cases resulted in a braking or throttle response by the host vehicle. Three cases involved a lane change by the host vehicle at the end of the scenario.
- Once again, ICC driving tended to produce harder braking compared to both manual driving and CCC driving.
- The minimum headway for ICC driving was lower than that for both manual driving and CCC driving.
- There were not sufficient data on response times for these scenarios to make a meaning comparison.

L-6.1.2 Cut-In

- There were no manual driving cases for comparison.
- Practically all these cases (17 out of 18) were triggered by the near encounter algorithm. However most of these cases (17) also resulted in a braking or throttle response by the driver of the host vehicle. The one exception ended in a lane change of the lead vehicle.
- Once again, ICC driving tended to produce harder braking, this time compared to CCC driving.
- Also for this scenario, the minimum headway was substantially shorter for ICC driving compared to CCC driving.
- There were not sufficient data on response times for these scenarios to make a meaning comparison.

L-6.1.3 Approach

- Most of these cases (21/28) were triggered by the near encounter algorithm. However most of these cases (15/21) also resulted in a braking or throttle response by the driver of the host vehicle.
- Eight cases involved a lane change by the host vehicle at the end of the scenario while four cases involved a lane change of the lead vehicle.

- ICC driving tended to produce harder braking compared to both manual driving and CCC driving.
- The minimum headways for ICC driving and manual driving were about the same, but lower than that for CCC driving. Part of the explanation for this difference may be in the different levels of initial conditions between the modes.
- There were not sufficient data on response times for these scenarios to make a meaning comparison. In most cases there was no clear stimuli as would be expected for this scenario.

L-6.1.4 Lead Vehicle Deceleration

- A greater number of these events were triggered by a near encounter (16) as were triggered by braking (12). A substantial number of these cases (25) resulted in a braking or throttle response by the host vehicle. Four cases involved a lane change by the host vehicle at the end of the scenario.
- Once again, ICC driving tended to produce harder braking compared to both manual driving and CCC driving. However, in this sample, ICC driving tended to encounter lead vehicles that braked at higher levels (0.19g) compared to CCC driving (0.10 g) and manual driving (0.11 g).
- The minimum headways for ICC driving was about the same as that for CCC driving, which in turn were greater than that for manual driving. Again, part of the explanation for this difference may be in the different levels of initial conditions between the modes (range, range rate, lead vehicle deceleration levels).
- Regarding response times, there were more cases with distinct response times for this scenario compared to the *approach* scenario, but still not a sufficient amount for a meaningful comparison. Nineteen of the cases had a lead vehicle decelerating at a level of 0.1 g or less, perhaps not a large enough to provide a clear stimulus or prompt a clear response.

L-6.2 Arterials

The results of the extreme value scenario analysis using the top 5 cases for 50 drivers on arterials are shown in Figure L-7 and Tables L-8 and L-9. Figure L-7 shows the resulting distributions for the braking events and the near encounter events. Table L-8 shows the resulting scenario data grouped by driving scenario type and cruise mode. Table L-9 shows similar results as Table L-8 but grouped by driver.

The following general observations can be made about the resulting data:

- A total of 17 cases were captured from 11 drivers. Thirty nine drivers did not produce any cases that met the requirements for this analysis
- There were 3 ICC cases, 3 CCC cases, and 11 manual cases.
- The braking levels in this analysis ranged from 0.05 g to 0.19 g for ICC driving, from 0.05 g to 0.16 g for CCC driving, and 0.04 g to 0.18 g for

manual driving. There are not enough distributions points in Figure L-5 to make any meaningful comparisons.

- The *approach* scenario had the highest number of cases (8) and was the only scenario type that had ICC cases (3).

The following observations are made by scenario type from the resulting data:

L-6.2.1 Lane Change

- There was only one lane change scenario which occurred under manual driving. This scenario was not considered safety critical.

L-6.2.2 Cut-In

- There were no ICC driving cases for comparison.
- Of the three cases observed, one resulted in a minimum headway of about 5 meters, or about one car length.

L-6.2.3 Approach

- Seven of the eight cases were triggered by the near encounter algorithm. All of these cases also resulted in a braking or throttle response by the driver of the host vehicle.
- ICC driving tended to produce slightly harder brakings and lower minimum headways even though initial ranges tended to be higher, and the initial range rates lower for ICC between the modes.

L-6.2.4 Lead Vehicle Deceleration

- There were no ICC cases of this scenario for comparison with manual or CCC driving.
- None of the observed cases seemed to be safety critical in terms of the level of the lead vehicle deceleration, the braking level of the host vehicle or the minimum headways encountered.

L-6.3 Ramps

The results of the extreme value scenario analysis using the top 5 cases for 50 drivers on ramps are shown in Tables L-10 and L-11. No distribution figure is shown for lack of data in three of the six categories. Table L-10 shows the resulting scenario data grouped by driving scenario type and cruise mode. Table L-11 shows similar results as Table L-10 but grouped by driver.

The following general observations can be made about the resulting data:

- There were only 8 scenario cases involving 6 drivers. Fifty four drivers did not produce any cases that met the requirements for this analysis.
- There were 7 ICC cases, 0 CCC cases, and 1 manual case.

- Not surprisingly, the dominant scenario type was *lead vehicle deceleration* (6). There were also two *approach* scenarios.
- The braking levels in this analysis ranged from 0.08 g to 0.34 g for ICC driving. The one other case, for manual driving, involved a braking level of .09 g.

The following observations are made by scenario type from the resulting data:

L-6.3.1 Lane Change

- There were no *lane change* scenarios.

L-6.3.2 Cut-in

- There were no *cut-in* scenarios.

L-6.3.3 Approach

- There were two approach cases, one involving manual driving and one involving ICC driving.
- The case involving ICC driving showed a substantially higher braking level and a substantially lower minimum headway, although the initial range was shorter and the initial range rate was higher.

L-6.3.4 Lead Vehicle Deceleration

- All the six lead vehicle deceleration cases involved ICC driving. Since there were no non-ICC driving cases, there was no basis for comparison.
- Three of the cases were triggered by braking events and three were triggered by near encounter events. The cases triggered by the near encounter events also resulted in braking by the driver of the host vehicle.
- Two of the ICC cases involved the lead vehicle braking at moderate to high levels. In both of these cases the duration of the brakings was less than two seconds. In one of these two cases the braking level of the host vehicle was .34 g and the minimum approach was about 2.4 meters or less than one car length. In the other case the braking level of the host vehicle was 0.14 g and the minimum approach was about 5 meters.

L-6.4 Freeways, Arterials and Ramps Combined

Overall there were 41 ICC cases, 38 CCC cases, and 28 manual cases that were examined in the resulting analysis of the top five cases for 50 drivers. Normalized by overall test mode mileage, the rate of occurrence is as follows: ICC – 0.0020 case per kilometer; CCC – 0.0064 case per kilometer; and manual – 0.0012 case per kilometer. By this measure, once again ICC driving produces a higher rate of critical pre-crash scenarios, compared to manual driving, but is bounded by CCC driving which produces the highest rate.

L-7 Extreme Value Analysis – Additional Considerations for Higher (0.25 G) Brakings - Top 5 Cases for 50 Drivers

This section further examines the extreme value scenarios by including all brakings levels of the host vehicle that exceeded 0.25 g for 50 drivers. First, Figure L-8 shows the breakdown of all the braking events for 50 drivers by cruise mode and roadway type, that were triggered by deceleration levels of 0.25 g or higher. As can be seen, most of these braking events (91%) occurred on arterials and ramps. Only 7 cases (6 %) involved ICC driving on freeways.

An additional 19 cases of 0.25 g or higher braking events were found beyond those included in the above section on **Extreme Value Analysis - Top 5 Cases for 50 Drivers**. These 19 cases all occurred on arterials and only one of these, involving ICC driving, met the requirements stated above to be included in the analysis. Most of the rest were excluded because they occurred at intersections. Of the 19 cases, 6 involved ICC driving and they were all for the same driver. (One of these, as just mentioned, was the only one to be included in the analysis.)

There were 154 additional near encounter cases where the breaking level required to bring the host vehicle to within 0.3 second of the lead vehicle was equal to or greater than 0.25 g. Of these, 91 occurred on freeways, 50 on arterials, and 13 on ramps. However only two of these cases involved a braking of the host vehicle that exceeded 0.25g. Both of these were for manual driving and both occurred on freeways.

L-7.1 Freeways

It is thus fair to assume that the three additional cases uncovered will have minimal impact on the above analysis. However for completeness the new distribution and resulting scenario data with the additions are shown for freeways and arteries. Figure L-9 shows the resulting distributions data for freeways. Table L-12 shows the resulting scenario data grouped by driving scenario type and cruise mode for freeways. Table L-13 shows the resulting scenario data grouped by driver for freeways.

The following general observations can be made about the resulting data:

- The effect on the previous freeway analysis was to add two cases. As mentioned, both of these involved manual driving. Both of these also involved a *lead vehicle deceleration* scenario.
- In one case the lead vehicle decelerated at 0.36 g for about 2 seconds and the host vehicle responded by also decelerating at about 0.36 g. The host vehicle driver seemed to exhibit reckless driving by following too closely, driving over the right solid lane shoulder and in effect changing lane to avoid a collision. The minimum approach was about 4.5 meters.
- In the other case, the lead vehicle decelerated at 0.3 g for about 2 seconds and the host vehicle responded by decelerating at about the same level. The minimum approach was 1.5 meters. However, the speeds were relatively low during the scenario for freeways, and the host driver may have been

anticipating the event by braking before the scenario developed. Overall, with the inclusion of the two additional cases, the braking levels were still higher and minimum approaches lower with ICC driving. The margins were somewhat reduced.

L-7.2 Arterials

Figure L-10 shows the resulting distributions data for arterials. Table L-14 shows the resulting scenario data grouped by driving scenario type and cruise mode for arteries. Table L-15 shows the resulting scenario data grouped by driver for arterials.

The following general observations can be made about the resulting data:

- The effect on the previous arterials analysis was to add one case. As mentioned, this case involved ICC driving. The scenario was a *lead vehicle deceleration* for a left turn.
- The lead vehicle decelerated at 0.24 g for about 7 seconds and the host vehicle responded by decelerating at about 0.25 g. The initial range was 75 meters and the minimum approach was about 24 meters. Since in the previous arterial analysis, there was no ICC case for *lead vehicle deceleration* the additional case provided a basis, albeit limited, for comparison. The braking level for the single ICC case was substantially higher than that for each of the other cases for this scenario. The minimum approach was higher for the ICC case, but the initial range was also one of the highest.

L-7.3 Ramps

There were no additional 0.25 g or higher braking cases to be added to the ramp analysis.

L-8 Extreme Value Analysis – Only 0.25 G or Higher Braking Cases - 50 Drivers

If only the 0.25 g or higher braking cases were included in the scenario analysis there would be little basis for comparison. Table L-16 shows these cases grouped by road type, scenario type and cruise mode. As can be seen, there are only a total of nine cases, eight of them involving ICC driving. On arterials and ramps there was only one case each, thus providing no basis for comparison. On freeways, there was only one case each for the *approach*, *cut-in* and *lane change* scenarios, again providing no basis for comparison for these scenarios. Only the *lead vehicle deceleration* scenario on freeways had a few cases for comparison. There were three ICC driving cases and one manual driving case. For these the manual driving braking level was the highest. One of the ICC cases showed one of the closest minimum headways from the test. A further reviewer-based analysis of all these ICC cases is given below.

L-9 Subjective Analysis – ICC Scenarios

In this section, the ICC scenarios that have been identified and discussed above are analyzed to determine if use of the ICC may have contributed to the criticality of the event. Particular emphasis is placed on those cases that had the highest decelerations and closest minimum headways. The specific cases analyzed here are shown in Table L-17, and are grouped by road type, scenario type, and cruise mode.

L-9.1 Freeways

There were a total of 45 ICC freeway pre-crash scenario cases examined above, 31 included with the first 50 drivers analyzed (top 5 plus all 0.25 g cases) and 14 additional from the remaining 46 drivers (top single). The breakdown by scenario type was as follows: *lane change*, 4, *cut-in* 19, *approach* 11, and *lead vehicle deceleration*, 11. From these, the number of cases examined in this section is as follows: *lane change*, 1, *cut-in* 2, *approach* 4, and *lead vehicle deceleration*, 4. Each of these cases involved either a braking level greater than 0.23g or a minimum headway within one car length (approximately 5 meters),

L-9.1.1 Lane Change

One of the *lane-change* cases involved both a high braking (0.26 g) and a close approach (5 meters).

- The ICC vehicle was traveling at 32 m/s, the initial range was 24 meters, and the initial speed differential was 9 m/s. The minimum approach was 5 meters. *In this case the ICC was not a factor* as the driver braked almost immediately after making the lane change and proceeded to follow the lead vehicle off an exit ramp.

L-9.1.2 Cut-In

One of the *cut-in* cases involved both a high braking (0.50 g) and a close minimum headway (3 meters). One other case involved a close minimum headway (5 meters).

- The high braking case occurred near on on-ramp as other vehicles were merging. The traffic was moderate and the host vehicle driver was in one of the center lanes. The ICC vehicle was traveling at 26 m/s, the initial range to the cut-in vehicle was 9 meters, and the initial speed differential was 5.5 m/s. The ICC system had been decelerating the host vehicle (due to another lead vehicle) at .03 g before the cut-in and had just started decelerating the vehicle at 0.07 g when the driver braked at 6 meters. The minimum approach was 3 meters. *In this case the ICC may have been a factor* as the driver might have waited (on the order of a second or two) to see to what degree the system would resolve the situation. The merging vehicle kept changing lanes from the first lane to eventually the fourth (out of five) lane. The host vehicle was in the third lane.
- The close minimum headway *cut-in* case occurred at night. The ICC vehicle was traveling at 35 m/s, the initial range was 20 meters, and the initial speed differential was 5 m/s. The ICC system decelerated the vehicle at 0.06 g before the driver braked at 11 m/s. The minimum approach was 5 meters. *In*

this case the ICC may have been a factor as the driver might have waited to see to what degree the system would resolve the situation.

L-9.1.3 Approach

Three of the *approach* cases involved high braking (greater than 0.23 g) and one involved a close minimum headway (within a car length).

- One high braking *approach* case (0.23 g) involved multiple scenarios (approaching a lead vehicle, lead vehicle switching lanes, approaching another lead vehicle) and a roadside hazard. Even though there was an initial high speed differential, the minimum approach in the case was still a fairly adequate 12 meters and *the ICC system was not considered a factor*.
- Another high braking *approach* case (0.24 g) occurred at night. The ICC vehicle was traveling at 32 m/s, the initial range was 40 meters, and the initial speed differential was 5 m/s. The ICC system decelerated the vehicle at 0.05 g before the driver braked. The minimum approach was 8 meters and the ICC vehicle changed lanes at the end of the scenario to maneuver around the lead vehicle. *In this case the ICC may have been a factor* as the driver might have waited to see to what degree the system would resolve the situation.
- The third high braking *approach* case (0.30 g) occurred on a curve. The ICC vehicle was traveling at 30 m/s, the initial range was 52 meters, and the initial speed differential was 9 m/s. The ICC system decelerated the vehicle at 0.07 g before the driver braked at 12 meters. The minimum approach was 6 meters. *In this case the ICC may also have been a factor* as the driver might have waited to see to what degree the system would resolve the situation.
- The last *approach* case occurred as a vehicle in front of the host vehicle switched lanes. The host vehicle then approached a new lead vehicle. The ICC vehicle was traveling at 27 m/s, the initial range to the new lead vehicle was 52 meters, and the initial speed differential was 5.5 m/s. The ICC system decelerated the vehicle first before the driver braked at 0.11 g. The minimum headway was 4.5 meters. *In this case the ICC may have been a factor* as the driver might have waited to see to what degree the system would resolve the situation.

L-9.1.4 Lead Vehicle Deceleration

Four of the *lead vehicle deceleration* cases involved either a high braking on the part of the host vehicle, or a close approach or both.

- In all cases, the lead vehicle deceleration was relatively high, the travel speeds of both vehicles were the same and high, and the initial separations were large. The host vehicle decelerations were 0.22 g, 0.26 g, 0.30 g, and 0.30 g. Only one of these cases involved a close (less than one car length) approach. *In three of the cases the ICC may have been a factor* as the driver might have waited (on the order of five seconds in one case) to see to what degree the system would resolve the situation. *<u>In the other case the ICC was not</u> a factor* as the driver braked early in the scenarios.

L-9.2 Arterials

There were a total of 7 ICC resulting arterial cases examined above, 4 included with the first 50 drivers analyzed (top 5 plus all 0.25 g cases) and 3 additional from the remaining 46 drivers (top single). The breakdown by scenario type is as follows: *lane change*, 0, *cut-in 0*, *approach*, *5*, and *lead vehicle deceleration*, 2. From these cases, one *lead vehicle deceleration* case is examined in this section.

L-9.2.1 Lead Vehicle Deceleration

There was only one case that involved high braking (greater than 0.25 g) or close minimum headway (5 meters).

- In this scenario, which occurred on a rural two-lane roadway, the lead vehicle decelerated at 0.24 g to avoid a left-turning vehicle, and the host vehicle decelerated at 0.25 g, about 4 seconds later. The ICC vehicle was traveling at 24 m/s, the initial range was 75 meters, and the initial speed differential was 6 fps. The ICC system decelerated the vehicle at 0.03 g before the driver braked at a range of 55 meters. The minimum approach was 24 meters. *In this case the ICC <u>was not</u> a factor* as the driver braked sufficiently early before the scenario was completed.

L-9.3 Ramps

There were a total of 9 ICC ramp cases examined above, 8 included with the first 50 drivers analyzed (top 5 plus all 0.25 g cases) and one additional from the remaining 46 drivers (top single). The breakdown by scenario type was as follows: *lane change*, 0, *cut-in 0*, *approach*, *2*, and *lead vehicle deceleration*, 7. From these cases, three *lead vehicle deceleration* cases are examined in this section.

L-9.3.1 Lead Vehicle Deceleration

There were three cases that involved high braking (greater than 0.25 g) or close minimum headway (5 meters).

- In one case, the lead vehicle braked at 0.18 g for 8 seconds and the host vehicle braked at 0.17 g five seconds later. The initial speed for both vehicles was 24 m/s and the initial range was 55 meters. The ICC system decelerated the vehicle at 0.04 g before the driver braked at a range of 40 meters. The minimum approach was 3 meters, which occurred on the ramp. *In this case the ICC <u>was not</u> a factor* as the driver braked sufficiently early before the scenario was completed. However, it is worth noting in this case that the sensor lost track of the lead vehicle for two seconds in the initial part of the ramp, which curved to the right. Although the driver braked and disengaged the ICC system three seconds before the sensor lost track, a potential problem could have existed had the driver or any other driver delayed braking for an additional three seconds. The vehicle might have surged ahead in the ramp to the set speed, interpreting the lost track as no vehicle ahead.

- In the second case, the lead vehicle braked first at 0.40 g for one second and then at 0.05 g for 12 seconds. The host vehicle braked at 0.14 g two seconds after the first braking of the lead vehicle. The initial speed of the host vehicles was 29 m/s, the initial range was 35 meters, and the initial closing rate was 2 m/s. The ICC system decelerated the vehicle at 0.05 g for about one second before the driver braked at a range of 20 meters. The minimum approach was 4.5 meters, which occurred on the ramp. *In this case the ICC <u>was not</u> a factor* as the driver braked early in the ramp, but could have braked earlier still just before the ramp.
- The last scenario occurred at night and actually consisted of two stages of a *lead vehicle deceleration* scenario. In the first stage, the lead vehicle decelerated at 0.08 g for 8 seconds, and in the second stage decelerated at 0.28 g for 2 seconds. At the beginning of the first stage, both vehicles were traveling at 20 m/s, and the range was 20 meters. The ICC system decelerated the vehicle during the first stage at 0.05 g. The host vehicle driver braked at 0.34 g almost simultaneously with the lead vehicle as it initially decelerated for the second stage. At this point the range was only about 6 meters. The minimum approach was less than 3 meters, and occurred near the end of the ramp. *In this case the ICC <u>may have been</u> a factor* as the driver waited seven seconds from the time the lead vehicle first braked before braking.

L-10 Summary

The pre-crash scenario basis together with a prioritization by critical cases provided an orderly and efficient means for better understanding the effect that ICC has on driving safety. Within this basis and prioritization, extreme value analyses were conducted with respect to braking levels and near encounters. A reviewer-based analysis was also conducted on the most critical cases.

ICC driving resulted in fewer braking events greater than 0.05 g as well as a fewer number of near encounters (requiring a braking level of 0.05 g or greater to bring the host vehicle to within 0.3 second of the lead vehicle) compared to both CCC driving and manual driving.

However, at a higher level of criticality, as reflected in the scenario cases with higher brakings, and lower minimum headways, ICC seems to have a possible negative influence on safety. In particular, ICC driving tended to produce harder braking compared to both manual driving and CCC driving. This was found for all scenarios. The minimum headways for ICC driving in a number of scenarios were lower than that for both manual driving and CCC driving. Part of the explanation for these differences may be in the different levels of initial conditions between the modes, that is, the initial ranges, range rates, and, for the applicable scenarios, the lead vehicle deceleration.

Another possible explanation may have been that the drivers were waiting on the system to resolve the situation.

Further evidence of harder braking for ICC driving is indicated in the results of the extreme value analysis that focused on 0.25 g or higher braking events. Eight out of nine cases that resulted were for ICC driving. The remaining case was for manual driving. Focusing on freeways, there were 6 cases for ICC driving and only 1 case for manual driving.

Overall, the extreme value analyses showed a substantially higher rate of the more critical scenarios for ICC driving compared to manual driving. Further, it is interesting to note that the analyses also showed a substantially higher rate for CCC driving compared to ICC driving. The ICC effect was particularly pronounced on ramps. These results held for both the Top Single Case analysis as well as the Top Five Cases analysis.

The extreme value scenario analysis showed four cases where the host vehicle braked rather high (greater than 0.3g). The highest braking level case (0.50 g) was for ICC driving during a *cut-in* on a freeway. The next highest braking level case (0.43 g) was for CCC driving during a *lead vehicle deceleration* scenario on a freeway. The remaining two cases were manual driving during a *lead vehicle deceleration* scenario on a freeway (braking level – 0.36 g), and ICC driving during a *lead vehicle deceleration* scenario on an exit ramp (braking level – 0.34 g). In the rest of the cases, the braking levels of the host vehicle did not exceed 0.3g. Most of the brakings, when they did occur, were below 0.12 g. With regard to near encounters, there were 16 cases where the minimum headway fell to or below 5 meters, 13 during ICC driving, 2 during manual driving and 1 during CCC driving.

In the subjective analysis, a total of 15 cases were examined. In nine of these cases the ICC was judged to be a factor in the criticality of the event. That is, the driver might have waited to see to what degree the system would resolve the situation before taking any action. With the waiting, which might have been intentional or not, the net result in many cases was harder braking and closer minimum headways.

This critical pre-crash scenario analysis thus shows a higher rate of occurrence of these scenarios for ICC driving, and when they occur, a tendency towards higher braking levels, and lower minimum headways also for ICC driving. This finding seems to indicate that drivers are waiting to see if the ICC system would resolve the situation developing during the scenarios. For those cases not resolved by the ICC, the driver eventually decides to intervene and brake. Consequently the braking levels are higher, and minimum headways shorter than would have normally been the case had the driver been driving in the manual mode. The implication is that drivers are learning about the system and, as they become more familiar with its operation under these conditions, their pattern of driving with ICC could be expected to change to match their driving pattern without ICC.

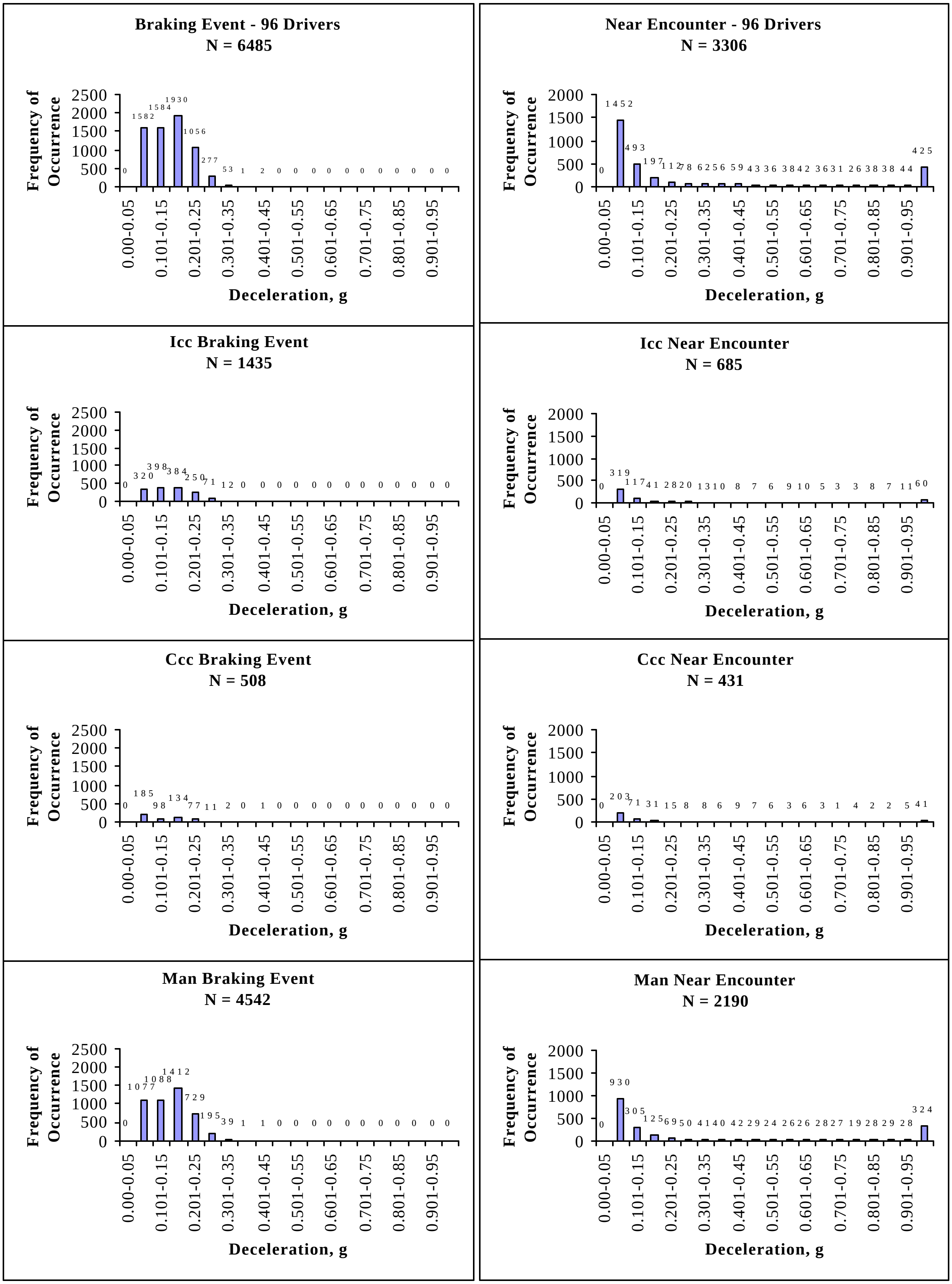

Figure L-1. Distribution of All Braking Events and Near Encounters – All Drivers

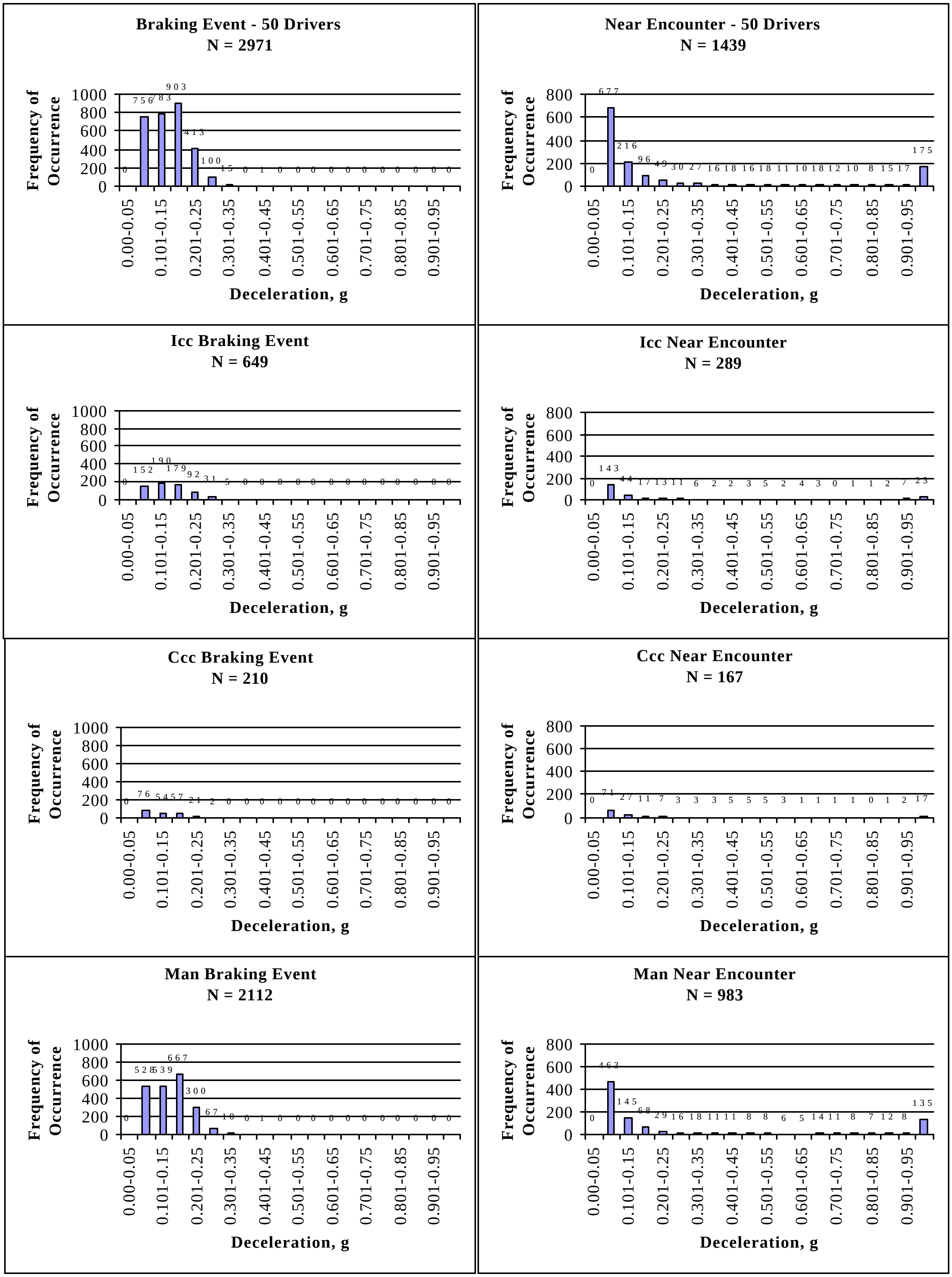

Figure L-2. Distribution of All Braking Events and Near Encounters – 50 Drivers

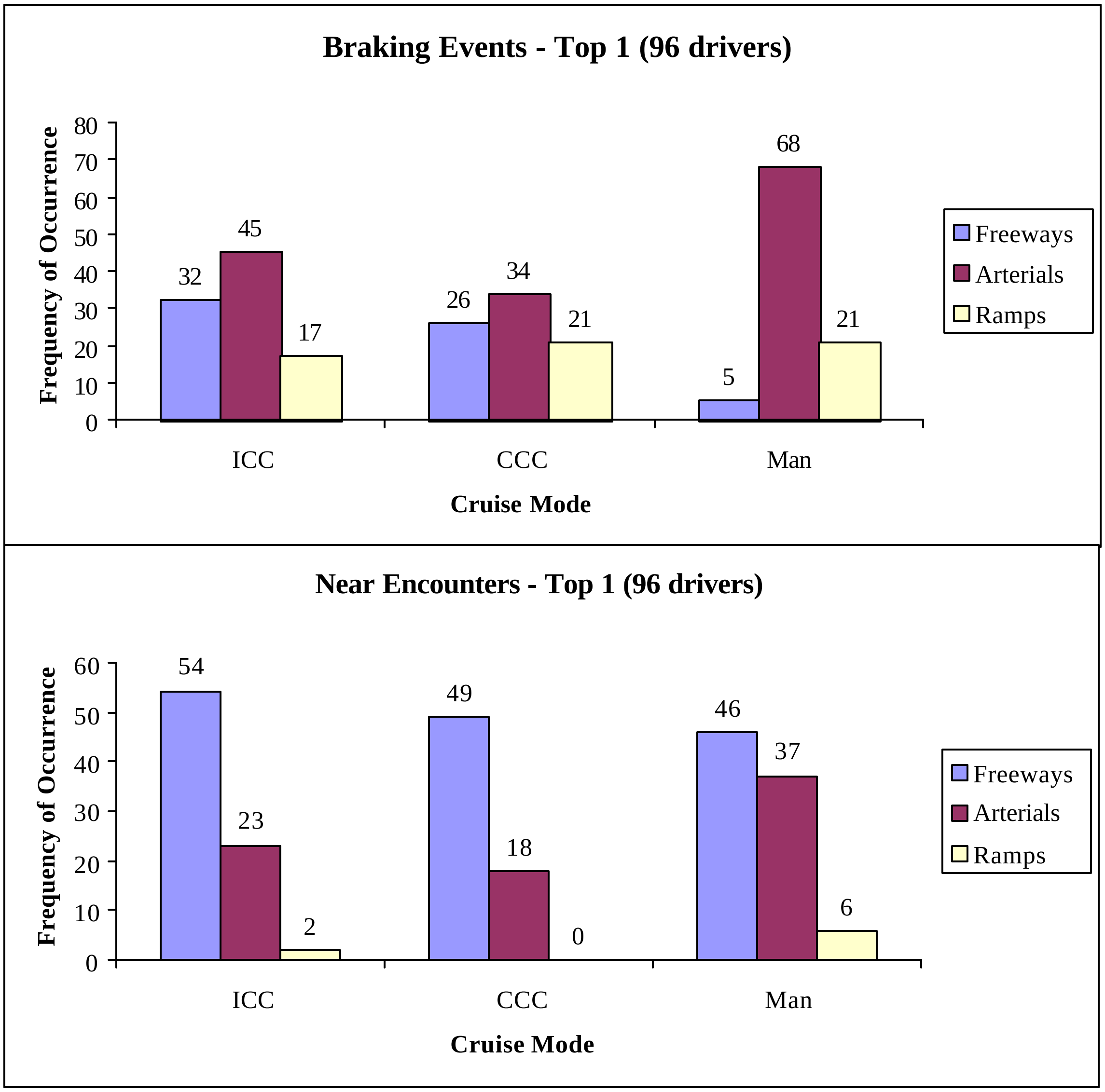

Figure L-3. Breakdown of Braking Events and Near Encounter Events by Cruise Mode and Roadway Type

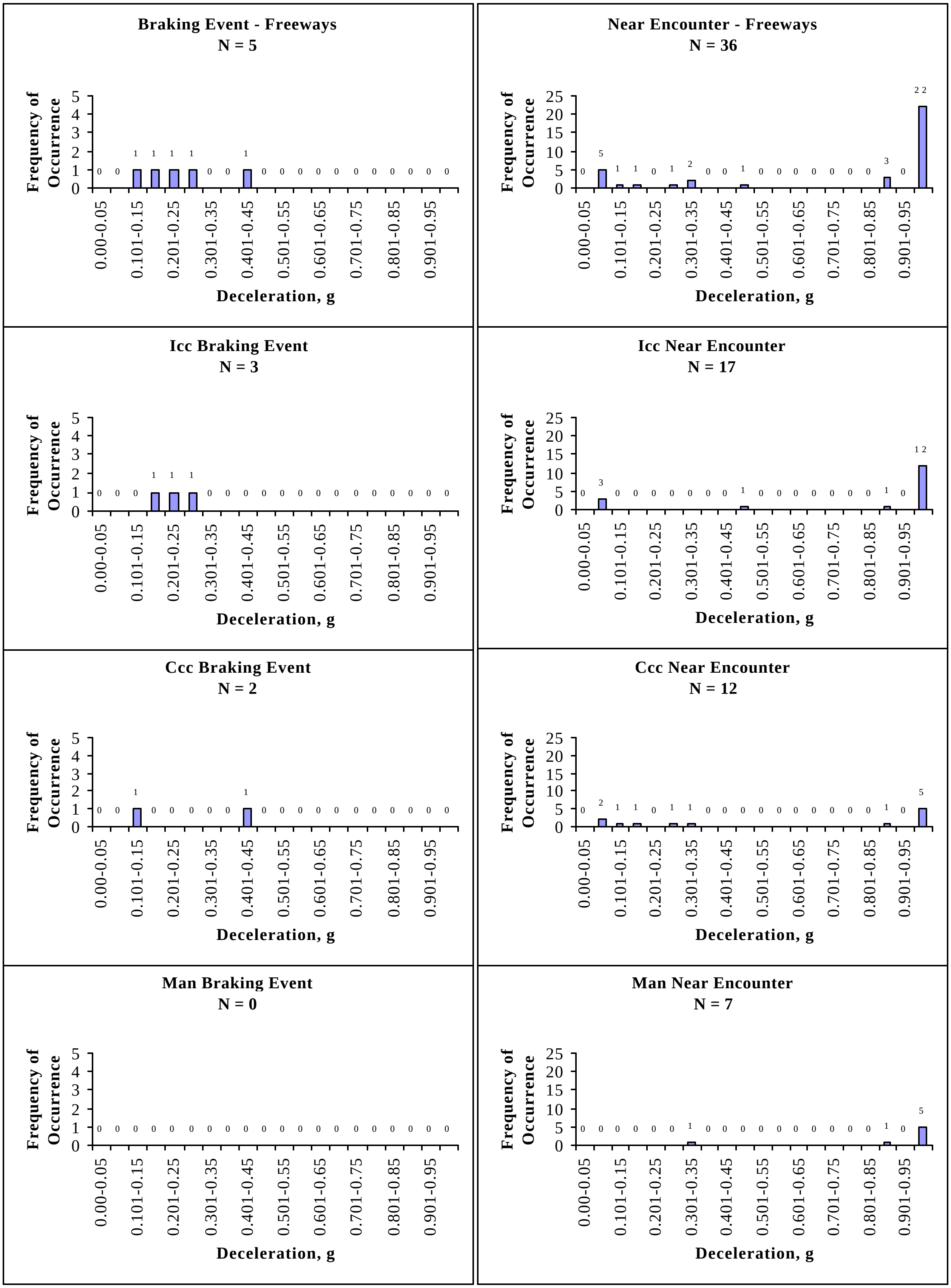

Figure L-4. Distribution of Braking Events and Near Encounters – Freeways – Top Singles Cases for All Drivers

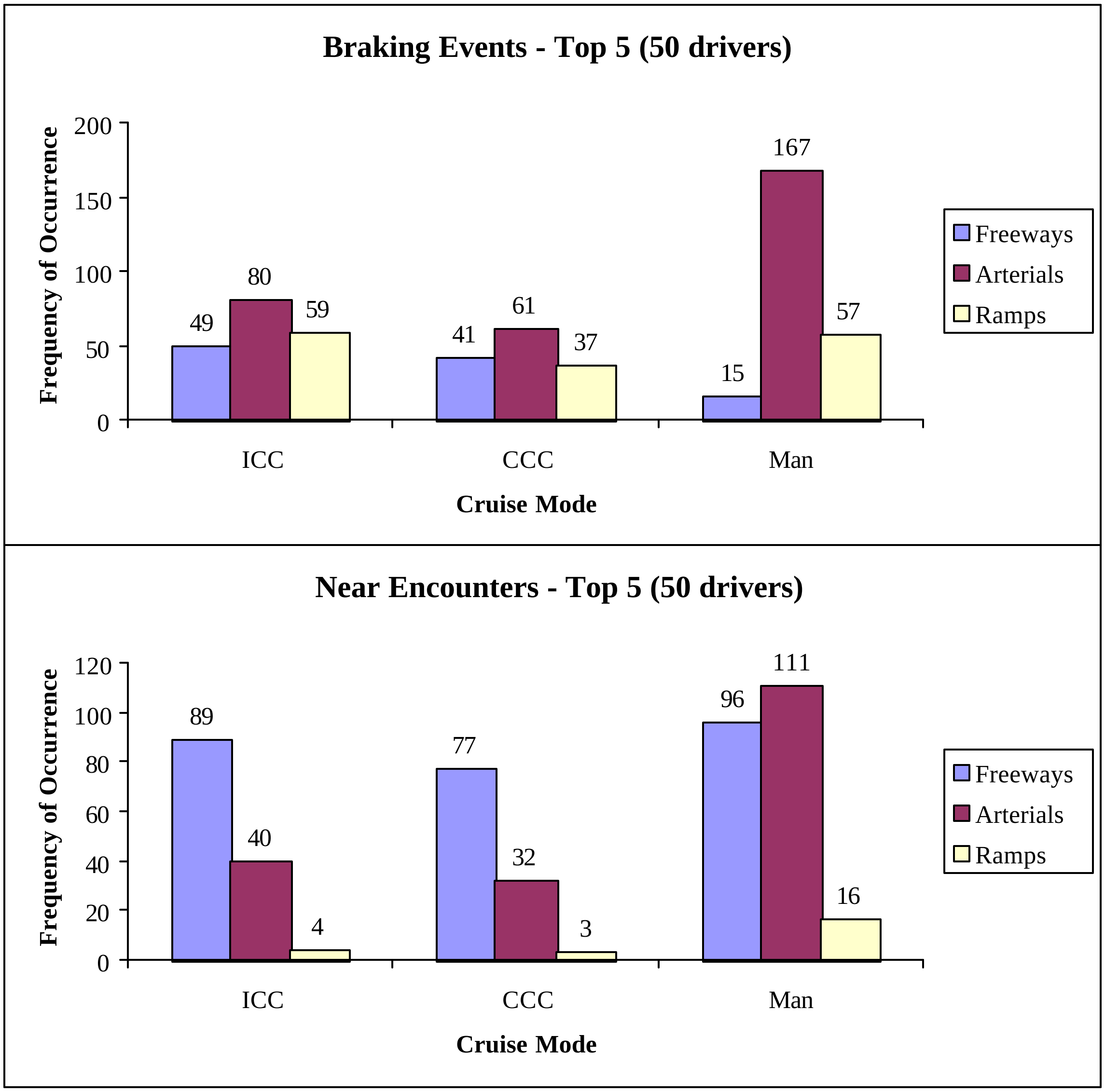

Figure L-5. Breakdown of Braking Events and Near Encounter Events by Cruise Mode and Roadway Type

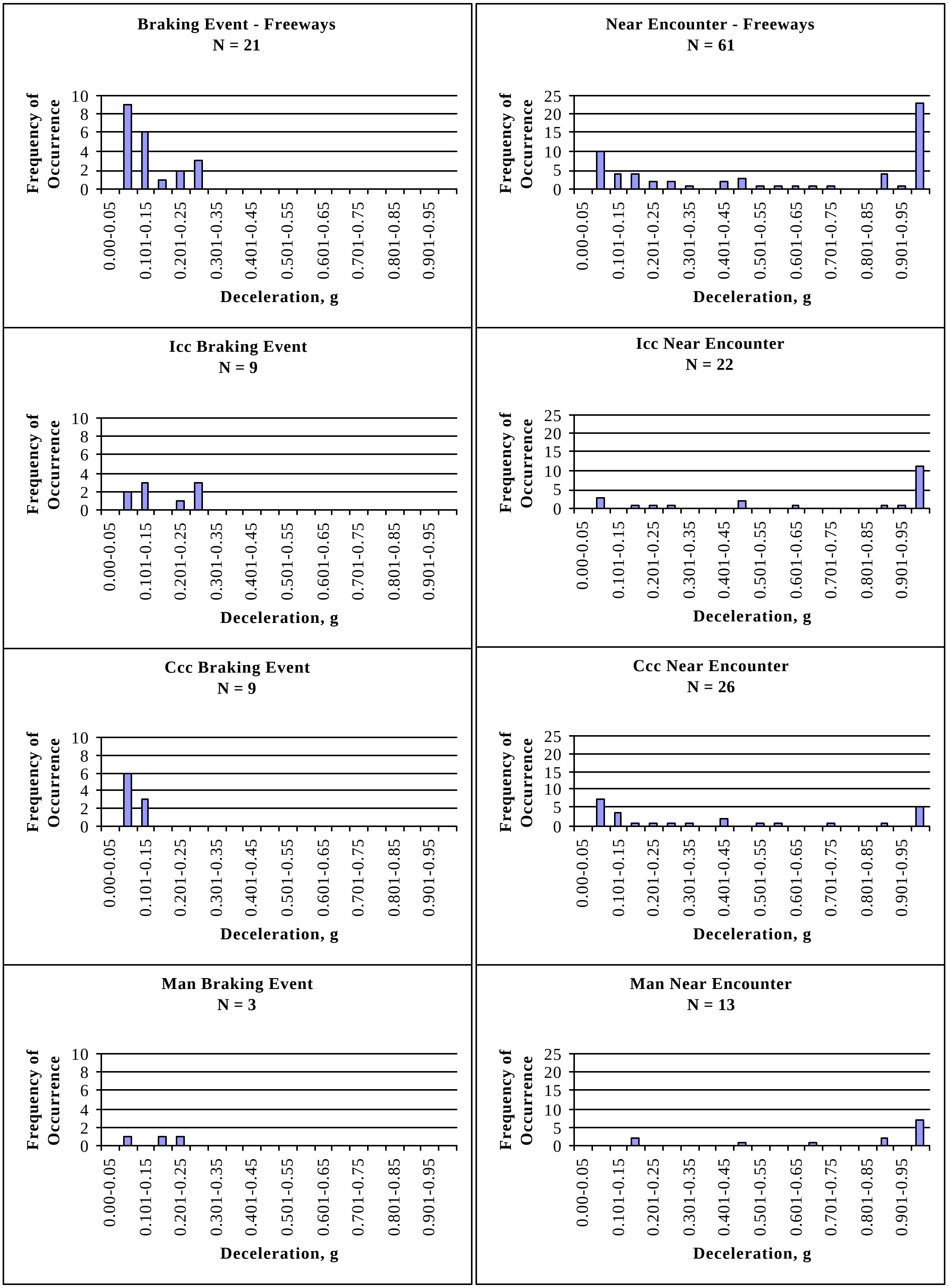

Figure L-6. Distribution of Braking Events and Near Encounters – Freeways – Top 5 Cases for 50 Drivers

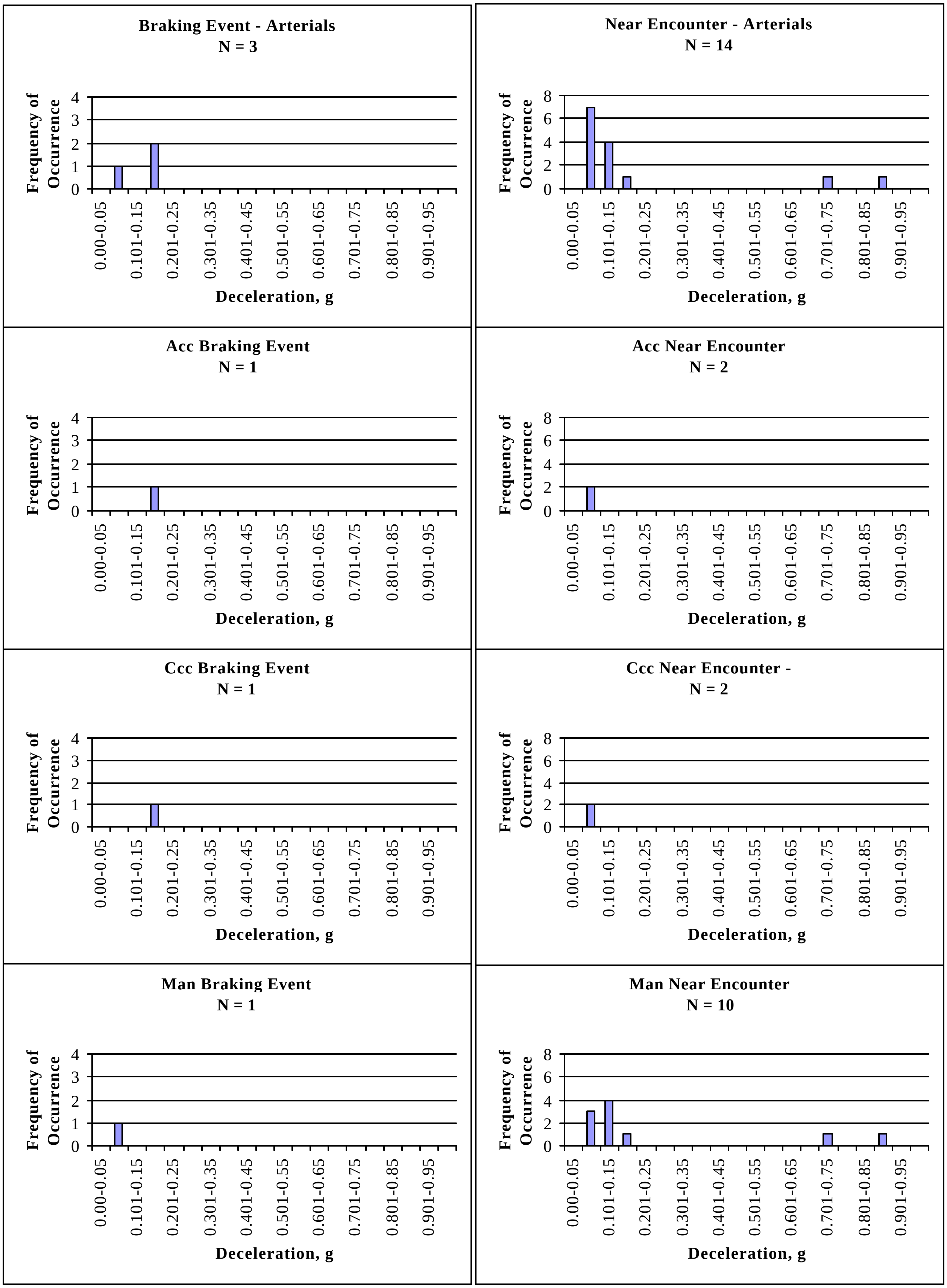

Figure L-7. Distribution of Braking Events and Near Encounters – Arterials – Top 5 Cases for 50 Drivers

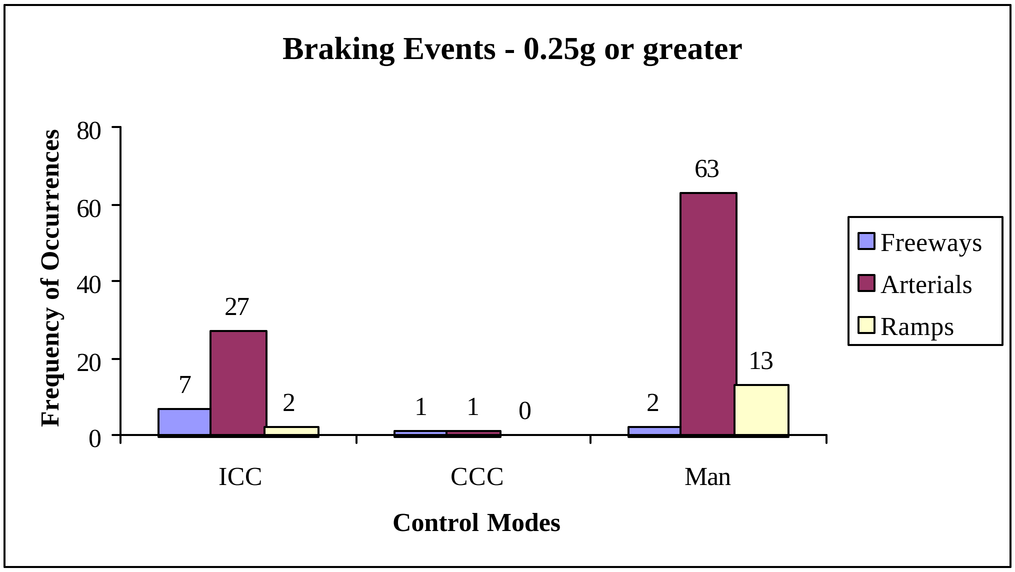

Figure L-8. Breakdown of Braking Events by Cruise Control Mode and Road Type – 50 Drivers

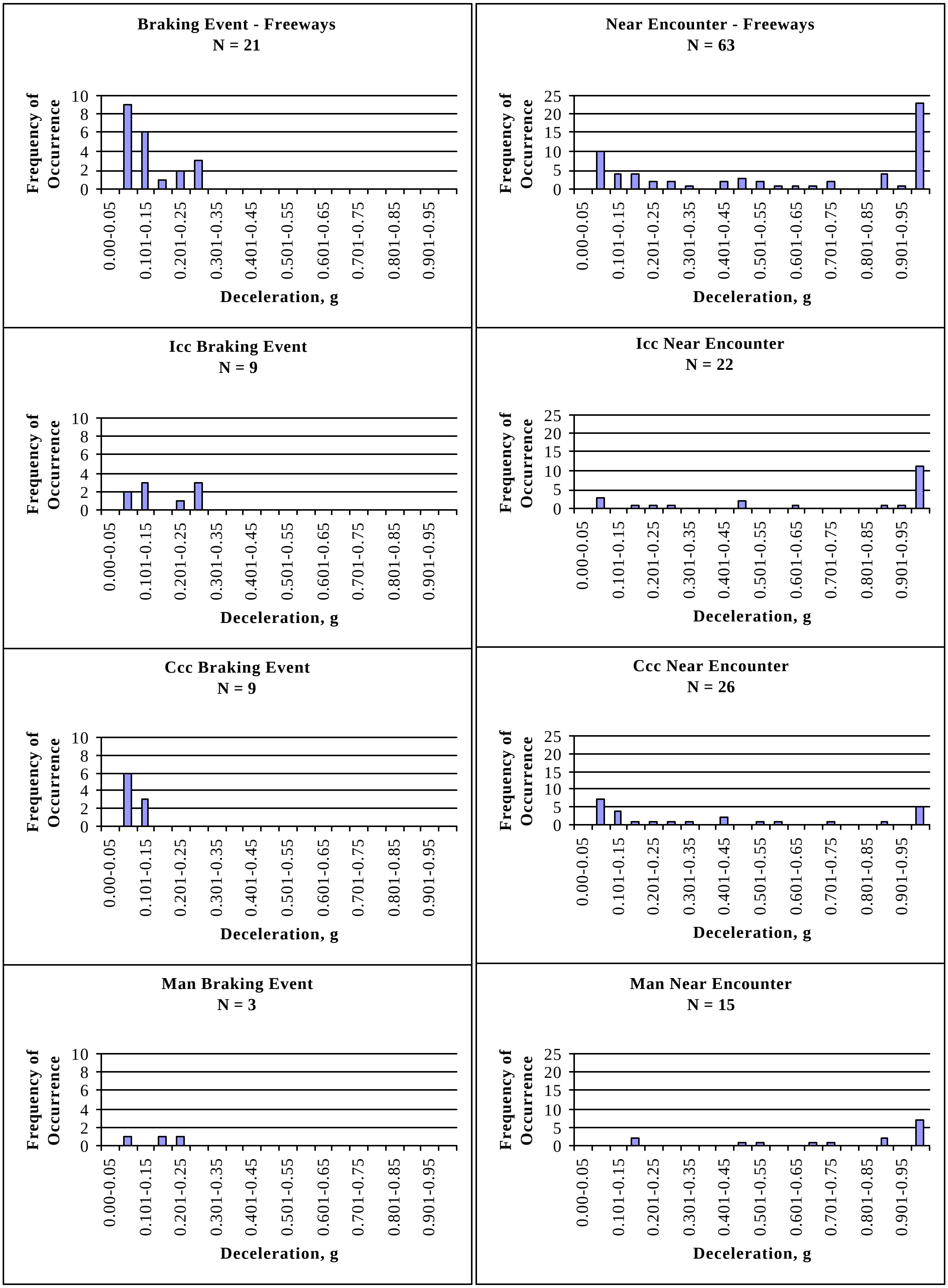

Figure L-9. Distribution of Braking Events and Near Encounters – Freeways – Top 5 Cases for 50 Drivers with Additional (2) 0.25 g cases

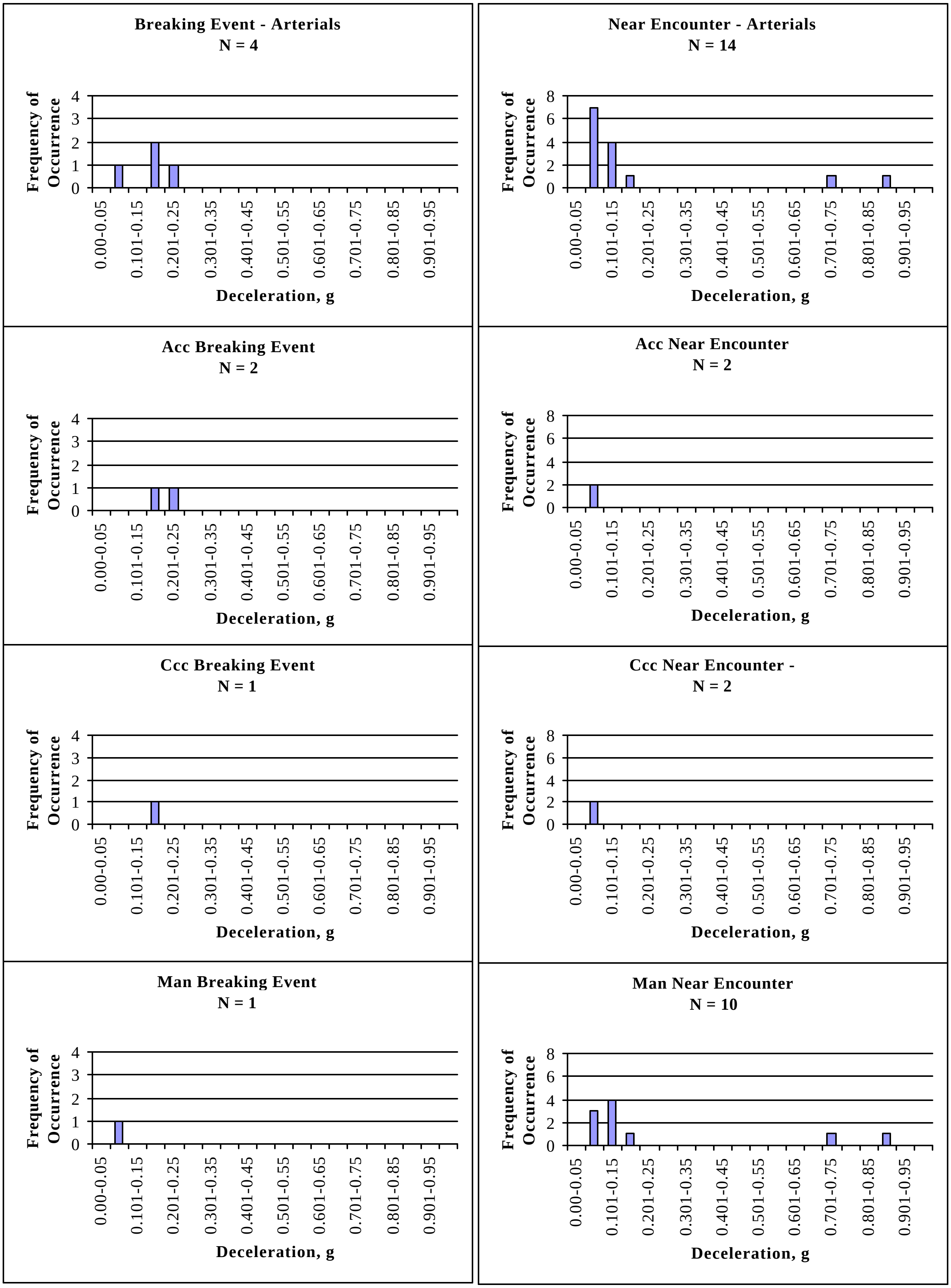

Figure L-10. Distribution of Braking Events and Near Encounters – Arterials – Top 5 cases for 50 Drivers with Additional (1) 0.25 g Case

Table L-1. Results of Extreme Value analysis – Freeways – Top singles cases for all drivers (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 640103	Approach	29.0	32.9	-4.0	86.9	4.9	22	0.15
MN 756600	Approach	29.3	32.0	-2.7	31.1	12.2	15	0.02
MN 1115300	Approach	28.0	31.4	-3.4	45.7	18.3	13	
	Average	**28.8**	**32.1**	**-3.4**	**54.6**	**11.8**	**17**	**0.09**
CN 341203	Approach	25.9	30.5	-4.6	33.5	13.7	6	0.11
CN 641307	Approach	29.3	33.8	-4.6	94.5	18.9	16	
CN 683800	Approach	28.6	32.0	-3.4	76.2	18.3	14	
CN 730804	Approach	27.4	34.1	-6.7	115.8	15.2	19	
CB 411200	Approach	27.7	35.1	-7.3	91.4	16.8	13	0.11
	Average	**27.8**	**33.1**	**-5.3**	**82.3**	**16.6**	**14**	**0.11**
IN 2410603	Approach	29.9	32.0	-2.1	30.5	6.1	21	0.03
IN 346603	Approach	21.3	30.5	-9.1	51.8	6.1	10	0.3
IN 9921507	Approach	32.0	33.5	-1.5	32.0	10.7	17	
IN 1175105	Approach	25.9	32.3	-6.4	82.3	19.8	13	0.04
	Average	**27.3**	**32.1**	**-4.8**	**49.1**	**10.7**	**15.25**	**0.12**
CN 140301	Lane change	29.0	30.5	-1.5	16.8	7.6	10	0.06
IN 645403	Lane change	30.5	34.1	-3.7	15.2	13.7	4	0.06
	Average	**30.5**	**34.1**	**-3.7**	**15.2**	**13.7**	**4**	**0.06**
MN 514204	Lead veh. deceleration (LVD), 0.03g, 8 sec	30.5	30.5	0.0	16.8	9.1	13	0.03
MN 1090702	Lead veh. deceleration (LVD), 0.04g, 16 sec	29.3	29.3	0.0	18.3	4.6	16	0.15
MN 1171401	Lead veh. deceleration (LVD), 0.05g, 21 sec	31.4	31.7	-0.3	31.7	6.1	21	0.08
Average	**LVD = 0.04g**	**30.4**	**30.5**	**-0.1**	**22.2**	**6.6**	**17**	**0.09**
CN 070903	Lead veh. deceleration (LVD), 0.07g, 4 sec	28.6	29.9	-1.2	16.8	7.6	6	0.10
CN 220101	Lead veh. deceleration (LVD), 0.08g, 6 sec	26.8	26.8	0.0	36.6	9.1	17	0.11
CN 800106	Lead veh. deceleration (LVD), 0.04g, 8 sec	32.6	32.6	0.0	19.8	7.6	9	0.1
CN 872300	Lead veh. deceleration (LVD), 0.05g, 12 sec	31.4	31.4	0.0	24.4	7.6	12	0.06
CN 1002505	Lead veh. deceleration (LVD), 0.06g, 10 sec	32.6	32.6	0.0	24.4	6.7	12	0.06
CB 1071000	Lead veh. deceleration (LVD), 0.48g, 5 sec	27.4	27.4	0.0	30.5	9.1	6	0.43
Average	**LVD = 0.18g**	**29.9**	**30.1**	**-0.2**	**25.4**	**8.0**	**10**	**0.14**
IN 7319804	Lead veh. deceleration (LVD), 0.06g, 15 sec	33.2	35.4	-2.1	74.7	9.1	18	0.12
IB 596701	Lead veh. deceleration (LVD), 0.41g, 8 sec	30.5	30.5	0.0	36.6	9.1	9	0.3
IB 645402	Lead veh. deceleration (LVD), 0.18g, 7 sec	29.9	29.9	0.0	22.9	9.1	7	0.22
IB 1164200	Lead veh. deceleration (LVD), 0.18g, 15 sec	25.9	25.9	0.0	51.8	12.2	22	0.19
Average	**LVD = 0.14g**	**29.9**	**30.4**	**-0.5**	**46.5**	**9.9**	**14**	**0.21**
MN 9930900	Cut-in	22.9	28.3	-5.5	30.2	15.2	6	
CN 044400	Cut-in	22.6	32.6	-10.1	16.8	10.4	6	0.21
CN 853500	Cut-in	32.0	33.8	-1.8	14.6	9.8	4	0.07
	Average	**27.3**	**33.2**	**-5.9**	**15.7**	**10.1**	**5**	**0.14**
IN 142205	Cut-in	22.9	22.2	0.6	9.1	4.6	12	0.04
IN 217002	Cut-in	20.4	23.8	-3.4	12.2	6.1	16	0.07
IN 229800	Cut-in	26.8	28.0	-1.2	10.7	4.6	10	0.08
IN 274801	Cut-in	25.3	29.6	-4.3	21.3	6.1	11	0.08
IN 567107	Cut-in	28.6	32.3	-3.7	18.3	7.6	8	0.05
IN 598302	Cut-in	26.8	28.0	-1.2	6.1	4.6	4	0.08
IN 603401	Cut-in	27.4	32.0	-4.6	13.7	6.1	7	0.14
IN 056000	Cut-in	27.4	31.4	-4.0	22.2	15.8	6	0.06
IN 5519500	Cut-in	29.0	31.7	-2.7	12.2	9.1	3	0.07
IN 1095002	Cut-in	30.2	35.1	-4.9	19.5	4.6	7	0.09
IN 1164401	Cut-in	25.0	27.7	-2.7	18.3	12.2	5	0.06
	Average	**26.4**	**29.3**	**-2.9**	**14.9**	**7.4**	**8**	**0.07**

Table L-2. Results of Extreme Value analysis – Freeways – Top single cases for all drivers (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
CN 044400	Cut-in		22.6	32.6	16.8	10.4	6	0.99	0.21
IN 056000	Cut-in	Acc authority, no braking	27.4	31.4	22.2	15.8	6		0.06
CN 070903	LVD, 0.07g, 4 sec.	two stage	28.6	29.9	16.8	7.6	6	-	0.10
CN 140301	Lane change	night	29.0	30.5	16.8	7.6	10	-	0.06
IN 142205	Cut-in	no braking, Acc authority	22.9	22.2	9.1	4.6	12	3	0.04
IN 217002	Cut-in		20.4	23.8	12.2	6.1	16	-	0.07
IN 229800	Cut-in	night, Acc auth. no braking, speed is 80 @ 15	26.8	28.0	10.7	4.6	10	-	0.08
CN 220101	LVD, 0.08g, 6 sec.	night, end w/ Lc to avoid collision	26.8	26.8	36.6	9.1	17	-	0.11
IN 2410603	Approach	LVD slightly	29.9	32.0	30.5	6.1	21	0.5	0.03
IN 274801	Cut-in	on merge	25.3	29.6	21.3	6.1	11	-	0.08
CN 341203	Approach	night, cut out first, Lc to avoid collision	25.9	30.5	33.5	13.7	6	-	0.11
IN 346603	Approach	on curve, Acc first @ 0.07, driver braked at 40ft	21.3	30.5	51.8	6.1	10	-	0.3
CB 411200	Approach	Ms	27.7	35.1	91.4	16.8	13	-	0.11
MN 514204	LVD, 0.03g, 8sec.	coast-no braking response	30.5	30.5	16.8	9.1	13	-	0.03
IN 5519500	Cut-in	Acc authority, no braking	29.0	31.7	12.2	9.1	3		0.07
IN 567107	Cut-in	Icc authority, no braking	28.6	32.3	18.3	7.6	8	-	0.05
IB 596701	LVD, 0.41g, 8 sec.		30.5	30.5	36.6	9.1	9	2	0.3
IN 598302	Cut-in	speed is 90 @ 15	26.8	28.0	6.1	4.6	4	2.2	0.08
IN 603401	Cut-in		27.4	32.0	13.7	6.1	7	-	0.14
IB 645402	LVD, 0.18g, 7 sec.		29.9	29.9	22.9	9.1	7		0.22
MN 640103	Approach		29.0	32.9	86.9	4.9	22		0.15
CN 641307	Approach	lane change to avoid collision	29.3	33.8	94.5	18.9	16		
IN 645403	Lane change	Acc authority, no braking	30.5	34.1	15.2	13.7	4		0.06
CN 683800	Approach	lane change to avoid collision	28.6	32.0	76.2	18.3	14		
CN 730804	Approach	lane change to avoid collision	27.4	34.1	115.8	15.2	19		
IN 7319804	LVD, 0.06g, 15 sec.	Acc authority for 1st 6 sec.	33.2	35.4	74.7	9.1	18	3.7	0.12
MN 756600	Approach		29.3	32.0	31.1	12.2	15		0.02
CN 800106	LVD, 0.04g, 8 sec.		32.6	32.6	19.8	7.6	9	3.8	0.1
CN 853500	Cut-in		32.0	33.8	14.6	9.8	4		0.07
CN 872300	LVD, 0.05g, 12sec		31.4	31.4	24.4	7.6	12	3.1	0.06
MN 9930900	Cut-in	lane change to avoid collision	22.9	28.3	30.2	15.2	6		
IN 9921507	Approach	Icc authority, no braking	32.0	33.5	32.0	10.7	17		
CN 1002505	LVD, 0.06g, 10sec		32.6	32.6	24.4	6.7	12		0.06
CB 1071000	LVD, 0.48g, 5sec		27.4	27.4	30.5	9.1	6	1	0.43*
MN 1090702	LVD, 0.04g, 16 sec.		29.3	29.3	18.3	4.6	16		0.15
IN 1095002	Cut-in		30.2	35.1	19.5	4.6	7		0.09
MN 1115300	Approach	lane change to avoid collision	28.0	31.4	45.7	18.3	13		
IB 1164200	LVD, 0.18g, 15sec		25.9	25.9	51.8	12.2	22		0.19
IN 1164401	Cut-in	Icc authority, no braking	25.0	27.7	18.3	12.2	5		0.06
MN 1171401	LVD, 0.05g, 21sec		31.4	31.7	31.7	6.1	21		0.08
IN 1175105	Approach	Icc authority, no braking & lc to avoid collision	25.9	32.3	82.3	19.8	13		0.04

MN - Manual Near Encounter CN - CCC Near Encounter IN - ICC Near Encounter
MB - Manual Braking CB - CCC Braking IB - ICC Braking

Table L-3. Results of Extreme Value analysis – Arterials – Top Singles cases for all drivers (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 1061803	Approach	7.0	20.1	-13.1	>30	21.3	7	0.14
CN 740500	Approach	8.5	19.8	-11.3	>30	18.3	11	0.15
CN 240201	Approach	28.0	29.0	-0.9	18.3	6.1	20	0.06
Average		**18.3**	**24.4**	**-6.1**	**>30**	**12.2**	**16**	**0.11**
IN 743202	Approach	9.1	22.2	-13.1	>30	18.3	9	0.05
IN 915803	Approach	6.4	20.1	-13.7	>30	16.8	7	0.14
Average		**7.8**	**21.2**	**-13.4**	**>30**	**17.5**	**8**	**0.10**
MN 358600	Lead veh. deceleration (LVD), 0.2g, 6 sec	17.1	18.3	-1.2	61.0	19.8	6	0.14
CN 191801	Lead veh. deceleration (LVD), 0.04g, 9 sec	22.9	23.2	-0.3	47.2	6.1	17	0.06
IN 1074201	Lead veh. deceleration (LVD), 0.12g, 9 sec	22.9	24.7	-1.8	61.0	25.9	10	0.04
MN 7813900	Cut in	16.8	21.6	-4.9	10.7	6.1	6	0.11
CB 341701	Cut in	20.1	30.2	-10.1	>30	15.2	16	0.16

Table L-4. Results of Extreme Value analysis – Arterials – Top Singles cases for all drivers (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
CN 191801	LVD, 0.04g, 9 sec		22.9	23.2	47.2	6.1	17		0.06
CN 240201	Approach		28.0	29.0	18.3	6.1	20		0.06
CB 341701	Cut in	lc to avoid collision, night	20.1	30.2	>42	15.2	16		0.16
MN 358600	LVD, 0.2g, 6 sec	lc to avoid collision	17.1	18.3	61.0	19.8	6		0.14
CN 740500	Approach		8.5	19.8	>30	18.3	11		0.15
IN 743202	Approach	Icc authority, no braking	9.1	22.2	>30	18.3	9		0.05
MN 7813900	Cut in		16.8	21.6	10.7	6.1	6		0.11
IN 915803	Approach		6.4	20.1	>30	16.8	7		0.14
MN 1061803	Approach		7.0	20.1	>30	21.3	7		0.14
IN 1074201	LVD, 0.12g, 9 sec	Icc authority & lc to avoid collision	22.9	24.7	61.0	25.9	10		0.04

Table L-5. Results of Extreme Value analysis – Ramps – Top Singles cases for all drivers

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
IN 5015302	LVD, 0.4, 1sec & 0.05g, 12 sec	in ramp	26.5	28.6	35.1	4.6	11		0.14
IB 1134602	LVD, .09g, 7 sec		20.7	25.3	67.1	27.4	10		0.18
Average	**LVD = 0.18g**		**23.6**	**27.0**	**51.1**	**16.0**	**11**		**0.16**

Table L-6. Results of Extreme Value analysis – Freeways – Top 5 cases for 50 drivers (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 416011	Approach	28.0	39.6	-11.6	45.7	9.1	14	0.15
MN 5912610	Approach	28.3	31.7	-3.4	54.9	6.1	22	0.05
MN 613813	Approach	23.5	30.5	-7.0	100.6	15.2	13	
MN 7918500	Approach	27.1	32.6	-5.5	106.7	12.2	18	0.11
	Average	**26.7**	**33.6**	**-6.9**	**77.0**	**10.7**	**17**	**0.10**
CN 070801	Approach	25.0	27.1	-2.1	54.9	15.2	20	0.12
CN 141706	Approach	21.3	22.9	-1.5	30.5	4.6	16	0.14
CN 185602	Approach	27.4	30.5	-3.0	73.1	12.2	16	
CN 212100	Approach	27.4	29.0	-1.5	21.3	9.1	9	0.05
CN 300103	Approach	27.7	29.3	-1.5	30.5	15.2	30	0
CN 300104	Approach	28.0	29.0	-0.9	21.3	16.8	14	0.06
CN 341203	Approach	25.9	30.5	-4.6	33.5	13.7	6	0.11
CN 414200	Approach	32.0	34.1	-2.1	32.0	10.7	16	0.07
CN 506202	Approach	26.8	29.9	-3.0	61.0	13.7	15	0
CN 601700	Approach	29.6	32.3	-2.7	57.9	9.1	21	0.08
CN 800507	Approach	29.9	32.0	-2.1	35.1	13.7	15	
CN 800105	Approach	29.3	32.3	-3.0	39.6	10.7	11	0.1
CB 060400	Approach	24.4	28.3	-4.0	88.4	24.4	21	0.06
CB 141501	Approach	15.2	22.2	-7.0	42.7	24.4	9	0.13
CB 341202	Approach	25.9	31.1	-5.2	45.7	15.2	10	0.06
CB 370700	Approach	21.3	24.4	-3.0	77.7	18.3	25	0.10
CB 411200	Approach	27.7	35.1	-7.3	91.4	16.8	13	0.11
	Average	**26.2**	**29.4**	**-3.2**	**49.2**	**14.3**	**16**	**0.08**
IN 142804	Approach	21.9	27.4	-5.5	51.8	4.6	16	0.11
IN 2410603	Approach	29.9	32.0	-2.1	30.5	6.1	21	0.03
IN 346603	Approach	21.3	30.5	-9.1	51.8	6.1	10	0.3
IN 599402	Approach	27.1	32.3	-5.2	39.6	7.6	12	0.24
IN 9011002	Approach	25.9	27.4	-1.5	32.0	7.6	16	
IB 142206	Approach	13.4	25.9	-12.5	15.2	12.2	5	0.23
IB 482808	Approach	20.7	27.4	-6.7	109.7	25.9	22	0.05
	Average	**25.2**	**29.9**	**-4.7**	**41.1**	**6.4**	**15**	**0.17**
CN 170101	Cut-in	25.9	29.9	-4.0	12.2	10.7	8	0.07
CN 560107	Cut-in	32.0	34.1	-2.1	15.2	9.1	7	
CN 784101	Cut-in	26.2	27.1	-0.9	9.1	7.6	4	0.11
CB 353702	Cut-in	28.6	32.0	-3.4	30.5	22.9	9	0.07
	Average	**28.2**	**30.8**	**-2.6**	**16.8**	**12.6**	**7**	**0.08**
IN 075702	Cut-in	22.9	28.0	-5.2	30.5	16.8	8	0.05
IN 142205	Cut-in	22.9	22.2	0.6	9.1	4.6	12	0.04
IN 142202	Cut-in	20.4	25.9	-5.5	9.1	3.0	7	0.50
IN 143000	Cut-in	21.3	24.4	-3.0	9.1	4.6	8	0.20
IN 154907	Cut-in	27.1	30.5	-3.4	9.1	6.1	6	0.05
IN 217002	Cut-in	20.4	23.8	-3.4	12.2	6.1	16	0.07
IN 229800	Cut-in	26.8	28.0	-1.2	10.7	4.6	10	0.08
IN 274801	Cut-in	25.3	29.6	-4.3	21.3	6.1	11	0.08
IN 4013800	Cut-in	25.9	32.0	-6.1	42.7	19.8	8	0.07
IN 564401	Cut-in	23.8	31.1	-7.3	30.5	12.2	7	0.2
IN 567107	Cut-in	28.6	32.3	-3.7	18.3	7.6	8	0.05
IN 598302	Cut-in	26.8	28.0	-1.2	6.1	4.6	4	0.08
IN 603401	Cut-in	27.4	32.0	-4.6	13.7	6.1	7	0.14
IN 605601	Cut-in	28.0	31.7	-3.7	12.2	9.1	5	0.07
	Average	**24.8**	**28.5**	**-3.7**	**16.8**	**7.9**	**8**	**0.12**

MN 070802	Lead veh. deceleration (LVD), 0.06g, 5 sec	25.9	25.9	0.0	15.2	9.1	6	0.06
MN 144401	Lead veh. deceleration (LVD), 0.08g, 8 sec	20.7	20.7	0.0	18.3	4.6	14	0.08
MN 144701	Lead veh. deceleration (LVD), 0.21g, 4 sec	26.8	26.8	0.0	10.7	6.1	6	0.21
MN 416012	Lead veh. deceleration (LVD). 0.03g, 7 sec	25.9	25.9	0.0	12.2	6.1	7	0.04
MN 514204	Lead veh. deceleration (LVD), 0.03g, 8sec	30.5	30.5	0.0	16.8	9.1	13	0.03
MN 5613100	Lead veh. deceleration (LVD), 0.10g, 3 sec	32.0	32.0	0.0	14.3	6.1	12	0.05
MN 5611301	Lead veh. deceleration (LVD), 0.05g, 10 sec	29.6	29.6	0.0	22.9	6.1	12	0.12
MB 141704	Lead veh. deceleration (LVD), 0.42g, 12 sec	25.9	25.9	0.0	30.5	6.1	14	0.22
MB 820201	Lead veh. deceleration (LVD), 0.15g, 8 sec	27.4	26.8	0.6	59.4	13.7	15	0.2
MB 1083200	Lead veh. deceleration (LVD), 0.09g, 8 sec	29.9	29.9	0.0	51.8	35.1	14	0.07
Average	**LVD = 0.16g**	**27.5**	**27.4**	**0.1**	**25.2**	**10.2**	**11.3**	**0.11**
CN 070903	Lead veh. deceleration (LVD), 0.07g, 4 sec	28.6	29.9	-1.2	16.8	7.6	6	0.10
CN 102300	Lead veh. deceleration (LVD), 0.05g, 6 sec	29.0	30.5	-1.5	27.4	12.2	12	0.15
CN 141105	Lead veh. deceleration (LVD), 0.06g, 8 sec	29.0	29.0	0.0	10.7	6.1	8	0.09
CN 141103	Lead veh. deceleration (LVD), 0.08g, 8 sec	35.1	33.5	1.5	18.3	9.1	16	
CN 220101	Lead veh. deceleration (LVD), 0.08g, 6 sec	26.8	26.8	0.0	36.6	9.1	17	0.11
CN 600300	Lead veh. deceleration (LVD), 0.05g, 6 sec	31.7	31.7	0.0	25.9	7.6	8	0.1
CN 601601	Lead veh. deceleration (LVD), 0.15g, 3sec	32.6	32.0	0.6	16.8	7.6	4	
CN 800106	Lead veh. deceleration (LVD), 0.04g, 8 sec	32.6	32.6	0.0	19.8	7.6	9	0.1
CB 141001	Lead veh. deceleration (LVD), 0.19g, 7 sec	24.7	23.2	1.5	32.0	21.3	13	0.12
CB 342000	Lead veh. deceleration (LVD), 0.05g, 7 sec	27.4	29.9	-2.4	36.6	16.8	10	0.09
CB 410103	Lead veh. deceleration (LVD), 0.06g, 9 sec	29.0	29.0	0.0	19.8	12.2	7	0.08
Average	**LVD = 0.08g**	**29.7**	**29.8**	**-0.1**	**23.7**	**10.7**	**10**	**0.10**
IN 346602	Lead veh. deceleration (LVD), 0.03g, 7 sec	25.9	26.8	-0.9	32.0	10.7	7	
IB 314000	Lead veh. deceleration (LVD), 0.21g, 3 sec	27.4	25.9	1.5	16.8	13.7	5	0.09
IB 359901	Lead veh. deceleration (LVD), 0.12g, 15 sec	29.6	29.0	0.6	45.7	10.7	18	0.11
IB 415400	Lead veh. deceleration (LVD), 0.10g, 14 sec	30.5	32.0	-1.5	35.1	24.4	7	0.13
IB 596602	Lead veh. deceleration (LVD), 0.30g, 9 sec	26.5	26.5	0.0	24.4	6.1	10	0.26
IB 596701	Lead veh. deceleration (LVD), 0.41g, 8 sec	30.5	30.5	0.0	36.6	9.1	9	0.3
IB 804002	Lead veh. deceleration (LVD), 0.13g, 15 sec	29.6	29.6	0.0	32.0	10.7	15	0.14
IB 823003	Lead veh. deceleration (LVD), 0.25g, 10 sec	29.3	29.3	0.0	18.3	3.0	12	0.3
Average	**LVD = 0.19g**	**28.6**	**28.7**	**0.0**	**30.1**	**11.0**	**10**	**0.19**
MN 316000	Lane change	25.0	25.9	-0.9	7.0	6.1	4	0.05
MN 321805	Lane change	27.4	30.8	-3.4	32.0	10.7	10	0.12
	Average	**26.2**	**28.3**	**-2.1**	**19.5**	**8.4**	**7**	**0.09**
CN 102001	Lane change	29.0	32.0	-3.0	27.4	12.2	4	0
CN 140301	Lane change	29.0	30.5	-1.5	16.8	7.6	10	0.06
CN 800516	Lane change	31.7	33.8	-2.1	48.8	7.6	17	0.07
	Average	**29.9**	**32.1**	**-2.2**	**31.0**	**9.1**	**10**	**0.04**
IN 567902	Lane change	28.6	33.2	-4.6	42.7	7.6	11	0.03
IN 605602	Lane change	22.9	32.0	-9.1	24.4	4.6	7	0.26
	Average	**22.9**	**32.0**	**-9.1**	**24.4**	**4.6**	**7**	**0.26**

Table L-7. Results of Extreme Value analysis – Freeways – Top 5 cases for 50 drivers (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
CB 060400	Approach	night	24.4	28.3	88.4	24.4	21	-	0.06
MN 070802	LVD, 0.06g, 5 sec	false targets	25.9	25.9	15.2	9.1	6	-	0.06
CN 070903	LVD, 0.07g, 4 sec	two stage	28.6	29.9	16.8	7.6	6	-	0.10
CN 070801	Approach	false targets	25.0	27.1	54.9	15.2	20	-	0.12
IN 075702	Cut-in	merge from ramp	22.9	28.0	30.5	16.8	8	-	0.05
CN 102001	Lane change (Lc)	const. speed, Lc to avoid collision	29.0	32.0	27.4	12.2	4	-	0
CN 102300	LVD, 0.05g, 6 sec		29.0	30.5	27.4	12.2	12	-	0.15
MN 144401	LVD, 0.08g, 8 sec	heavy traffic	20.7	20.7	18.3	4.6	14	0.8	0.08
MN 144701	LVD, 0.21g, 4 sec	merge situation	26.8	26.8	10.7	6.1	6	-	0.21
CN 140301	Lane change	night	29.0	30.5	16.8	7.6	10	-	0.06
CN 141105	LVD, 0.06g, 8 sec	night	29.0	29.0	10.7	6.1	8	-	0.09
CN 141706	Approach		21.3	22.9	30.5	4.6	16	2.1	0.14
CN 141103	LVD, 0.08g, 8 sec	end in lane change	35.1	33.5	18.3	9.1	16	-	
IN 142205	Cut-in	no braking, Acc authority	22.9	22.2	9.1	4.6	12	3	0.04
IN 142202	Cut-in	Ne, merge situation, heavy traffic	20.4	25.9	9.1	3.0	7		0.50
IN 143000	Cut-in	night	21.3	24.4	9.1	4.6	8	0.4	0.20
IN 142804	Approach	switch (cut-out), Acc authority	21.9	27.4	51.8	4.6	16	-	0.11
MB 141704	LVD to stop, 0.42g, 12 sec		25.9	25.9	30.5	6.1	14	1.3	0.22
CB 141501	Approach	switch (cut-out)	15.2	22.2	42.7	24.4	9	-	0.13
CB 141001	LVD, 0.19g, 7 sec	lane blockage	24.7	23.2	32.0	21.3	13	3.7	0.12
IB 142206	Approach	switch-cut-out, roadside hazard, multi-scenarios (Ms)	13.4	25.9	15.2	12.2	5	-	0.23
IN 154907	Cut-in	no braking, Acc authority	27.1	30.5	9.1	6.1	6	-	0.05
CN 170101	Cut-in	brake early	25.9	29.9	12.2	10.7	8	-	0.07
CN 185602	Approach	lane change to avoid collision	27.4	30.5	73.1	12.2	16	-	
IN 217002	Cut-in		20.4	23.8	12.2	6.1	16	-	0.07
CN 212100	Approach	lane change to avoid collision	27.4	29.0	21.3	9.1	9	-	0.05
IN 229800	Cut-in	night, Acc auth. no braking, speed is 80 @ 15	26.8	28.0	10.7	4.6	10	-	0.08
CN 220101	LVD, 0.08g, 6 sec	night, end w/ Lc to avoid collision	26.8	26.8	36.6	9.1	17	-	0.11
IN 2410603	Approach	LVD slightly	29.9	32.0	30.5	6.1	21	0.5	0.03
IN 274801	Cut-in	on merge	25.3	29.6	21.3	6.1	11	-	0.08
CN 300103	Approach		27.7	29.3	30.5	15.2	30	-	0
CN 300104	Approach		28.0	29.0	21.3	16.8	14	-	0.06
IB 314000	LVD, 0.21g, 3 sec	night, Ms	27.4	25.9	16.8	13.7	5	2	0.09

MN 316000	Lane change		25.0	25.9	7.0	6.1	4	-	0.05
MN 321805	Lane change		27.4	30.8	32.0	10.7	10	-	0.12
CB 342000	LVD, 0.05g, 7 sec	Ms, approach first	27.4	29.9	36.6	16.8	10	-	0.09
CB 341202	Approach	night, Ms, Lc first	25.9	31.1	45.7	15.2	10	-	0.06
CN 341203	Approach	night, cut out first, Lc to avoid collision	25.9	30.5	33.5	13.7	6	-	0.11
IN 346603	Approach	on curve, Acc first @ 0.07, driver braked at 40ft	21.3	30.5	51.8	6.1	10	-	0.3
IN 346602	LVD, 0.03g, 7 sec	Lc to avoid collision	25.9	26.8	32.0	10.7	7	-	
			0.0	0.0	0.0	0.0			
IB 359901	LVD, 0.12g, 15 sec		29.6	29.0	45.7	10.7	18	-	0.11
CB 353702	Cut-in		28.6	32.0	30.5	22.9	9	-	0.07
CB 370700	Approach	night	21.3	24.4	77.7	18.3	25	-	0.10
IN 4013800	Cut-in	truck in adjacent lane	25.9	32.0	42.7	19.8	8	-	0.07
IB 415400	LVD, 0.1g, 14 sec	Ms, 4 stages	30.5	32.0	35.1	24.4	7	1.4	0.13
CB 411200	Approach	Ms	27.7	35.1	91.4	16.8	13	-	0.11
CB 410103	LVD, 0.06g, 9 sec	night	29.0	29.0	19.8	12.2	7	1.0	0.08
MN 416011	Approach	night	28.0	39.6	45.7	9.1	14	1	0.15
MN 416012	LVD. 0.03g, 7 sec	night, Ms	25.9	25.9	12.2	6.1	7	-	0.04
CN 414200	Approach		32.0	34.1	32.0	10.7	16	-	0.07
IB 482808	Approach		20.7	27.4	109.7	25.9	22	-	0.05
CN 506202	Approach	Ms	26.8	29.9	61.0	13.7	15	-	0
MN 514204	LVD, 0.03g, 8sec	coast-no braking response	30.5	30.5	16.8	9.1	13	-	0.03
CN 560107	Cut-in	lead veh. cut-out to avoid collision	32.0	34.1	15.2	9.1	7	-	
MN 5613100	LVD, 0.1g, 3 sec		32.0	32.0	14.3	6.1	12	-	0.05
IN 564401	Cut-in		23.8	31.1	30.5	12.2	7	-	0.2
IN 567107	Cut-in	Icc authority, no braking	28.6	32.3	18.3	7.6	8	-	0.05
IN 567902	Lane change	Icc authority, Lc to avoid collision	28.6	33.2	42.7	7.6	11	-	0.03
MN 5611301	LVD, 0.05g, 10 sec		29.6	29.6	22.9	6.1	12	-	0.12
IB 596701	LVD, 0.41g, 8 sec		30.5	30.5	36.6	9.1	9	2	0.3
IB 596602	LVD, 0.3g, 9 sec	twilight	26.5	26.5	24.4	6.1	10	-	0.26
MN 5912610	Approach		28.3	31.7	54.9	6.1	22	-	0.05
IN 598302	Cut-in	speed is 90 @ 15	26.8	28.0	6.1	4.6	4	2.2	0.08
IN 599402	Approach	night, Lc to avoid collision, Icc initially at 0.05g	27.1	32.3	39.6	7.6	12	-	0.24
CN 601700	Approach		29.6	32.3	57.9	9.1	21	-	0.08
CN 600300	LVD, 0.05g, 6 sec		31.7	31.7	25.9	7.6	8	-	0.1
CN 601601	LVD, 0.15g, 3sec	Ne, Lc to avoid collision	32.6	32.0	16.8	7.6	4	-	
IN 603401	Cut-in		27.4	32.0	13.7	6.1	7	-	0.14
IN 605602	Lane change	Ne, speed is 67 @ 15	22.9	32.0	24.4	4.6	7	-	0.26
IN 605601	Cut-in	Icc authority	28.0	31.7	12.2	9.1	5	-	0.07
MN 613813	Approach	Ne, high closing, Lc to avoid coll.	23.5	30.5	100.6	15.2	13	-	

CN 784101	Cut-in	lead veh. cuts across 2 lanes	26.2	27.1	9.1	7.6	4	-	0.11
MN 7918500	Approach	Lc to avoid collision	27.1	32.6	106.7	12.2	18		0.11
IB 804002	LVD, 0.13g, 15 sec	no icc response	29.6	29.6	32.0	10.7	15	0.8	0.14
CN 800106	LVD, 0.04g, 8 sec		32.6	32.6	19.8	7.6	9	3.8	0.1
CN 800516	Lane change		31.7	33.8	48.8	7.6	17	-	0.07
CN 800507	Approach	lane change to avoid collision	29.9	32.0	35.1	13.7	15	-	
CN 800105	Approach		29.3	32.3	39.6	10.7	11	-	0.1
IB 823003	LVD, 0.25g, 10 sec	near stop, speed is < 15 @ 10	29.3	29.3	18.3	3.0	12	3.7	0.3
MB 820201	LVD, 0.15g, 8 sec	double LVD	27.4	26.8	59.4	13.7	15	3.2	0.2
IN 9011002	Approach	Lc to avoid collision (accel)	25.9	27.4	32.0	7.6	16	-	
MB 1083200	LVD, .09g, 8 sec		29.9	29.9	51.8	35.1	14		0.07

Table L-8. Results of Extreme Value analysis – Arterials – Top 5 cases for 50 drivers (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 155501	Approach	10.7	23.2	-12.5	30.5	9.1	16	0.15
MN 353603	Approach	11.3	20.7	-9.4	>60	30.5	9	0.13
MN 431300	Approach	13.7	25.9	-12.2	76.2	47.2	13	0.04
MN 820202	Approach	10.7	22.9	-12.2	>60	35.1	12	0.04
Average		**11.6**	**23.2**	**-11.6**	**>60**	**30.5**	**13**	**0.09**
CN 240201	Approach	28.0	29.0	-0.9	18.3	6.1	20	0.06
IN 306600	Approach	18.9	21.3	-2.4	85.3	30.5	13	0.05
IN 435700	Approach	15.2	26.5	-11.3	45.7	10.7	12	0.08
IB 155400	Approach	19.8	25.9	-6.1	80.8	19.8	15	0.19
Average		**18.0**	**24.6**	**-6.6**	**70.6**	**20.3**	**13**	**0.11**
MN 290601	Cut in	12.2	22.2	-10.1	15.2	4.6	13	0.11
MN 7813900	Cut in	16.8	21.6	-4.9	10.7	6.1	6	0.11
Average		**14.5**	**21.9**	**-7.5**	**13.0**	**5.3**	**10**	**0.11**
CB 341701	Cut in	20.1	30.2	-10.1	>42	15.2	16	0.16
MN 350104	Lead veh. decelerates, 0.2g for 8 sec	21.3	18.3	3.0	53.3	15.2	10	0.16
MN 358600	Lead veh. decelerates, 0.2g for 6 sec	17.1	18.3	-1.2	61.0	19.8	6	0.14
MN 430802	Lead veh. decelerates, 0.04g for 6 sec	22.9	22.9	0.0	33.5	19.8	7	0.06
Average	**LVD = 0.17g**	**20.4**	**19.8**	**0.6**	**49.3**	**18.3**	**7.7**	**0.12**
CN 430805	Lead veh. decelerates, 0.08g for 7 sec	23.5	25.0	-1.5	45.7	18.3	9	0.05
MB 405900	Lead veh. decelerates, 0.07g for 11 sec	24.4	22.9	1.5	91.4	79.2	11	0.05
MN 793902	Lane change	18.9	24.7	-5.8	39.6	16.8	6	0.18

Table L-9. Results of Extreme Value analysis – Arterials – Top 5 cases for 50 drivers (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
MN 155501	Approach		10.7	23.2	30.5	9.1	16		0.15
IB 155400	Approach	lane change (lc) to avoid collision	19.8	25.9	80.8	19.8	15	1.3	0.19
CN 240201	Approach		28.0	29.0	18.3	6.1	20		0.06
MN 290601	Cut in	lc to avoid collision, night	12.2	22.2	15.2	4.6	13		0.11
IN 306600	Approach	false tracking of lead veh. after lc	18.9	21.3	85.3	30.5	13		0.05
CB 341701	Cut in	lc to avoid collision, night	20.1	30.2	>42	15.2	16		0.16
MN 350104	LVD, 0.2g, 8 sec	right turn, lc to avoid collision	21.3	18.3	53.3	15.2	10		0.16
MN 353603	Approach	lc to avoid collision, curve, ms	11.3	20.7	>60	30.5	9		0.13
MN 358600	LVD, 0.2g, 6 sec	lc to avoid collision	17.1	18.3	61.0	19.8	6		0.14
MB 405900	LVD, 0.07g, 11 sec		24.4	22.9	91.4	79.2	11		0.05
IN 435700	Approach	night, wet	15.2	26.5	45.7	10.7	12		0.08
CN 430805	LVD, 0.08g, 7 sec	lc to avoid collision	23.5	25.0	45.7	18.3	9		0.05
MN 430802	LVD, 0.04g, 6 sec		22.9	22.9	33.5	19.8	7		0.06
MN 431300	Approach		13.7	25.9	76.2	47.2	13		0.04
MN 7813900	Cut in		16.8	21.6	10.7	6.1	6		0.11
MN 793902	Lane change	lc to avoid collision	18.9	24.7	39.6	16.8	6		0.18
MN 820202	Approach		10.7	22.9	>60	35.1	12		0.04

Table L-10. Results of Extreme Value analysis – Ramps – Top 5 cases for 50 drivers (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 601501	Approach	27.4	29.0	-1.5	61.0	13.7	21	0.09
IB 802702	Approach	25.9	29.0	-3.0	48.8	7.6	18	0.19
Average		**26.7**	**29.0**	**-2.3**	**54.9**	**10.7**	**20**	**0.14**
IN 142505	Lead veh. deceleration (LVD), 0.18g, 8 sec	24.4	24.4	0.0	54.9	3.0		0.17
IB 177005	Lead veh. deceleration (LVD), 0.04g, 10 sec	25.9	25.9	0.0	24.4	15.2	11	0.08
IB 232801	Lead veh. deceleration (LVD), 0.05g, 24 sec	26.2	26.2	0.0	22.9	13.7	13	0.09
IN 502600	Lead veh. deceleration (LVD), 0.08g, 28 sec & 0.28g, 2 sec	20.1	20.1	0.0	19.8	2.4	11	0.34
IN 5015302	Lead veh. deceleration (LVD), 0.4, 1sec & 0.05g, 12 sec	26.5	28.6	-2.1	35.1	4.6	11	0.14
IB 602601	Lead veh. deceleration (LVD), 0.06g, 19sec	29.6	29.6	0.0	21.3	9.1	12	0.11
Average	**LVD = 0.14g**	**25.4**	**25.8**	**-0.4**	**29.7**	**8.0**	**12**	**0.16**

Table L-11. Results of Extreme Value analysis – Ramps – Top 5 cases for 50 drivers (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
IN 142505	LVD, 0.18g, 8 sec	initiated before ramp end	24.4	24.4	54.9	3.0			0.17
IB 177005	LVD, 0.04g, 10 sec	before ramp	25.9	25.9	24.4	15.2	11		0.08
IB 232801	LVD, 0.05g, 24 sec	before ramp lead veh. signaling	26.2	26.2	22.9	13.7	13		0.09
IN 502600	LVD, 0.08g, 8 sec & 0.28g, 2 sec	in ramp, 1st phase control by ICC	20.1	20.1	19.8	2.4	11	2.2, 7.2	0.34
IN 5015302	LVD, 0.40, 1sec & 0.05g, 12 sec	in ramp	26.5	28.6	35.1	4.6	11		0.14
MN 601501	Approach	in ramp, lc to avoid collision	27.4	29.0	61.0	13.7	21	1	0.09
IB 602601	LVD, 0.06g, 19sec	in ramp	29.6	29.6	21.3	9.1	12		0.11
IB 802702	Approach	Icc control initially 0.06g	25.9	29.0	48.8	7.6	18	1	0.19

Table L-12. Results of Extreme Value analysis – Freeways – Top 5 cases for 50 drivers with additional (2)* 0.25g cases (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 416011	Approach	28.0	39.6	-11.6	45.7	9.1	14	0.15
MN 5912610	Approach	28.3	31.7	-3.4	54.9	6.1	22	0.05
MN 613813	Approach	23.5	30.5	-7.0	100.6	15.2	13	
MN 7918500	Approach	27.1	32.6	-5.5	106.7	12.2	18	0.11
	Average	**26.7**	**33.6**	**-6.9**	**77.0**	**10.7**	**17**	**0.10**
CN 070801	Approach	25.0	27.1	-2.1	54.9	15.2	20	0.12
CN 141706	Approach	21.3	22.9	-1.5	30.5	4.6	16	0.14
CN 185602	Approach	27.4	30.5	-3.0	73.1	12.2	16	
CN 212100	Approach	27.4	29.0	-1.5	21.3	9.1	9	0.05
CN 300103	Approach	27.7	29.3	-1.5	30.5	15.2	30	0
CN 300104	Approach	28.0	29.0	-0.9	21.3	16.8	14	0.06
CN 341203	Approach	25.9	30.5	-4.6	33.5	13.7	6	0.11
CN 414200	Approach	32.0	34.1	-2.1	32.0	10.7	16	0.07
CN 506202	Approach	26.8	29.9	-3.0	61.0	13.7	15	0
CN 601700	Approach	29.6	32.3	-2.7	57.9	9.1	21	0.08
CN 800507	Approach	29.9	32.0	-2.1	35.1	13.7	15	
CN 800105	Approach	29.3	32.3	-3.0	39.6	10.7	11	0.1
CB 060400	Approach	24.4	28.3	-4.0	88.4	24.4	21	0.06
CB 141501	Approach	15.2	22.2	-7.0	42.7	24.4	9	0.13
CB 341202	Approach	25.9	31.1	-5.2	45.7	15.2	10	0.06
CB 370700	Approach	21.3	24.4	-3.0	77.7	18.3	25	0.10
CB 411200	Approach	27.7	35.1	-7.3	91.4	16.8	13	0.11
	Average	**26.2**	**29.4**	**-3.2**	**49.2**	**14.3**	**16**	**0.08**
IN 142804	Approach	21.9	27.4	-5.5	51.8	4.6	16	0.11
IN 2410603	Approach	29.9	32.0	-2.1	30.5	6.1	21	0.03
IN 346603	Approach	21.3	30.5	-9.1	51.8	6.1	10	0.3
IN 599402	Approach	27.1	32.3	-5.2	39.6	7.6	12	0.24
IN 9011002	Approach	25.9	27.4	-1.5	32.0	7.6	16	
IB 142206	Approach	13.4	25.9	-12.5	15.2	12.2	5	0.23
IB 482808	Approach	20.7	27.4	-6.7	109.7	25.9	22	0.05
	Average	**25.2**	**29.9**	**-4.7**	**41.1**	**6.4**	**15**	**0.17**

CN 170101	Cut-in	25.9	29.9	-4.0	12.2	10.7	8	0.07
CN 560107	Cut-in	32.0	34.1	-2.1	15.2	9.1	7	
CN 784101	Cut-in	26.2	27.1	-0.9	9.1	7.6	4	0.11
CB 353702	Cut-in	28.6	32.0	-3.4	30.5	22.9	9	0.07
	Average	**28.2**	**30.8**	**-2.6**	**16.8**	**12.6**	**7**	**0.08**
IN 075702	Cut-in	22.9	28.0	-5.2	30.5	16.8	8	0.05
IN 142205	Cut-in	22.9	22.2	0.6	9.1	4.6	12	0.04
IN 142202	Cut-in	20.4	25.9	-5.5	9.1	3.0	7	0.50
IN 143000	Cut-in	21.3	24.4	-3.0	9.1	4.6	8	0.20
IN 154907	Cut-in	27.1	30.5	-3.4	9.1	6.1	6	0.05
IN 217002	Cut-in	20.4	23.8	-3.4	12.2	6.1	16	0.07
IN 229800	Cut-in	26.8	28.0	-1.2	10.7	4.6	10	0.08
IN 274801	Cut-in	25.3	29.6	-4.3	21.3	6.1	11	0.08
IN 4013800	Cut-in	25.9	32.0	-6.1	42.7	19.8	8	0.07
IN 564401	Cut-in	23.8	31.1	-7.3	30.5	12.2	7	0.2
IN 567107	Cut-in	28.6	32.3	-3.7	18.3	7.6	8	0.05
IN 598302	Cut-in	26.8	28.0	-1.2	6.1	4.6	4	0.08
IN 603401	Cut-in	27.4	32.0	-4.6	13.7	6.1	7	0.14
IN 605601	Cut-in	28.0	31.7	-3.7	12.2	9.1	5	0.07
	Average	**24.8**	**28.5**	**-3.7**	**16.8**	**7.9**	**8**	**0.12**
MN 070802	Lead veh. deceleration (LVD), 0.06g, 5 sec	25.9	25.9	0.0	15.2	9.1	6	0.06
MN 144401	Lead veh. deceleration (LVD), 0.08g, 8 sec	20.7	20.7	0.0	18.3	4.6	14	0.08
*MN 144404	Lead veh. deceleration (LVD), 0.36g, 2 sec	18.3	19.8	-1.5	7.6	4.6	8	0.36
*MN 144602	Lead veh. deceleration (LVD), 0.30g, 2 sec	15.2	16.8	-1.5	4.6	1.5	3	0.3
MN 144701	Lead veh. deceleration (LVD), 0.21g, 4 sec	26.8	26.8	0.0	10.7	6.1	6	0.21
MN 416012	Lead veh. deceleration (LVD). 0.03g, 7 sec	25.9	25.9	0.0	12.2	6.1	7	0.04
MN 514204	Lead veh. deceleration (LVD), 0.03g, 8sec	30.5	30.5	0.0	16.8	9.1	13	0.03
MN 5613100	Lead veh. deceleration (LVD), 0.10g, 3 sec	32.0	32.0	0.0	14.3	6.1	12	0.05
MN 5611301	Lead veh. deceleration (LVD), 0.05g, 10 sec	29.6	29.6	0.0	22.9	6.1	12	0.12
MB 141704	Lead veh. deceleration (LVD), 0.42g, 12 sec	25.9	25.9	0.0	30.5	6.1	14	0.22
MB 820201	Lead veh. deceleration (LVD), 0.15g, 8 sec	27.4	26.8	0.6	59.4	13.7	15	0.2
MB 1083200	Lead veh. deceleration (LVD), 0.09g, 8 sec	29.9	29.9	0.0	51.8	35.1	14	0.07
Average	**LVD = 0.16g**	**25.7**	**25.9**	**-0.2**	**22.0**	**9.0**	**10**	**0.15**
CN 070903	Lead veh. deceleration (LVD), 0.07g, 4 sec	28.6	29.9	-1.2	16.8	7.6	6	0.10
CN 102300	Lead veh. deceleration (LVD), 0.05g, 6 sec	29.0	30.5	-1.5	27.4	12.2	12	0.15
CN 141105	Lead veh. deceleration (LVD), 0.06g, 8 sec	29.0	29.0	0.0	10.7	6.1	8	0.09
CN 141103	Lead veh. deceleration (LVD), 0.08g, 8 sec	35.1	33.5	1.5	18.3	9.1	16	
CN 220101	Lead veh. deceleration (LVD), 0.08g, 6 sec	26.8	26.8	0.0	36.6	9.1	17	0.11
CN 600300	Lead veh. deceleration (LVD), 0.05g, 6 sec	31.7	31.7	0.0	25.9	7.6	8	0.1
CN 601601	Lead veh. deceleration (LVD), 0.15g, 3sec	32.6	32.0	0.6	16.8	7.6	4	
CN 800106	Lead veh. deceleration (LVD), 0.04g, 8 sec	32.6	32.6	0.0	19.8	7.6	9	0.1
CB 141001	Lead veh. deceleration (LVD), 0.19g, 7 sec	24.7	23.2	1.5	32.0	21.3	13	0.12
CB 342000	Lead veh. deceleration (LVD), 0.05g, 7 sec	27.4	29.9	-2.4	36.6	16.8	10	0.09
CB 410103	Lead veh. deceleration (LVD), 0.06g, 9 sec	29.0	29.0	0.0	19.8	12.2	7	0.08
Average	**LVD = 0.08g**	**29.7**	**29.8**	**-0.1**	**23.7**	**10.7**	**10**	**0.10**
IN 346602	Lead veh. deceleration (LVD), 0.03g, 7 sec	25.9	26.8	-0.9	32.0	10.7	7	
IB 314000	Lead veh. deceleration (LVD), 0.21g, 3 sec	27.4	25.9	1.5	16.8	13.7	5	0.09
IB 359901	Lead veh. deceleration (LVD), 0.12g, 15 sec	29.6	29.0	0.6	45.7	10.7	18	0.11
IB 415400	Lead veh. deceleration (LVD), 0.10g, 14 sec	30.5	32.0	-1.5	35.1	24.4	7	0.13
IB 596602	Lead veh. deceleration (LVD), 0.30g, 9 sec	26.5	26.5	0.0	24.4	6.1	10	0.26
IB 596701	Lead veh. deceleration (LVD), 0.41g, 8 sec	30.5	30.5	0.0	36.6	9.1	9	0.3
IB 804002	Lead veh. deceleration (LVD), 0.13g, 15 sec	29.6	29.6	0.0	32.0	10.7	15	0.14
IB 823003	Lead veh. deceleration (LVD), 0.25g, 10 sec	29.3	29.3	0.0	18.3	3.0	12	0.3
Average	**LVD = 0.19g**	**28.6**	**28.7**	**0.0**	**30.1**	**11.0**	**10**	**0.19**

MN 316000	Lane change	25.0	25.9	-0.9	7.0	6.1	4	0.05
MN 321805	Lane change	27.4	30.8	-3.4	32.0	10.7	10	0.12
	Average	**26.2**	**28.3**	**-2.1**	**19.5**	**8.4**	**7**	**0.09**
CN 102001	Lane change	29.0	32.0	-3.0	27.4	12.2	4	0
CN 140301	Lane change	29.0	30.5	-1.5	16.8	7.6	10	0.06
CN 800516	Lane change	31.7	33.8	-2.1	48.8	7.6	17	0.07
	Average	**29.9**	**32.1**	**-2.2**	**31.0**	**9.1**	**10**	**0.04**
IN 567902	Lane change	28.6	33.2	-4.6	42.7	7.6	11	0.03
IN 605602	Lane change	22.9	32.0	-9.1	24.4	4.6	7	0.26
	Average	**22.9**	**32.0**	**-9.1**	**24.4**	**4.6**	**7**	**0.26**

Table L-13. Results of Extreme Value analysis – Freeways – Top 5 cases for 50 drivers with additional (2)* 0.25g cases (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
CB 060400	Approach	night	24.4	28.3	88.4	24.4	21	-	0.06
MN 070802	LVD, 0.06g, 5 sec	false targets	25.9	25.9	15.2	9.1	6	-	0.06
CN 070903	LVD, 0.07g, 4 sec	two stage	28.6	29.9	16.8	7.6	6	-	0.10
CN 070801	Approach	false targets	25.0	27.1	54.9	15.2	20	-	0.12
IN 075702	Cut-in	merge from ramp	22.9	28.0	30.5	16.8	8	-	0.05
CN 102001	Lane change (Lc)	const. speed, Lc to avoid collision	29.0	32.0	27.4	12.2	4	-	0
CN 102300	LVD, 0.05g, 6 sec		29.0	30.5	27.4	12.2	12	-	0.15
MN 144401	LVD, 0.08g, 8 sec	heavy traffic	20.7	20.7	18.3	4.6	14	0.8	0.08
*MN 144404	LVD, 0.36g, 2 sec	Lc to avoid collision, reckless driving over it solid lane shoulder	18.3	19.8	7.6	4.6	8	-	0.36
*MN 144602	LVD, 0.30g, 2 sec	break before scenario	15.2	16.8	4.6	1.5	3	-	0.3
MN 144701	LVD, 0.21g, 4 sec	merge situation	26.8	26.8	10.7	6.1	6	-	0.21
CN 140301	Lane change	night	29.0	30.5	16.8	7.6	10	-	0.06
CN 141105	LVD, 0.06g, 8 sec	night	29.0	29.0	10.7	6.1	8	-	0.09
CN 141706	Approach		21.3	22.9	30.5	4.6	16	2.1	0.14
CN 141103	LVD, 0.08g, 8 sec	end in lane change	35.1	33.5	18.3	9.1	16	-	
IN 142205	Cut-in	no braking, Acc authority	22.9	22.2	9.1	4.6	12	3	0.04
IN 142202	Cut-in	Ne, merge situation, heavy traffic	20.4	25.9	9.1	3.0	7		0.50
IN 143000	Cut-in	night	21.3	24.4	9.1	4.6	8	0.4	0.20
IN 142804	Approach	switch (cut-out), Acc authority	21.9	27.4	51.8	4.6	16	-	0.11
MB 141704	LVD to stop, 0.42g, 12 sec		25.9	25.9	30.5	6.1	14	1.3	0.22
CB 141501	Approach	switch (cut-out)	15.2	22.2	42.7	24.4	9	-	0.13
CB 141001	LVD, 0.19g, 7 sec	lane blockage	24.7	23.2	32.0	21.3	13	3.7	0.12
IB 142206	Approach	switch-cut-out, roadside hazard, multi-scenarios (Ms)	13.4	25.9	15.2	12.2	5	-	0.23
IN 154907	Cut-in	no braking, Acc authority	27.1	30.5	9.1	6.1	6	-	0.05
CN 170101	Cut-in	brake early	25.9	29.9	12.2	10.7	8	-	0.07
CN 185602	Approach	lane change to avoid collision	27.4	30.5	73.1	12.2	16	-	

IN 217002	Cut-in		20.4	23.8	12.2	6.1	16	-	0.07
CN 212100	Approach	lane change to avoid collision	27.4	29.0	21.3	9.1	9	-	0.05
IN 229800	Cut-in	night, Acc auth. no braking, speed is 80 @ 15	26.8	28.0	10.7	4.6	10	-	0.08
CN 220101	LVD, 0.08g, 6 sec	night, end w/ Lc to avoid collision	26.8	26.8	36.6	9.1	17	-	0.11
IN 2410603	Approach	LVD slightly	29.9	32.0	30.5	6.1	21	0.5	0.03
IN 274801	Cut-in	on merge	25.3	29.6	21.3	6.1	11	-	0.08
CN 300103	Approach		27.7	29.3	30.5	15.2	30	-	0
CN 300104	Approach		28.0	29.0	21.3	16.8	14	-	0.06
IB 314000	LVD, 0.21g, 3 sec	night, Ms	27.4	25.9	16.8	13.7	5	2	0.09
MN 316000	Lane change		25.0	25.9	7.0	6.1	4	-	0.05
MN 321805	Lane change		27.4	30.8	32.0	10.7	10	-	0.12
CB 342000	LVD, 0.05g, 7 sec	Ms, approach first	27.4	29.9	36.6	16.8	10	-	0.09
CB 341202	Approach	night, Ms, Lc first	25.9	31.1	45.7	15.2	10	-	0.06
CN 341203	Approach	night, cut out first, Lc to avoid collision	25.9	30.5	33.5	13.7	6	-	0.11
IN 346603	Approach	on curve, Acc first @ 0.07, driver braked at 40ft	21.3	30.5	51.8	6.1	10	-	0.3
IN 346602	LVD, 0.03g, 7 sec	Lc to avoid collision	25.9	26.8	32.0	10.7	7	-	
			0.0	0.0	0.0	0.0			
IB 359901	LVD, 0.12g, 15 sec		29.6	29.0	45.7	10.7	18	-	0.11
CB 353702	Cut-in		28.6	32.0	30.5	22.9	9	-	0.07
CB 370700	Approach	night	21.3	24.4	77.7	18.3	25	-	0.10
IN 4013800	Cut-in	truck in adjacent lane	25.9	32.0	42.7	19.8	8	-	0.07
IB 415400	LVD, 0.1g, 14 sec	Ms, 4 stages	30.5	32.0	35.1	24.4	7	1.4	0.13
CB 411200	Approach	Ms	27.7	35.1	91.4	16.8	13	-	0.11
CB 410103	LVD, 0.06g, 9 sec	night	29.0	29.0	19.8	12.2	7	1.0	0.08
MN 416011	Approach	night	28.0	39.6	45.7	9.1	14	1	0.15
MN 416012	LVD. 0.03g, 7 sec	night, Ms	25.9	25.9	12.2	6.1	7	-	0.04
CN 414200	Approach		32.0	34.1	32.0	10.7	16	-	0.07
IB 482808	Approach		20.7	27.4	109.7	25.9	22	-	0.05
CN 506202	Approach	Ms	26.8	29.9	61.0	13.7	15	-	0
MN 514204	LVD, 0.03g, 8sec	coast-no braking response	30.5	30.5	16.8	9.1	13	-	0.03
CN 560107	Cut-in	lead veh. cut-out to avoid collision	32.0	34.1	15.2	9.1	7	-	
MN 5613100	LVD, 0.1g, 3 sec		32.0	32.0	14.3	6.1	12	-	0.05
IN 564401	Cut-in		23.8	31.1	30.5	12.2	7	-	0.2
IN 567107	Cut-in	Icc authority, no braking	28.6	32.3	18.3	7.6	8	-	0.05
IN 567902	Lane change	Icc authority, Lc to avoid collision	28.6	33.2	42.7	7.6	11	-	0.03
MN 5611301	LVD, 0.05g, 10 sec		29.6	29.6	22.9	6.1	12	-	0.12

IB 596701	LVD, 0.41g, 8 sec		30.5	30.5	36.6	9.1	9	2	0.3
IB 596602	LVD, 0.3g, 9 sec	twilight	26.5	26.5	24.4	6.1	10	-	0.26
MN 5912610	Approach		28.3	31.7	54.9	6.1	22	-	0.05
IN 598302	Cut-in	speed is 90 @ 15	26.8	28.0	6.1	4.6	4	2.2	0.08
IN 599402	Approach	night, Lc to avoid collision, Icc initially at 0.05g	27.1	32.3	39.6	7.6	12	-	0.24
CN 601700	Approach		29.6	32.3	57.9	9.1	21	-	0.08
CN 600300	LVD, 0.05g, 6 sec		31.7	31.7	25.9	7.6	8	-	0.1
CN 601601	LVD, 0.15g, 3sec	Ne, Lc to avoid collision	32.6	32.0	16.8	7.6	4	-	
IN 603401	Cut-in		27.4	32.0	13.7	6.1	7	-	0.14
IN 605602	Lane change	Ne, speed is 67 @ 15	22.9	32.0	24.4	4.6	7	-	0.26
IN 605601	Cut-in	Icc authority	28.0	31.7	12.2	9.1	5	-	0.07
MN 613813	Approach	Ne, high closing, Lc to avoid coll.	23.5	30.5	100.6	15.2	13	-	
CN 784101	Cut-in	lead veh. cuts across 2 lanes	26.2	27.1	9.1	7.6	4	-	0.11
MN 7918500	Approach	Lc to avoid collision	27.1	32.6	106.7	12.2	18		0.11
IB 804002	LVD, 0.13g, 15 sec	no icc response	29.6	29.6	32.0	10.7	15	0.8	0.14
CN 800106	LVD, 0.04g, 8 sec		32.6	32.6	19.8	7.6	9	3.8	0.1
CN 800516	Lane change		31.7	33.8	48.8	7.6	17	-	0.07
CN 800507	Approach	lane change to avoid collision	29.9	32.0	35.1	13.7	15	-	
CN 800105	Approach		29.3	32.3	39.6	10.7	11	-	0.1
IB 823003	LVD, 0.25g, 10 sec	near stop, speed is < 15 @ 10	29.3	29.3	18.3	3.0	12	3.7	0.3
MB 820201	LVD, 0.15g, 8 sec	double LVD	27.4	26.8	59.4	13.7	15	3.2	0.2
IN 9011002	Approach	Lc to avoid collision (accel)	25.9	27.4	32.0	7.6	16	-	
MB 1083200	LVD, .09g, 8 sec		29.9	29.9	51.8	35.1	14		0.07

Table L-14. Results of Extreme Value analysis – Arterials – Top 5 cases for 50 drivers with additional (1)* 0.25g cases (grouped by scenario and cruise control mode)

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
MN 155501	Approach	10.7	23.2	-12.5	30.5	9.1	16	0.15
MN 353603	Approach	11.3	20.7	-9.4	>60	30.5	9	0.13
MN 431300	Approach	13.7	25.9	-12.2	76.2	47.2	13	0.04
MN 820202	Approach	10.7	22.9	-12.2	>60	35.1	12	0.04
Average		**11.6**	**23.2**	**-11.6**	**>60**	**30.5**	**13**	**0.09**
CN 240201	Approach	28.0	29.0	-0.9	18.3	6.1	20	0.06
IN 306600	Approach	18.9	21.3	-2.4	85.3	30.5	13	0.05
IN 435700	Approach	15.2	26.5	-11.3	45.7	10.7	12	0.08
IB 155400	Approach	19.8	25.9	-6.1	80.8	19.8	15	0.19
Average		**18.0**	**24.6**	**-6.6**	**70.6**	**20.3**	**13**	**0.11**
MN 290601	Cut in	12.2	22.2	-10.1	15.2	4.6	13	0.11
MN 7813900	Cut in	16.8	21.6	-4.9	10.7	6.1	6	0.11
Average		**14.5**	**21.9**	**-7.5**	**13.0**	**5.3**	**10**	**0.11**
CB 341701	Cut in	20.1	30.2	-10.1	>42	15.2	16	0.16

MN 350104	Lead veh. decelerates, 0.2g for 8 sec	21.3	18.3	3.0	53.3	15.2	10	0.16
MN 358600	Lead veh. decelerates, 0.2g for 6 sec	17.1	18.3	-1.2	61.0	19.8	6	0.14
MN 430802	Lead veh. decelerates, 0.04g for 6 sec	22.9	22.9	0.0	33.5	19.8	7	0.06
*IB 665301	Lead vehicle decelerates, 0.24g, 7 sec	22.6	24.4	-1.8	74.7	24.4	10	0.25
Average	**LVD = 0.17g**	**21.0**	**21.0**	**0.0**	**55.6**	**19.8**	**8.3**	**0.15**
CN 430805	Lead veh. decelerates, 0.08g for 7 sec	23.5	25.0	-1.5	45.7	18.3	9	0.05
MB 405900	Lead veh. decelerates, 0.07g for 11 sec	24.4	22.9	1.5	91.4	79.2	11	0.05
MN 793902	Lane change	18.9	24.7	-5.8	39.6	16.8	6	0.18

Table L-15. Results of Extreme Value analysis – Arterials – Top 5 cases for 50 drivers with additional (1)* 0.25g cases (grouped by drivers)

File Name	Driver Scenario	Comment	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)
MN 155501	Approach		10.7	23.2	30.5	9.1	16		0.15
IB 155400	Approach	lane change (lc) to avoid collision	19.8	25.9	80.8	19.8	15	1.3	0.19
CN 240201	Approach		28.0	29.0	18.3	6.1	20		0.06
MN 290601	Cut in	lc to avoid collision, night	12.2	22.2	15.2	4.6	13		0.11
IN 306600	Approach	false tracking of lead veh. after lc	18.9	21.3	85.3	30.5	13		0.05
CB 341701	Cut in	lc to avoid collision, night	20.1	30.2	>42	15.2	16		0.16
MN 350104	LVD, 0.2g, 8 sec	right turn, lc to avoid collision	21.3	18.3	53.3	15.2	10		0.16
MN 353603	Approach	lc to avoid collision, curve, ms	11.3	20.7	>60	30.5	9		0.13
MN 358600	LVD, 0.2g, 6 sec	lc to avoid collision	17.1	18.3	61.0	19.8	6		0.14
MB 405900	LVD, 0.07g, 11 sec		24.4	22.9	91.4	79.2	11		0.05
IN 435700	Approach	night, wet	15.2	26.5	45.7	10.7	12		0.08
CN 430805	LVD, 0.08g , 7 sec	lc to avoid collision	23.5	25.0	45.7	18.3	9		0.05
MN 430802	LVD, 0.04g, 6 sec		22.9	22.9	33.5	19.8	7		0.06
MN 431300	Approach		13.7	25.9	76.2	47.2	13		0.04
*IB 665301	LVD, 0.24g, 7 sec	dec. for left turn	22.6	24.4	74.7	24.4	10		0.25
MN 7813900	Cut in		16.8	21.6	10.7	6.1	6		0.11
MN 793902	Lane change	lc to avoid collision	18.9	24.7	39.6	16.8	6		0.18
MN 820202	Approach		10.7	22.9	>60	35.1	12		0.04

Table L-16. Results of Extreme Value analysis – 0.25g or higher braking cases – 50 drivers

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Braking Level (g)
Freeways								
IN 346603	Approach	21.3	30.5	-9.1	51.8	6.1	10	0.30
IN 142202	Cut-in	20.4	25.9	-5.5	9.1	3.0	7	0.50
IN 605602	Lane change	22.9	32.0	-9.1	24.4	4.6	7	0.26
MN 144404	LVD, 0.36g, 2sec	18.3	19.8	-1.5	7.6	4.6	8	0.36
MN 144602	LVD, 0.30g, 2sec	15.2	16.8	-1.5	4.6	1.5	3	0.30
Average	**LVD = 0.33g**	**16.8**	**18.3**	**-1.5**	**6.1**	**3.0**	**6**	**0.33**

IB 596602	LVD, 0.3g, 9sec	26.5	26.5	0.0	24.4	6.1	10	0.26
IB 596701	LVD, 0.41g, 8sec	30.5	30.5	0.0	36.6	9.1	9	0.30
IB 823003	LVD, 0.25g, 10sec	29.3	29.3	0.0	18.3	3.0	12	0.30
Average	**LVD = 0.32g**	**28.8**	**28.8**	**0.0**	**26.4**	**6.1**	**10**	**0.29**
Arterials								
IB 665301	LVD, 0.24g, 7sec	22.6	24.4	-1.8	74.7	24.4	10	0.25
Ramps								
IN 502600	LVD, 0.08g, 8sec & 0.28g, 2sec	20.1	20.1	0.0	19.8	2.4	11	0.34

Table L-17. Subjective analysis of ICC scenarios

File Name	Driver Scenario	Lead Veh. Velocity (m/s)	Icc Veh. Velocity (m/s)	Diff. Velocity (m/s)	Initial Range (m)	Min. Headway (m)	Duration Time (sec)	Reaction Time (sec)	Braking Level (g)	Was ICC a Factor
Freeways										
IB 142206	Approach	13.4	25.9	-12.5	15.2	12.2	5		0.23	no
IN 142804	Approach	21.9	27.4	-5.5	51.8	4.6	16		0.11	yes
IN 599402	Approach	27.1	32.3	-5.2	39.6	7.6	12		0.24	yes
IN 346603	Approach	21.3	30.5	-9.1	51.8	6.1	10		0.30	yes
Average		**21.0**	**29.0**	**0.0**	**39.6**	**7.6**	**11**		**0.22**	
IN 605602	Lane change	22.9	32.0	-9.1	24.4	4.6	7		0.26	no
IB 596602	LVD, 0.3g, 9sec	26.5	26.5	0.0	24.4	6.1	10		0.26	yes
IB 596701	LVD, 0.41g, 8sec	30.5	30.5	0.0	36.6	9.1	9		0.30	no
IB 645402	LVD, 0.18g, 7sec	29.9	29.9	0.0	22.9	9.1	7		0.22	yes
IB 823003	LVD, 0.25g, 10sec	29.3	29.3	0.0	18.3	3.0	12		0.30	yes
Average	**LVD = 0.32g**	**29.0**	**29.0**	**0.0**	**25.5**	**6.9**	**10**		**0.27**	
IN 142202	Cut-in	20.4	25.9	-5.5	9.1	3.0	7		0.50	yes
IN 1095002	Cut-in	30.2	35.1	-4.9	19.5	4.6	7		0.09	yes
Average		**25.3**	**30.5**	**0.0**	**14.3**	**3.8**	**7**		**0.30**	
Arterials										
IB 665301	LVD, 0.24g, 7 sec	22.6	24.4	-1.8	74.7	24.4	10		0.25	no
Ramps										
IN 142505	LVD, .18g, 8sec	24.4	24.4	0.0	54.9	3.0			0.17	no
IN 502600	LVD, .08g, 28sec & .28g, 2sec	20.1	20.1	0.0	19.8	2.4	11	2.2, 7.2	0.34	yes
IN 5015302	LVD, .4, 1sec & .05g, 12sec	26.5	28.6	-2.1	35.1	4.6	11		0.14	no

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Appendix M

Intelligent Cruise Control Systems and Traffic Flow Behavior

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M-1 Introduction

It is estimated that 90% of the accidents occur on the highways as a consequence of human driving errors [1]. Hence, vehicle safety technologies such as the Intelligent Cruise Control (ICC) systems, and the Collision Warning Systems (CWS) are anticipated to actively enhance the safety of vehicles and passengers on the highways. In additions, such technologies are aimed at providing convenience to the driver either by augmenting or automating his/her driving. Inherent to this hypothesis is the assumption that such technologies, if well designed, either eliminate or minimize human driving errors without introducing any new problems that compromise vehicle safety. Automotive manufacturers are currently designing vehicles equipped with such systems and such vehicles are expected to enter the market in the near future.

In the initial stages of deployment of vehicles equipped with ICC systems (henceforth, they will be referred to as the ICC vehicles), mixed traffic flows are envisioned traffic flows which consist of manually controlled vehicles and automatically controlled vehicles. The Level of Market Penetration (LMP) indicates the percentage of ICC vehicles in a mixed traffic. The report addresses the determination of the impact of ICC vehicles on the traffic flow behavior as a function of the LMP. An understanding of the automatic and manual vehicle following behavior is central to understanding the behavior of the mixed traffic. An investigation of vehicle-following, either manual or automatic, involves two tasks:

1. the determination of the spacing policy (i.e. a rule that dictates the desired vehicle velocity as a function of the following distance or vice-versa), and

2. the manipulation of vehicle dynamics so that the spacing policy is always obeyed.

It is intuitive that the safety of a vehicle on a highway is intimately related to the employed spacing policy and to the control of the vehicle dynamics according to the employed spacing policy.

M-2 ICC Vehicles and Traffic Flow Behavior

Prior to addressing the determination of the impact of ICC vehicles on the traffic flow behavior, one must understand how the traffic flow behavior is characterized and why the ICC vehicles affect traffic flow behavior.

The Fundamental Traffic Characteristic (FTC) [4] is typically used to characterize the behavior of a traffic flow on a section of a highway. An example of a FTC is given in Figure M-1.

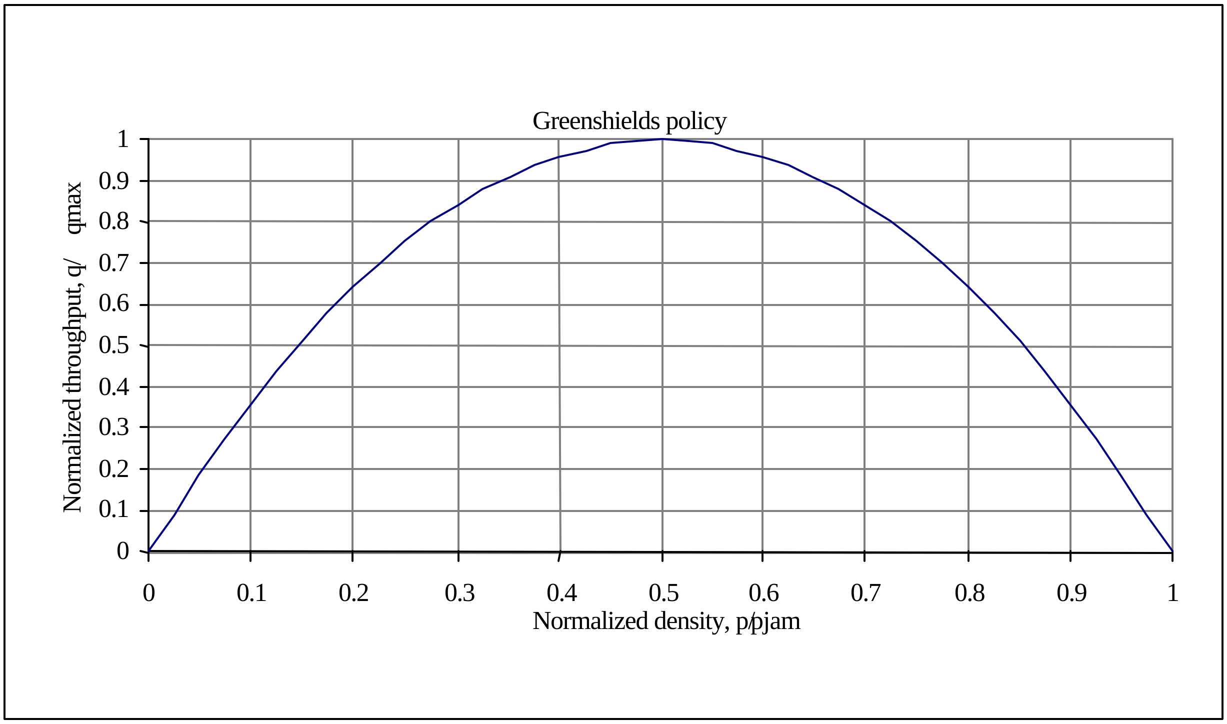

Figure M-1 A Typical Fundamental Traffic Characteristic

The FTC is a locus of the equilibrium operating conditions and is either given in terms of an equilibrium traffic velocity-density or equivalently, in terms of a volume-density relationship. In this appendix, the latter is used. From a practical standpoint, two quantities are of interest - the peak traffic volume (also known as the capacity), and the critical density (or the density at capacity). The capacity is indicative of the performance of traffic - a higher capacity is always desirable. It must be emphasized that the critical traffic density is as important as the capacity. A reduction in the critical density with an increase in the capacity necessitates higher operational traffic velocities to realize the gains in traffic capacity and may not always be desirable.

The critical traffic density is also important in understanding the propagation of density disturbances (commonly referred to as shock waves) in the traffic. Typically, at operating traffic densities greater than the critical density, the slope of the (volume-density) FTC is negative. This indicates that the throughput of vehicles decreases with an increase in traffic density. An increase in traffic density can occur due to a sudden influx of vehicles, say at the beginning of a commute hour or after a football game. As a result, if the slope of the FTC is negative at the operating equilibrium, density disturbances propagate upstream without attenuation, resulting in an undesirable traffic flow behavior [5, 8]. In addition, the magnitude of the slope determines the velocity of propagation of disturbances.

Since the macroscopic behavior of a traffic flow is an aggregation of the behavior of the constituent vehicles, ICC vehicles directly impact traffic flow behavior. For a given velocity, the average following distance of a mixed traffic is a function of the spacing policy of ICC vehicles, spacing policy of manual vehicles and the relative distribution of these vehicles in the traffic. As a result, the aggregate velocity-density relationship and consequently, the volume-density relationship changes with the deployment of ICC vehicles. The FTC is altered and the corresponding values of capacity and critical density change.

A question of importance is, what are the consequences of an alteration in the FTC, or equivalently the traffic flow behavior? Traffic operations, such as ramp metering, variable message signs are based on an empirically determined FTC [6]. When the FTC is altered, such operations are affected directly. In light of such a direct impact on traffic operations, it is imperative to understand how the ICC vehicles affect traffic flow behavior.

While much of the above discussion concerns the relationship between vehicle velocity and following distance for manually and automatically controlled vehicles at equilibrium, the dynamics of a vehicle following control system affect the traffic flow behavior. With near ideal vehicle following systems, where the lags from sensing to actuation are small, and where the vehicle following is stable (i.e. absence of any slinky type effect), a description of traffic flow behavior at equilibrium is adequate. Manually and automatically controlled vehicles have significant lags; therefore, a description of the manual and automatic vehicle following dynamics is necessary to obtain a complete picture of the mixed traffic flow behavior.

In this report, mixed traffic flows are analyzed by considering dynamical models of manual and automatic vehicle following behavior.

M-3 Vehicle Following Models

In developing a dynamical model for describing human driver, the following assumptions are made:

1. **Consistency of human driving:** It is assumed that if a human driver encounters the same set of driving conditions, his/her response is identical. This is a very strong assumption and enables the prediction of human response (velocity of a manually controlled vehicle) as a function of the driving conditions [3].
2. **No dependence on preview driving information:** It is assumed that the human driver responds solely to the changes in the range and range rate, and the vehicle velocity. This assumption circumvents the need for modeling the acquisition and subsequent processing by the human driver of the information about the adjoining vehicles.
3. **Stable manual driving:** It is assumed that every human driver will track the preceding vehicle in a stable manner.

It is not the intention here, to obtain a detailed understanding of the dynamics of manual vehicle following behavior. Since macroscopic properties of the traffic are sought, the above assumptions are reasonable, as a first step, towards analyzing the mixed traffic flows.

A detailed understanding of the dynamics of manual vehicle following is central to applications such as the Collision Warning Systems (CWS). For example, a warning algorithm based on conservative estimates of the vehicle dynamics and driver lags may not be very effective with aggressive drivers and vice-versa. An effective warning algorithm must adapt to the dynamics of the human driver and act as an alert replica of the driver. The effectiveness of deployment of CWS is intimately dependent on the human vehicle following models employed in their design.

In this appendix, vehicle and the driver (either automatic or manual) are modeled together as a first order system. The velocity response of the vehicle is a function of the control actions of the driver. As a result, the models employed in this report for manual and automatic vehicle following have identical structure, and differ only in :

1. the employed spacing policy, and

2. the time constant for regulating the vehicle velocity.

In what follows, the structure of automatic and manual vehicle following models is developed first; then the specific models based on the developed structure are presented.
A vehicle and driver are modeled as:

$$\dot{v} = u(t)$$

Here v is the velocity of the vehicle, and $u(t)$ is the control effort. The velocity of a vehicle, therefore, is a function of the sensing, processing and actuation delays of the vehicle and the driver. Let the desired velocity of a vehicle at a following distance, Δ, be $v_{des}(\Delta)$. Then, the error, e_v, in regulating the velocity at its desired value is $v - v_{des}(\Delta)$. The error in regulating the acceleration at the desired level is $\dot{v} - \dot{v}_{des}(\Delta)$. It is hypothesized here, that the control effort, $u(t)$ is such that

$$u(t) = \dot{v}_{des}(\Delta) - \frac{1}{\tau} e_v = \dot{v}_{des}(\Delta) - \frac{1}{\tau}[v - v_{des}]$$

In the above equation, τ is the time constant associated with controlling the velocity.
The choice of v_{des} as a function of the following distance, Δ, specifies the spacing policy.
The closed loop dynamics of the vehicle and driver is, therefore, given by:

$$\dot{v} = \dot{v}_{des}(\Delta) - \frac{1}{\tau}[v - v_{des}]$$

Such a control effort will always try to regulate the velocity at its desired value. Notice that if the actual velocity is higher than the desired velocity, and the desired acceleration is zero, then the control effort is such that the velocity decreases to its desired velocity.

M-3.1 Model for Manual Driving

In developing a human driving model, the employed spacing policy is such that it is consistent with the empirically observed FTC [3]. In particular, the following expression for velocity as a function of density provided in [3] is used in this appendix:

$$v_{des} = v_f \log\left(\frac{\Delta + L_c}{\Delta}\right)$$

Here, v_f ,is an empirically determined constant, L_c is the distance between vehicles at standstill. Since the jam density is the density of traffic at standstill, the jam density, $r_{jam} = \frac{1}{L_c}$. The density of traffic at any given time can be given by:

$$r = \frac{1}{\overline{\Delta} + L_c}$$

where $\overline{\Delta}$ is the average following distance of vehicles in the traffic.
A time constant of 1.4 seconds is used in this report. The justification for using such a value of the time constant is that the observed reaction time of human drivers is of the same order of magnitude [3].

M-3.2 Model for Automatic Driving

In this report, it is assumed, unless otherwise stated that, ICC vehicles employ a constant time headway policy, i.e.

$$v_{des}(\Delta) = \frac{\Delta}{h_w}$$

where h_w is the employed time headway. A control time constant, τ , of 1 second is used here. Such a value is chosen based on the experience of the researcher with automatic vehicle following systems, [7].

M-4 Mixed Traffic Analysis - Theory and Simulation

A reasonable, yet strong, assumption about the mixed traffic is that the presence of ICC vehicles in the traffic does not alter the manual driving behavior.

M-4.1 Analysis of The FTC For Mixed Traffic

Consider a traffic consisting of two kinds of vehicles, each employing a different spacing policy. Let α be the percentage of vehicles of the first kind (say of type A) and the rest is of the second kind (say type B). Let $v_{des,A} = v_{des,A}(\rho)$. Let the function, v_{des}^{-1} be denoted by *h*. Therefore, the following distance desired of vehicles of type A at a velocity, v, is $h_A(v)$. Similarly, the following distance desired of vehicles of type B at a velocity, v, is $h_B(v)$. The average following distance, , of the traffic at a given velocity, v, therefore, is:

$$\overline{\Delta} = \boldsymbol{a}.h_A(v) + (1-\boldsymbol{a}).h_B$$

Therefore, the equilibrium traffic density and volume of the mixed traffic are given by the following expressions:

$$\frac{1}{\boldsymbol{r}_{mixed}(v)} = \overline{\Delta} = \boldsymbol{a}.h_A(v) + (1-\boldsymbol{a}).h_B$$

$$\frac{1}{q_{mixed}(v)} = \frac{\boldsymbol{a}.h_A(v) + (1-\boldsymbol{a}).h_B}{v} = \frac{\boldsymbol{a}}{q_A(v)} + \frac{(1-\boldsymbol{a})}{q_B(v)}$$

At equilibrium, ρ and v are not independent quantities. From the above relation, one can obtain a relationship between the equilibrium traffic volume, q_{mixed} and the equilibrium traffic density, ρ .

Figure M-2 shows how the presence of ICC vehicles in a traffic alters the FTC. In the figure, α is the percentage of manual vehicles in the traffic and equals *LMP*. Earlier in this appendix, LMP is also referred to as the level of market penetration of ICC vehicles in the traffic.

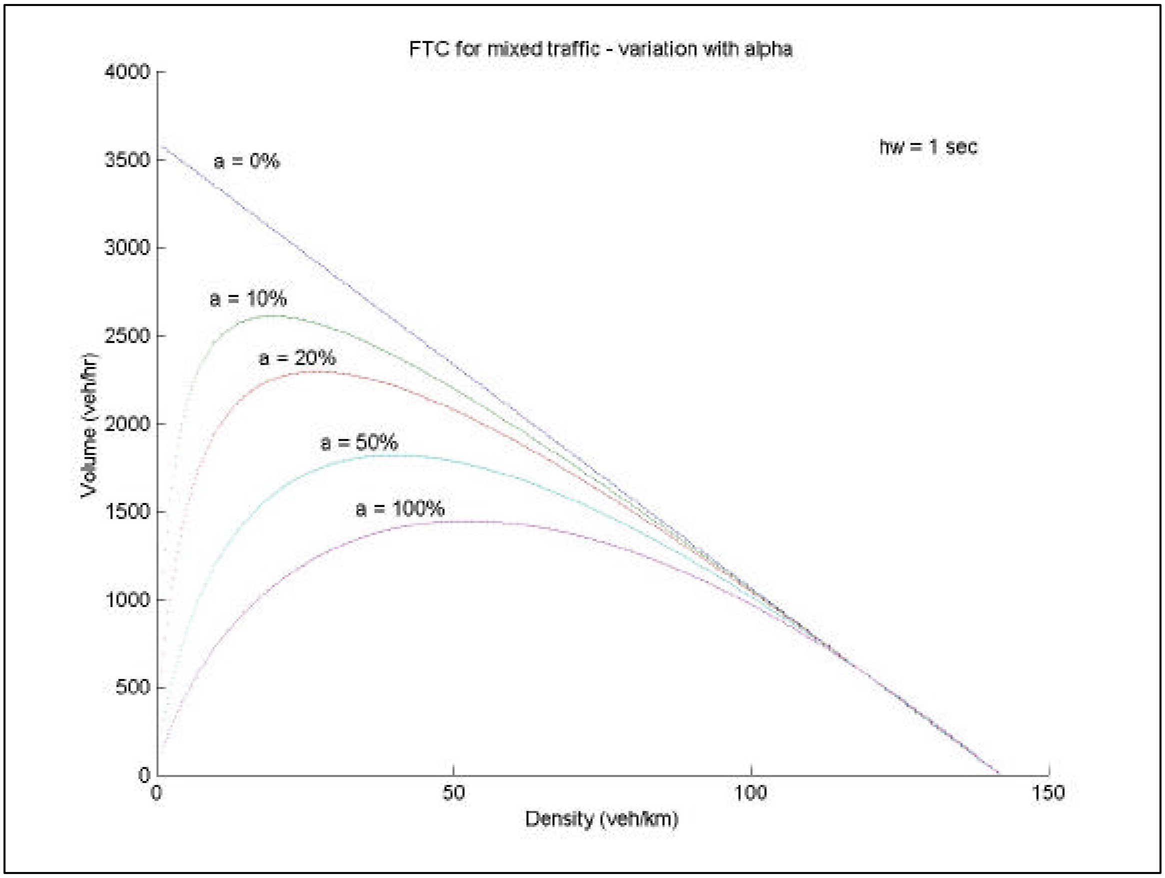

Figure M-2: Effect of The Presence of ICC Vehicles on The FTC

With an increasing percentage of ICC vehicles, although the capacity increases, the critical density decreases. As mentioned earlier, this requires a significant increase in the traffic velocity to realize the gain in traffic capacity.

Figure M-3 shows how a choice of time headway employed by ICC vehicles in the traffic affects the FTC. In this plot, it is assumed that the ICC vehicles constitute 50% of the traffic.

M-4.2 Simulation Results

The simulations have been conducted in the following manner. A section of the highway 1000 meters in length is considered. A ramp is situated 650 meters from the upstream end. Vehicles join the main traffic flow from the ramp at regular intervals of time. Δ, h_w and $v_{initial}$ are chosen as the parameters for simulation. Initially all vehicles are assumed to be travelling at the same velocity ($v_{initial}$). Vehicles are placed keeping the LMP in consideration.

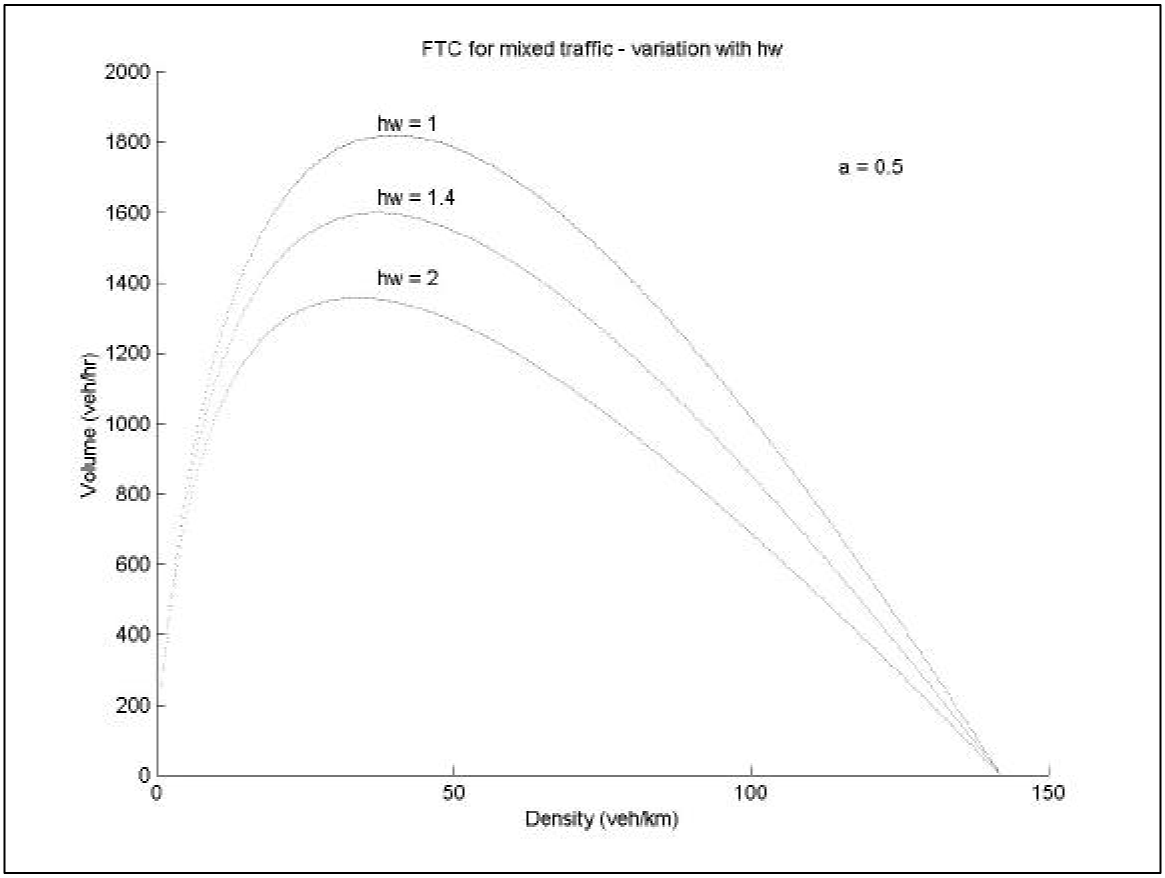

Figure M-3 Effect of The Time-Headway Employed by ICC Vehicles on The FTC

As the simulation proceeds vehicles are added to the mainstream via two modes:

1. From the upstream end.

2. From the ramp.

The initial velocity ($v_{initial}$) and the other parameters for the simulation define the initial state of the traffic on the FTC. The entry of vehicles from the ramp is a disturbance to the traffic flow. If the initial state of traffic is on the congestion side of the FTC then we note that the new vehicle entering from the ramp initiates a shock wave in the traffic flow that travels backwards in the traffic stream towards the upstream end. This will eventually lead to a jam at the upstream end. This is as inferred from the FTC. The converse phenomenon is observed if the initial state is on the rising side of the FTC. In this case the shock wave initiated by the vehicle entering from the ramp, travels forward in traffic pushing vehicles out downstream. This in turn results in an increase of the volume of flow as is also indicated by the FTC.

The effect of LMP can be seen from the fact that as the LMP increases, the capacity increases but the critical density drops. Hence at a given density, presence of a larger fraction of intelligent vehicles (higher LMP) will cause the state to be on the congestion side of the FTC. This, as we have already seen, can result in jams.

Figure M-4 corresponds to a fully automated traffic flow. In this traffic flow, all the vehicles employ a constant time headway policy. From the simulations, it is clear that traffic disturbances travel upstream, resulting in a jam at the upstream end.

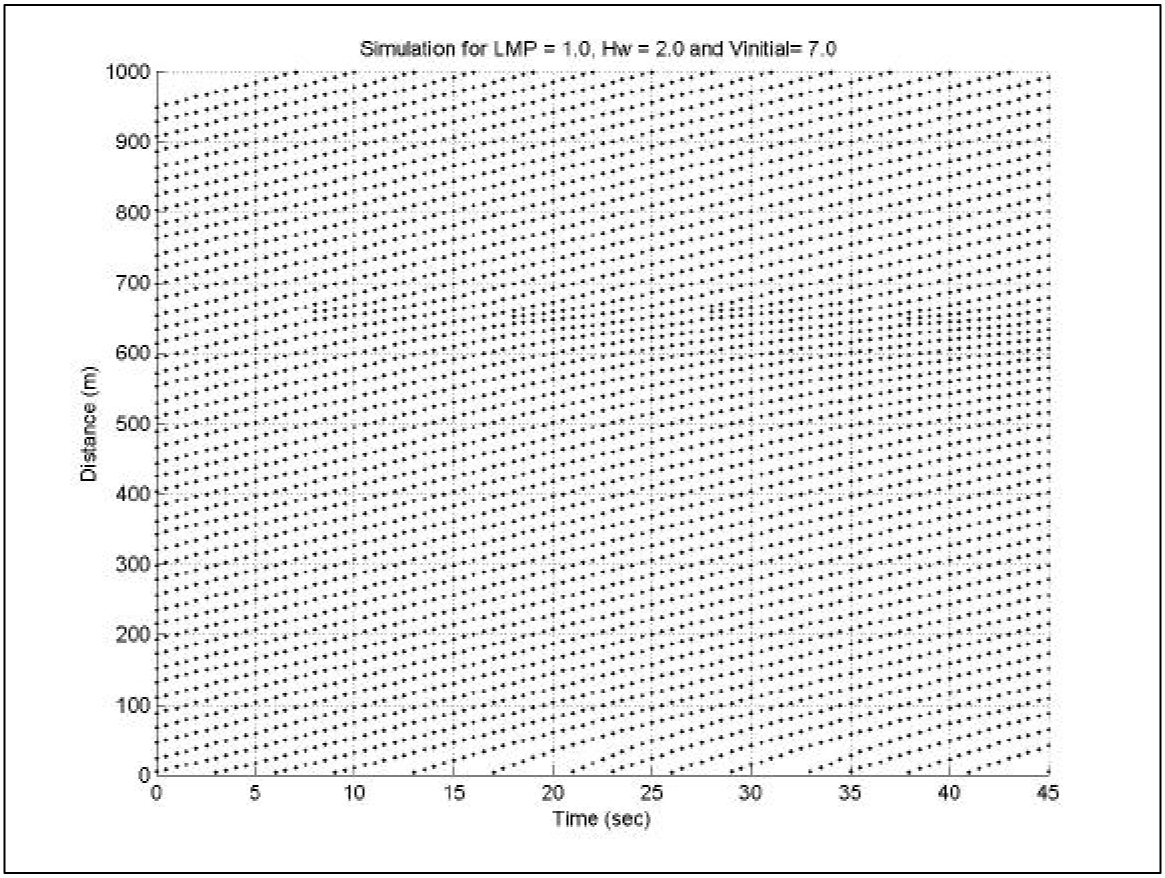

Figure M-4 Space-time Chart of Fully Automated Traffic Flow

M-5. References

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Appendix N

Cost Model Inflation Factors

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Inflation Factors

27-Dec-96

Source: U.S. Department of Defense

Fiscal Year	Yearly Escalation Factor	Base Year 1997 Compound	Fiscal Year	Yearly Escalation Factor	Base Year 1997 Compound
1969	1.0533	0.1973	1990	1.0410	0.8398
1970	1.0356	0.2043	1991	1.0430	0.8759
1971	1.0724	0.2191	1992	1.0300	0.9022
1972	1.0810	0.2369	1993	1.0240	0.9238
1973	1.1026	0.2612	1994	1.0200	0.9423
1974	1.0913	0.2850	1995	1.0190	0.9602
1975	1.0863	0.3096	1996	1.0200	0.9794
1976	1.0824	0.3351	1997	1.0210	1.0000
1977	1.1200	0.3753	1998	1.0210	1.0210
1978	1.1022	0.4137	1999	1.0210	1.0424
1979	1.1072	0.4580	2000	1.0210	1.0643
1980	1.1100	0.5084	2001	1.0210	1.0867
1981	1.0882	0.5532	2002	1.0210	1.1095
1982	1.0672	0.5904	2003	1.0210	1.1328
1983	1.0890	0.6429	2004	1.0260	1.1623
1984	1.0710	0.6886	2005	1.0260	1.1925
1985	1.0340	0.7120	2006	1.0260	1.2235
1986	1.0280	0.7319	2007	1.0260	1.2553
1987	1.0270	0.7517	2008	1.0260	1.2879
1988	1.0300	0.7742	2009	1.0260	1.3214
1989	1.0420	0.8067	2010	1.0260	1.3558

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